Ship Performance Management and the added value of a Ship Performance Monitoring System

A Spliethoff Group Case

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by

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Abstract

Harsh market conditions make optimising the performance in shipping more and more important. Shipping companies are becoming more and more data driven due to developments in data systems and these harsh market conditions. The goal of this research is to determine how and how much added value can be realised through shipping performance management with the help of a ship performance monitoring system within Spliethoff Group. This research continues after the development of the performance monitoring system. The demand or this research arrived from the fact that simply putting a performance monitoring system in place does not realise added value. Applying the knowledge creation from the performance monitoring system through well structured performance management is what realises the added value. Determining the methods and quantifying the potential results is what is done to realise the goal of this research.

During the research it is found that high data quality is of the utmost importance in order to accurately asses the performance of a vessel. A structured method for assessing the data collected by the performance monitoring is found and applied to the performance monitoring system as a verification. Data quality deficits such as the speed of the ETL processes, incorrect data blending and calculations are identified and corrected. This led to a near live, high quality data stream which can be used to asses and optimise the performance. Continual assessment and improvement of the data quality is recommended.

Suitable methods to analyse this data to create knowledge are determined. A form of hybrid modelling where simple theoretical models are fitted to the filtered data using regression is used to create baselines and give a clear overview of the effects of certain operational parameters on the performance of a vessel. These models can then also be used to increase the accuracy of tools such as the weather routing and voyage planning tool. Benchmarking between sister vessels or the baselines is seen as a good means to identify performance deficits. Visualising and analysing the data with the help of a BI tools is a good way to share the knowledge throughout the company.

The performance management in place at Spliethoff is assessed to form a baseline to improve upon. It became apparent that Spliethoff overall has a good idea how to optimise performance but it does not have the information or data needed to do so. Since there is no information about the gain in performance of certain tools they are not used correctly. Being able to show the performance gain from using these tools is an important benefit of the performance monitoring system. The communication and knowledge sharing throughout the company can also be improved with the use of the performance monitoring system. Poor follow up from upper management when performance deficits on top of this indicate that a lot of value can be created with an improved performance management plan which incorporates the performance monitoring system.

A new performance management plan based on ISO 50001 is proposed to realise this value. Due to the available data the management plan focuses on reducing fuel costs and optimising voyage planning.This is done by awareness creation through performance dashboards which also increase the information sharing between shore and vessel. A change in company culture to a more data based decision making and communicative culture is promoted and implemented through this plan.

To determine how much added value can be realised, the costs and value realisation potentials of the performance management system are specified. These are then used to determine the net present value of the performance management project for several scenarios. A large fleet and a small fleet implementation are researched. The total capital investment is either €543,000 when only the large consumers of the fleet are included (small fleet) or €1,310,000 when almost the entire fleet is included (large fleet). Only the direct monetary value is used to determine the net present value but indirect and non monetary values are also mentioned. The direct monetary value potentials are derived from operational cases where performance deficits have been identified. The resulting total added value (NPV) of the small fleet implementation ranges from €2,165,970 in a pessimistic scenario to €8,711,272 in an optimistic scenario after 11 years.€6,000,146is the expected total added value realisation for the small fleet implementation after 11 years. For the large fleet the results are: €4,966,756 for the pessimistic scenario, €18,103,704 for the optimistic scenario and and expected added value of €12,805,994 after 12 years. Most scenarios have a pay back period of less than 2 years with the exception of the pessimistic scenario of the large fleet which has less than 3 years. All indirect and non monetary value is seen as a bonus on top of this meaning that there certainly is a lot of added value to be realised by implementing performance management which is supported by a performance monitoring system.

Contents

1 Introduction

1.1. Background

This research project builds upon the research done by R. Grutterink named: Development of a Ship Performance Monitoring System and Data Analysis of Spliethoff Vessels. As the title describes, the goal of the previous research was to develop and implement a Ship Performance Monitoring System and to perform some initial performance data analysis.

The demand for this follow up project derives from the fact that simply putting a performance monitoring system (PMS) in place does not create added value to Spliethoff on its own. The way the information provided by the PMS is used is what creates the actual value. The manner in which the information is used is normally described in a Performance Management Plan. This research project is thus about developing performance management and the role of the PMS in it. The implementation of the PMS has to be justified by a positive net present value, meaning that the value realisation should way up against the costs of the system. The result of the net present value reflects the added value of the system for Spliethoff group. In short, research has to be done to determine where, how and how much value can be created with the help of the PMS. An important step that was missing in previous research is determining how to best bring forward and use the information provided by the PMS system. Motivating people to make changes to their everyday operations to increase performance is an important aspect of this research. This research project is done as a master thesis at the TU Delft for the Master Marine Technology – Shipping Management. The project is planned to last 8 months from its start date: 18-09-2017.

The first mention of performance monitoring as part of performance management in literature is given by Drinkwater [1967]. This shows that accurate measurements of ship performance have been available for a long time and has become even easier due to the development of sensors and digitisation. Noticeable is that new research on the subject of performance management shows up when fuel prices are high and thus efficient transport is needed to optimise profits. The last ten years (since 2007) research has been picked up again because of this increase in fuel costs and a decrease in cargo rates. The main subject of the research is often how to measure, model or benchmark performance. Strategy on how to use this knowledge to actually increase the performance is often missing. Johnson et al. [2014] is one of the first to mention the difficulty of implementing energy efficiency management in shipping. Energy efficiency management is closely related to performance management in the fact that both want to reduce fuel consumption. Performance management does it to reduce costs, energy efficiency management does it to reduce energy consumption (and also fuel costs). The goal of this research is to fill the gap between measuring ship performance and using the collected data to actually increase the performance of the vessels.

1.2. Research Question

The objective of this research project is to find an answer to the following research question:

How can a ship performance monitoring system be used to realise added value and how much added value can it realise in a ship performance management plan at Spliethoff Group?

1.3. Scope and Approach

The research is set up as an action research in which the added value of the performance monitoring system has to be determined and a performance management plan has to be developed and executed where possible. The execution is the “action” in action research. This means that action researchers spend a significant portion of their resources on the immediate implementation of the results of the research into a real working environment. This has the advantage of getting feedback on the results much quicker but it does come with the risk of slowing down the entire process.

A wide range of disciplines will be researched in this project. This is often the case with action research. The subject itself is also a reason for the many different disciplines involved since performance management involves many different layers of a shipping company. The main focus will be on the development of the performance management plan and the role of the PMS in this. In this research, **ship performance management** addresses the technical performance of the vessel (efficiency), operational performance on the vessel and on shore and the commercial performance internally and externally. The method of action research is chosen because it enables the researcher to keep a close connection between the theoretical and the practical because ideas can be quickly applied and tested in real world application if the action research is set up correctly. A correct set up would be that the research is supported by high level management which has the power to make these changes. Johnson [2016] identifies the risks of action research when a project does not go as planned and you are not able to carry out the action part of action research. Another risk is when the action part takes up too much time so it hinders the actual research part. A balance between action and research should be maintained throughout the project. Action research is chosen as a suitable research method because the research is done in close cooperation with the head of business development at Spliethoff Group. The starting point of the project is that the PMS has been implemented on six vessels of the fleet. Three vessels are of the same series and operate on similar trades. These vessels have delivered the most data and these three vessels will be used as a focus. The three focus vessels act as a pilot to base the decision of implementing the PMS system to the whole fleet on. The research previously done by Grutterink [2017] has to be validated before this research can built upon it. The validation is done in the form of a data quality assessment on the PMS.

Literature research will provide background information on performance monitoring and performance management. Besides literature, internal information at Spliethoff is also researched. This also involves previous research on vessel performance done at the company. The current practise at Spliethoff is specified to set a base line against which improvements can be measured.

The performance monitoring system is already in place and has been gathering data since January 2017. This data has to be analysed. The data quality will be assessed and be improved where needed. The data quality validation is the main part of the verification of the previously done research by Grutterink [2017]. While the results of debugging software will be discussed the debugging itself will not be discussed in the research even though this will be performed. During the analysis of the data, performance relations of the vessels will be specified. These performance relations should describe the relations between the required power and or fuel consumption against operational parameters of the vessel. The way in which these relations are created and presented is researched using literature and feedback from end users of the system. The available data determines which operational parameters will be researched but the most important parameters like speed, wind, waves and swell, draft and trim will be analysed. Filtering or normalising the data are options for data analysis. Filtering will be used to select the right data for analysis. Normalising has been done by Grutterink [2017] but this has proven to be unreliable and will thus not be used in this project. The relations are to be compared to theoretical models where possible. The data analysis will only produce a general overview of the relations between parameters. Several methods are used to do this analysis. They include regression analysis combined with theoretical modelling and benchmarking. The method used vary depending on the type of relation that has to be defined. Literature research on available methods of analysis is performed to determine what methods are used during the data analysis.

Research is done into ways to implements the acquired information from the data analysis in such a way that it can increase the performance of the vessels and thus create value for the company. This includes research into the current performance management and finding ways to improve on this with the use of the PMS. Internal research at the company is done to give an overview of the current goals, operations and available information. Interviews is one of the means used to acquire this information. The information on the current practise is then used as a baseline to improve upon. Different performance management strategies are researched. Is the SEEMP for instance a good enough strategy or would ISO:50001 be a better guideline? What are advantages and disadvantages of different strategies? It should be said that the SEEMP and ISO:50001 are

energy management strategies. These are not the same as performance management strategies but they can have a large common ground when it comes to reducing fuel costs. The final performance management plan will differ from an energy management plan but the energy management plans can be used as a base.
Also, ship performance optimising strategies are researched. Typical performance optimising strategies are optimising speed, optimising trim, weather routing, hull cleaning and voyage optimisation (Reduce wait or port time). A selection is made on which are applicable to Spliethoff and are possible with regards to available information.
It is also important to research how to bring forward information to the people of the company and how to involve them in the process of performance management. Involvement, control and rewarding good results are important part of making performance management successful. A mix of literature research and internal research is applied in this part of the research. The results of the research should produce a performance management plan. The role of the PMS system in this plan is then researched to find out what the added value of this system is. The research looks at the entire company and all stakeholders but should be limited to ship performance management and the effects of it. The focus will also mainly be on the value creation for Spliethoff directly

The added value of the PMS is researched. Firstly, the total added value of the new performance management plan is determined. The added value of the PMS is then the added value of the part of the total ship management plan that the PMS enables. It is difficult to specify the added value of the PMS on its own because as said before it is not the PMS system by itself that creates value. It is the actions that rely on the PMS inside the performance management that create the added value. A wide scope of value creating possibilities is addressed but the focus lies on direct monetary value creation for Spliethoff. This is done to reduce the uncertainty of the assumptions and to research if the project creates added value with well defined value potentials. Fleet wide implementation of the system is taken into account when defining the added value. Several scenarios are researched to asses the risk and give a upper and lower boundary of the possible added value realisation. It is important to avoid counting values double. Non-monetary values are not fully monetised and are regarded as a bonus on top of the direct monetary values.

1.4. Report structure

Part I: Data Analysis

Data Quality assessment

This part includes validation of the data, previous research and the quality of the data.

Performance Data Analysis

Performance data analysis methods are specified. The performance data gathered by the PMS is analysed using these methods. Influence of operational parameters is researched and baselines are produced.

Part II: Performance Management

Analysing the current performance management system

The current practise of performance management will be researched to establish a baseline to improve upon. Interviews will be an important means of gathering information.

Formulating a new proposed performance management plan

Improving upon the current performance management. A new performance management plan will be proposed and the role of the PMS discussed.

Part III: Added Value

Determining the added value

To finally determine the total added value of the new performance management and the PMS. An analysis is done to determine the costs and potential value creation possibilities. The Net Present Value of the performance monitoring project is to show how much added value can be realised.

I

Part 1: Data Analysis

2

Evaluation of the Performance Monitoring System

The Performance Monitoring System (PMS) was set up during previous research done by Grutterink [2017] at Spliethoff. The work has to be evaluated before it can be built upon further. The most important part that has to be evaluated is the data quality. An overview of the system is firstly given to provide background to the evaluation. Secondly, data quality assessment is done. Researching and improving data quality is very important before decisions and conclusions can be made with the help of the data. Lastly, an overview of the evaluated PMS with the made or proposed changes is given.

2.1. Overview Performance Monitoring System

An overview of the PMS is given to provide the reader with a better understanding of the system. The reader is referred back to Grutterink [2017] for a more detailed view of the PMS and the development process. In this section a more general overview is given. Figure 2.1 gives a general overview of the PMS infrastructure. In figure 2.1 the left dotted box shows parts of the PMS that are still under construction. Scrubber data is being added to the system with the main goal of monitoring the compliance with regulations. An alarm monitoring system which monitors engine room alarms is also under development.

In the vessel box of figure 2.1 we find the different sensors which connect to the datalogger. This datalogger samples the data in such a way that this can be stored in a structured way on the server on board of the vessel. This server then sends the data to a server on shore which is called the sensor database. Figure 2.1 shows how data is taken from the vessel and send to the different databases. What is missing in this visualisation is the weather data and the vessel messages data that are also added to the dashboard database. The weather data comes from an external source. The weather data is provided by a weather provider (MeteoGroup). The weather data consists of hind-cast data. Meaning that this data is produced by a weather model. The message data consists of the noon reports that the vessels fill out manually at noon and the arrival/departure messages. These messages contain route information like berthtime and distances.

The filling of the dashboard database is done with an ETL (Extract,Transform,Load) process. During this process, the data is extracted from their sources. A transformation is done in the form of calculations and pivoting of the data and lastly, the data is loaded onto the dashboard database. Figure 2.2 below gives a graphical overview of this step.

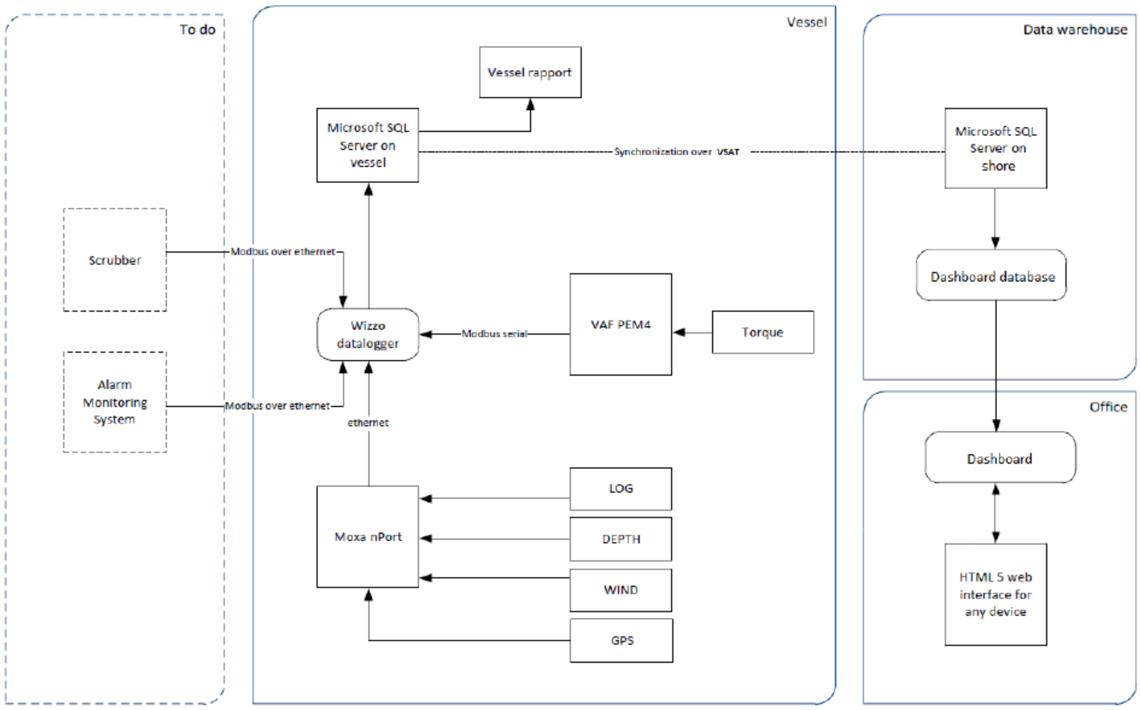

Figure 2.1: Complete Infrastructure including Vessel, Data Warehouse and Office [Grutterink [2017]]

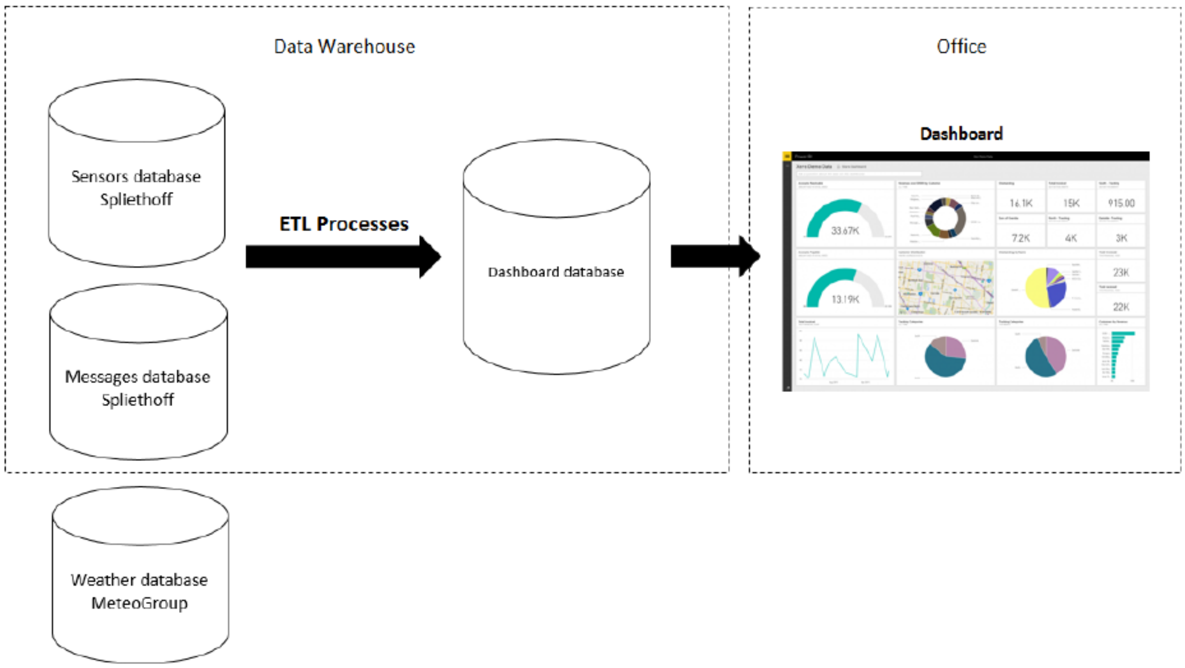

Figure 2.2: ETL Process from Sensor Database to Dashboard Database [Grutterink [2017]]

The dashboard database is set up in such a way that the business intelligence(BI) tools can easily use the data to make dashboards. An overview of how the dashboard database is set up is given in figure 2.3. The figure gives and overview of all the available data and the relations between them. The tag names for the data are shown in the figure too. The constants and coefficients in the database are added there because they are needed for calculations during the ETL process. The dashboards are made in Tableau. Tableau is software

that assists in handling large data sets and visualisation of the data. This type of software is also referred to as a Business Intelligence (BI) Tool. The dashboards that are made with the help of Tableau will be the main interface with the PMS for the end users. The dashboards are easily changed and shared and will change throughout the course of the research.
The different levels of the PMS have now become apparent. Three main levels can be defined. The sensor database level, the dashboard database level and the dashboard level. The sensor database is taken as one level because the database on board the vessels is almost equal to the one on shore. The only difference is that the database onshore contains the sensor data of all vessels. The end users only have access to the dashboards. The administrators have access to all levels. This means that the data quality at the dashboard level is most important. The administrators have to set up the PMS in such a way that this high data quality is achieved. To assess the current situation a data quality assessment is done. The assessment is described below in section 2.2.

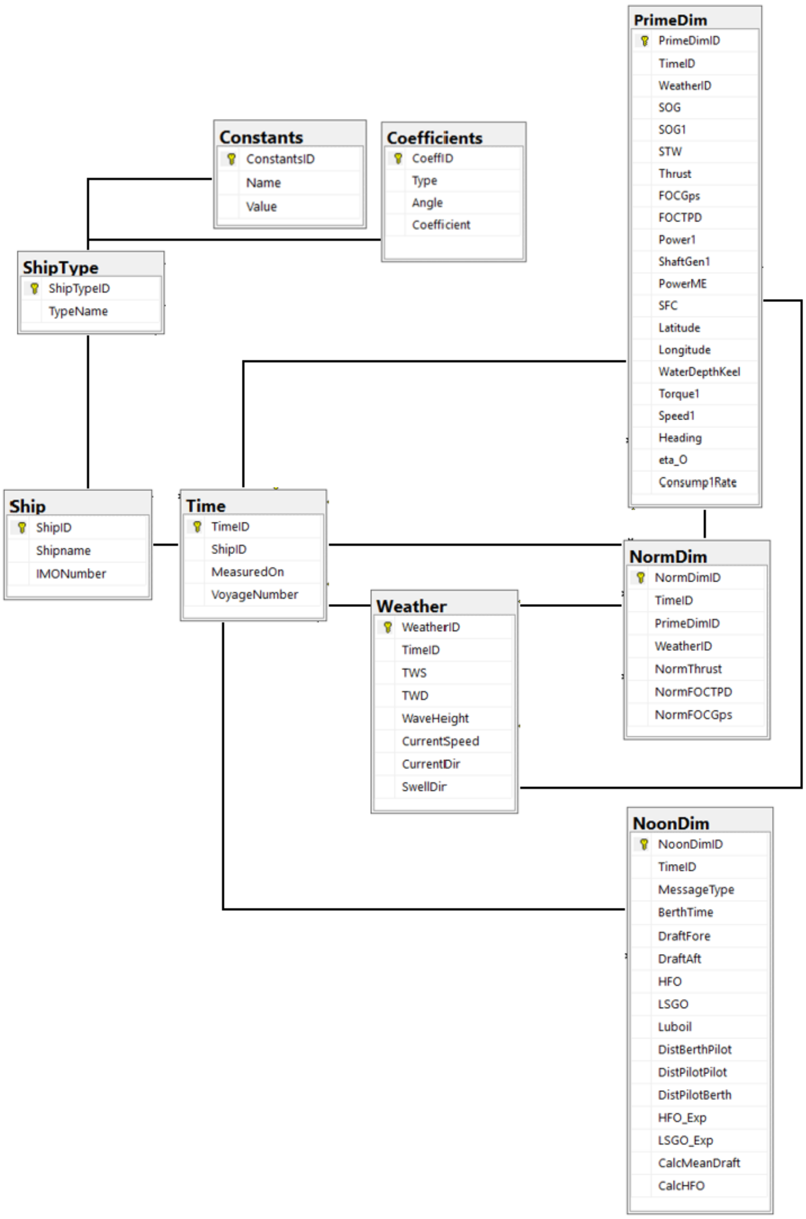

Figure 2.3: Entity/Relationship Diagram of Dashboard Database [Grutterink [2017]]

2.2. Data Quality Assessment

When trying to make relations or improve decision making with the use of a large set of data it is important that the data is of high enough quality. Low data quality may lead to misleading information or the information not being understood in the correct way. Pipino et al. [2002] states that the data quality can be specified with the use of the following dimensions which are specified in figure 2.4. By dividing the assessment of data quality up into these dimensions, the process of data quality assessment can be more structured.
Data quality is often assessed by interviewing or surveying the users. In the case of this research that is not possible since there are no users yet. The data quality is assessed from the experience that has been acquired by performing this research. The assessment is to be done again when there are more end users. It should also be noted that there are different levels to the PMS as described in section 2.1 above. The three main levels are the sensor database level, the dashboard database level and the dashboard level. This means that there are different levels of users too. Two user levels can be specified: An administrator and an end-user. The administrator has access to all levels and the end user only has access to the end-user level. The researcher has to assess the data quality at all levels.
Some dimensions are more subjective. This means that the opinion of one person cannot be valued as much as a larger group of users but in this case it will suffice since there is only one user. As said earlier the data quality assessment is to be performed again when the system is being used by a larger group of people. The data quality assessment will follow the same structure as indicated in figure 2.4 below. Metrics to specify the data quality are used when applicable but the focus lies on a qualitative assessment.

Dimensions	Definitions
Accessibility	the extent to which data is available, or easily and quickly retrievable
Appropriate Amount of Data	the extent to which the volume of data is appropriate for the task at hand
Believability	the extent to which data is regarded as true and credible
Completeness	the extent to which data is not missing and is of sufficient breadth and depth for the task at hand
Concise Representation	the extent to which data is compactly represented
Consistent Representation	the extent to which data is presented in the same format
Ease of Manipulation	the extent to which data is easy to manipulate and apply to different tasks
Free-of-Error	the extent to which data is correct and reliable
Interpretability	the extent to which data is in appropriate languages, symbols, and units, and the definitions are clear
Objectivity	the extent to which data is unbiased, unprejudiced, and impartial
Relevancy	the extent to which data is applicable and helpful for the task at hand
Reputation	the extent to which data is highly regarded in terms of its source or content
Security	the extent to which access to data is restricted appropriately to maintain its security
Timeliness	the extent to which the data is sufficiently up-to-date for the task at hand
Understandability	the extent to which data is easily comprehended
Value-Added	the extent to which data is beneficial and provides advantages from its use

Figure 2.4: Data Quality Assessment Dimensions [Pipino et al. [2002]]

Accessibility

Accessibility is described as the extent to which data is available, or easily and quickly retrievable. A metric to measure the accessibility is defined by equation 2.1 [Pipino et al. [2002]].

$$AccessibilityRatio = 1 - \frac{T_{Update}}{T_{Accessible}} \tag{2.1}$$

The accessibility varies a bit depending on what level in the PMS is being used. Making a query to the sensor database is easy and quick. The downside is that only sensor data is available in this database. Weather, Noon report data and calculated data is not available. The dashboard database which brings all this data together is updated every day in the morning. The updating process takes about 30 minutes for three vessels. The updating process happens daily at 06:00. This is manageable now but when more vessels are added to this system the time it takes to update will be too large and will hinder accessibility a lot. This causes the system to become unusable. If the metric for accessibility is calculated for an update time of 30 minutes and an accessible time of 23 and a half hours, gives an accessibility of 0.979. This is high which reflects the system being very accessible but as said before when more vessels are added this metric will drop significantly. The total fleet consists of around 105 vessels. Meaning that the update process would take around 35 times as long when all vessels are included in the system. This would mean an update time of around 17.5 hours. Clearly this is a problem which has to be addressed when more vessels are added to the database. The process of data storage and the ETL process will have to be adapted to become more efficient in the future.

Appropriate Amount of Data

Appropriate amount of data is defined by the extent to which the volume of data is appropriate to the task at hand. A metric for rating this is given by the minimum of two ratios, the ratio between the amount of data available divided by the amount of data needed and the amount of data needed divided by the amount of data given [Pipino et al. [2002]]. This makes sure that either having too much or too little data is covered. The effect of having too much data is that the user might be overwhelmed by the amount of information and that the computing time needed to process this data will become too large. Having too little data will make detailed analyses of the performance difficult because information might be missing.
Currently the data sampling rate is one sample every 5 minutes. This equals 288 data points every day per vessel. This sampling rate might be higher than needed since vessels trips take multiple days and variations in operational conditions do not vary quickly. Sampling once every ten minutes reduced the amount of data by a half which might make it more manageable. This being said, there are currently no issues with the volume of data. An argument against this is the fact that there are fluctuations in the measured data that fluctuate with a must higher frequency than the sampling frequency. Averaging these fluctuations out is easier when more data is available. The fluctuations can also be reduced by taking samples over a specific time interval and averaging this out into one data point instead of just point samples. This will be further discussed in the free-of-error dimension.
The actual amount of data needed is determined by the goals of the PMS. The goal that set the sampling rate to 5 minutes is that the position data together with the scrubber data will be used in the future to specify the location of where the scrubber went into closed loop operation accurately. A discount in harbour fees can be acquired when the vessel can accurately specify when the scrubber went into open loop when approaching the harbour. Meaning that the demand matches the supply of data at this moment in time and that the calculation of the metric is not needed.

Believability

The extent to which the data is regarded as true or credible. Most of the data that is directly related to the performance of the vessel comes from sensors. These sensors have a deviation of less than 1 percent. This data should thus be very believable. Weather data comes from a trusted supplier but since the data comes from a model it is not a 100% accurate. This means the believability can be compromised but until now the weather data has been believable. Noon report data is filled in by hand which makes it lose some believability due to the errors that are introduced and the lack of attention that is sometimes present when filled in. The PMS also performs some calculations. The calculations are not visible so the PMS is seen as some sort of black box. This might make the data less believable to some users because they cannot see what happened to the data. The calculations based on estimation should be avoided as much as possible to stay as close to the most believable sensor data. The PMS will on the other hand always contain these calculations since not everything can be measured due to the high cost of sensors. The users should be included into the PMS as much as possible to increase believability. Transparency into the black box calculations is also very important. No real metric for this is available since the believability is very subjective from user to user. A scoring system between zero and one can be used but since only the researcher in this case is doing the review no scoring is needed.

Completeness

The extent to which data is not missing and is of sufficient breadth or depth for the task at hand. There are some limitations to the PMS when it comes to completeness. Some is due to breakdowns of sensors which caused missing data for that time frame. Other limitations are caused by not having the required hardware or means to collect the data. For example to monitor propeller performance specifically, a thrust sensor would be needed. This sensor is very costly so these are not installed on the vessels. This means there are different levels to completeness. The first level where data is missing due to for instance a sensor malfunction varies per parameter and per vessel. One vessel for instance had an issue with the GPS. This caused a lot of missing speed data over a certain period. The other vessels did not have this problem. For this reason metrics are avoided to measure the quality of this level. It should be said that continues monitoring of missing values should continue and that corrections should be made when needed.

On another level we can look at what parameters are missing. For instance the thrust was mentioned above. Other parameters in the data that are still missing in the dashboard database are the fuel consumption of the auxiliary generators and the boilers. These are being measured but they are not yet available in the dashboard database. These will have to be added to increase the completeness. Propeller pitch and rudder angle would also increase completeness. Before these can be added, a way of measuring them has to be determined. A metric here could be: one subtracted by the amount of missing parameters divided by the available parameters. The metric is not calculated because this is a continuous process. More ideas pop up for what data is needed. What is important here is to make notice of the parameters that have to be added. The effect of not being fully complete is that it limits the amount and detail of analysis that can be done. The trade off between completeness and costs is most often the limiting factor. The cost of additional sensors to increase completeness has to be compensated by the value realisation it might bring. The result of this research project will also answer the question if the PMS system should be expanded if it proves to realise value.

Concise Representation

The extent to which the data is compactly represented. If the data is not represented in a concise manner it could overwhelm the end user and make them reluctant on using the PMS. The representation is dependent on how the data is visualised. If you want to look at the raw data in tables in the PMS, it might not be as concise. This being said a lot of effort has been and is being put into making the information as concise as possible so that the data can be used efficiently. Most data is shown in graphs. This gives a quick overview of the relations. By plotting the data in graphs you give a more concise view but it also takes away a level of detail. The PMS has a good balance between the two but fine tuning should be a continuous process in the future.

Consistent representation

The extent to which the data is presented in the same format. Data comes from three main sources. There is the sensor data, the weather data and data from noon reports. This data is automatically collected and stored away in a digital format. The presentation of the data is done through online dashboards. Since all data is digital it is easily presented. The only improvement that has to be done is the naming of the data. Some data fields miss a clear tag name or tag alias. This sometimes makes it unclear what for instance the unit of the data is. The tag names or tag alias should be changed so that they give a clear indication of what the data is and what the unit of the data is. If the tags are not changed it might lead to loss of understanding when users and administrators leave the project. Improving the tags will make it easier for new users to understand the PMS.

Ease of Manipulation

The extent to which the data is easy to manipulate and apply to different tasks. For the administrator of the system it is easy to manipulate the data so that it can be used for different tasks. The end users are not able to easily change the available data in order to use if for different tasks. They are depended on the administrator to supply them with the right data needed for the task. This is not a problem as long as the a good communication is present between the end user and the administrators about what data is needed.

Free-of-Error

The extent to which the data is correct and reliable. A metric for this could be one minus the amount of errors divided by the total amount of data [Pipino et al. [2002]]. There are two problems with using this metric. First of all the data set is very very large and an easy way of counting the errors does not exist. A second problem is that it is hard to judge when the data is showing an error. It is easy to show for very apparent errors where for instance the speed of the vessel is zero but the power delivered by the shaft is 8000 kilowatt. Instead of using this metric the errors will be discussed.

As said before it is very hard to test the large data set for errors. An error of 10 percent is very hard to indicate. On the other hand there are errors in the data that are very clear. These errors have to be corrected where possible and filtered out. One big cause for error is for instance that the speed through water (STW) could not be determined and was set to zero in some cases. This problem has to be addressed by improving the ETL process. Another problem as mentioned before in the appropriate amount of data dimension, is the fact that due to the low sampling rate compared to the fluctuation frequency of the measurements, a skewed vision might be given on the shaft power and torque. It would be better to take an average over the 5 minutes instead of taking just one value every 5 minutes. This will reduce the scatter once the data is plotted in a diagram and will make it easier to draw relations with other parameters. Due to the fluctuation sensor measurements and the sampling there is also another problem that occurs. The power, torque and revolutions of the shaft should be measured at the same time. Sometimes due to some retardation in the sampling process the three are measured at a different time. Since torque and revolutions multiplied with each other gives power, it can be easily tested if the measured power is correct. Figure 2.5 shows the spread due to this incorrect sampling (top graph) and the bottom graph shows the relation between torque and power when power is calculated from the multiplication of torque and revolutions. The colour grade called "Speed1" shows the variation in revolutions per minute. Clearly the retardation in the measurements of torque and power induce an error in the data. What the top graphs shows too is that the revolutions per minute measurements have also been faulty for a period. (Shown in orange in the top graph). Fortunately this sampling induced error only occurs in one percent of the measurements. Taking the average power and torque over a defined period will solve this problem. The sampling retardation only occurs in less than one percent of the measurements. The errors will be filtered out until the sampling method is changed so that it does not have an effect on the analysis.

It is clear that a large step in data quality can be made here by improving the sampling method and by changing the calculation of the speed through water in the ETL process.

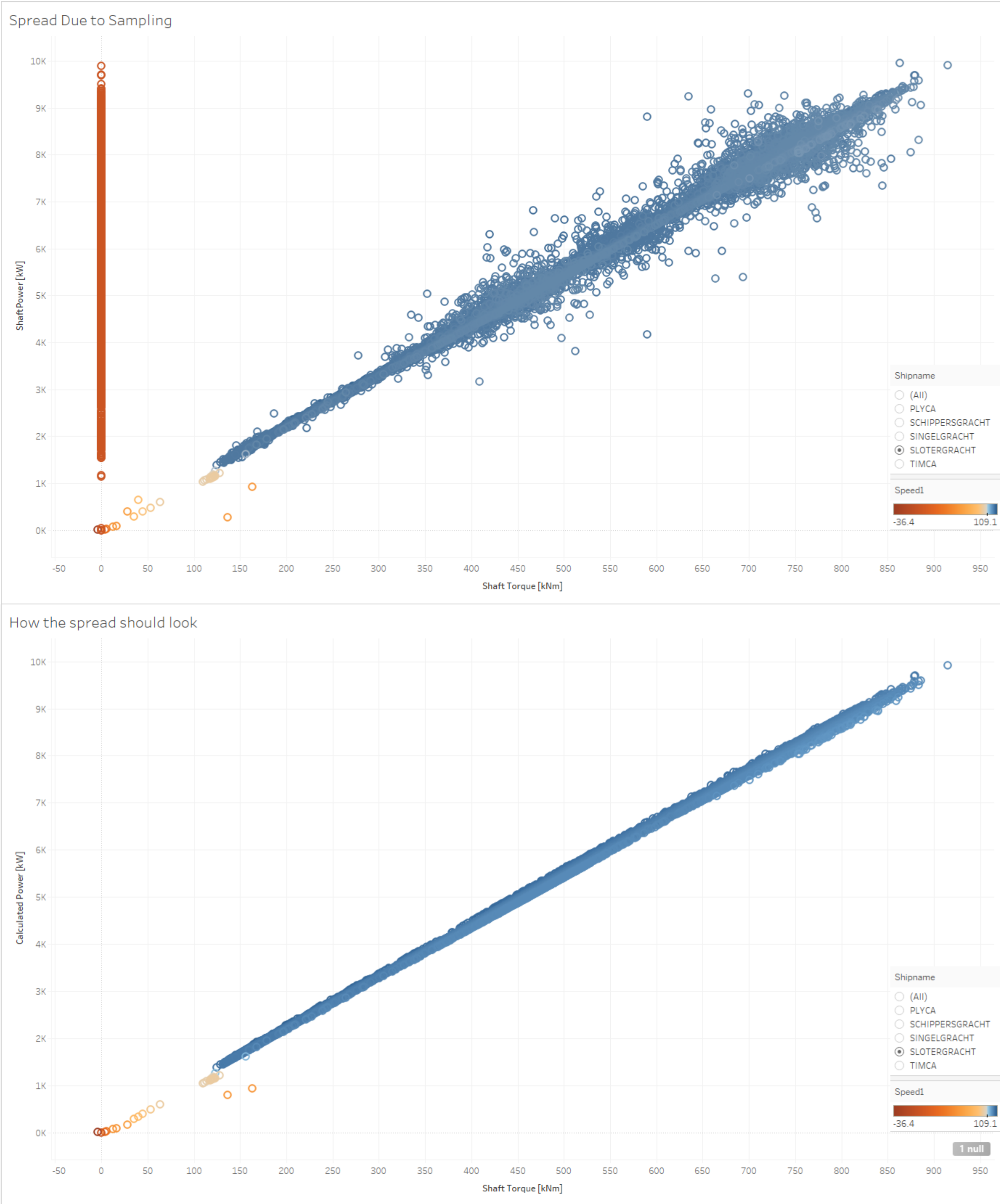

Figure 2.5: Spread due to wrong Sampling

Lastly, the calculations that are made in the PMS should be assessed. Normalising is done for some parameters with the goal to reduce the spread of the data and to make it easier to benchmark different vessels and situations against each other. These calculations are very hard to make when there is limited information about the properties of the ship. Extensive models of the components in the ship are needed to make accurate corrections. Since these models were not available in the research done by Grutterink [2017], a substantial amount of assumptions had to be made. This compromises the accuracy of the normalised data.

Interpretability

The extent to which the data is of appropriate language, symbols, units and the definitions are clear. Like believability this dimension is also subjective. The interpretability also varies in the different levels of the PMS. On the end user level the units and definitions are mostly clearly defined. This is assuming that all the end users have a general understanding of units and terms used in the maritime industry. A step in improving the interpretability can be made by improving on the tag names of the different data. An example of this is that a certain parameter is "speed1" this parameter gives the shaft revolutions per minute. This could be confusing and lead to wrong interpretation easily. Changing the tag names to a better description and have them include the units of the data will increase the interpretability a lot.

Objectivity

The extent to which the data is unbiased, unprejudiced and impartial. Subjectivity might lead to users not agreeing with the system. Most data is digital data coming from sensors. For this reason it can be assumed that the data is objective. Some data is acquired by hand by staff on board of the vessels but these are also based upon measurements and not opinions. It can be said that the data is fully objective and it will be hard for users to argue with the system.

Relevancy

The extent to which the data is helpful and applicable for the task at hand. The data in the PMS is relevant. This is because all data has been selected with the end goal in mind. Irrelevant data has thus been avoided in this way and users will not be overloaded with useless information. Wen designing the dashboards for the end users this is to be kept in mind as well.

Reputation

The extent to which the data is highly regarded in terms of its content. Reputation is something that is built up over time or through use. Since the intended end users have not been using the PMS yet, no reputation has been built up. The reputation is therefor not assessed.

Security

The extent to which access to data is restricted appropriately to maintain its security. The data is stored on several different servers as described in section 2.1 above. Before getting access to any of the databases a password is needed. Storage on board can be seen as the least secure because the vessel is connected to the internet but no advanced security system are in place yet. The other two databases on shore and the online dashboards are secured by the companies that provide them and they ensure a high level of security. A step to improve the security is to install more security measures on the onboard system.

Timeliness

The extent to which the data is sufficiently up-to-date for the task at hand. A metric to assess could be defined with the ratio of currency to volatility [Ballou et al. [1998]]. The difficulty with calculating this metric is that data is being added continuously. Meaning that the different data points could have a different result for this metric. What we can say about the timeliness is that the data is updated once a day during normal operation. Therefor the maximum delay is a whole day. Sometimes the data is not updated because the vessels does not have a network connection. The timeliness is then reduced. A maximum delay of one day is acceptable for normal data analysis but when following the operation of the vessel a more real time feed of data is required. On board there is a separate real time system which can be used.

Understandability

The extent to which the data is easily comprehended. Understandability is also a subjective dimension. The understandability can be improved upon by implementing better tag names as mentioned before. Training the end users will also increase the understandability. Poor understandability will lead to incorrect use of the PMS or to no use due to demotivation. When the system is rolled out to more users this will have to be tested again.

Value-added

The extent to which the data is beneficial and provides advantages from its use. This dimension will not be handled here since it is the main purpose of this research to determine the added value. The added value is determined in chapter 6.

2.3. Conclusion and Made or Proposed Changes to the PMS

The PMS achieves its goal of monitoring the vessels and bringing forward the information but during the data quality assessment in section 2.2, it became clear that a large step in data quality for some of the mentioned dimensions could still be made. Increasing the data quality has been one of the first tasks during this project. The improvement of the data quality was an unexpected task which caused the data analysis to take up more time than expected. The improvement of data quality was on the other hand needed for the performance management to be successful.
The main issues that were indicated by the data quality assessment were the time it took for the dashboard database to be updated every day. The accessibility was not a problem yet but it would become an issue once more ships and more data are added. A second issue was due to the sampling method. A large spread was introduced into the data due to only sampling strongly fluctuating measurements once every five minutes. Also relations between torque, rpm and power showed errors due to a delay in these samples. A solution for this problem was proposed in the form of sampling continuously over a longer period of time and taking the average of this period. Other incorrect or measured data due to fault or bugs in the system also had to be addressed. Security was also lacking since there were no cyber security measures installed onboard of the vessels. Lastly, the interpretability was criticised because of the incoherent tag names which did not give a clear name for all data and units were missing too. This caused the development of new data-logger software which implemented these required changes in sampling.

During the duration of the project several changes to the PMS have been made to adress these data quality issues. Firstly, a new database architecture has been developed which eliminates the need for the slow ETL processes. Performance of the system is now much faster and the data can now be updated every hour instead of every day. Also, rounding off errors in the old ETLs have been removed which further improved the data quality. During this change in database the change in tagnames will also be done to increase the interpretability and understandibility of the data. The sampling method will be changed so it is able to take an average value over a certain sampling period instead of just one point sample. This will reduce the scatter in the data and will increase the quality of the analysis. The cyber security has also been addressed throughout the duration of the project. Reducing the risk of data theft or manipulation significantly.
Even though the data quality assessment brought required changes to light which caused delays during the project, it was vital to the performance of the system. This also means that the data quality should be assessed periodically to further improve upon the system or to prevent the system from developing data quality problems.

3 Performance Data Analysis

The PMS will only add value if the information it supplies can support decision making and in this way optimise operations. Finding relations between operational parameters and the performance of the vessel is key information in optimising performance. Determining a way to measure or indicate performance is also important. A single good metric to specify the total performance of the vessel might be hard to define since there are so many variables that have an influence on the operation of the vessel. Also gaining performance on one side of the operations might reduce performance on the other side. Giving insight between the relationships of the performance influencing parameters might reduce the need for one specific metric that defines performance. Creating knowledge by visualising these relations might be more valuable than simply formulating models to calculate with. The goal of this chapter is to determine the best way of analysing and visualising the data to create the most knowledge and value for the end users and also to perform this analysis and visualisation and discuss the results.
The performance relations can only be drawn if the data needed to make these relations is available. This means that firstly, an overview of the available data is given to determine what relations can be drawn. Secondly, different analysis methods found in literature are discussed and the methods for this analysis are selected. Thirdly, the analysis is done with the selected methods and the results are discussed. A conclusion can then be drawn on if the PMS system can deliver enough information to be able to optimise vessel performance.

3.1. Overview of the Data

At the dashboard database level of the PMS, there are four main sources of data. These four data sources have been named: Prime, Noon, Norm, Weather. The sources and the data they contain are shown in table 3.1. The data overview given in this table already consists of selected data which comes from a larger pool of data. The selection has been made in order to discard the data which is not of use at this moment in time. This means that the shown data overview below only shows relevant data. The importance of the different parameters also does not vary significantly. All the selected data is important in giving a complete overview of the performance of the vessel.

The four data sources contain different types of data. The prime data source contains all the primary operational data that comes from sensor data or is calculated from sensor data. The noon data source consists of noon, arrival and departure message data. Norm contains normalised data for the influence of waves, wind, water depth and current [Grutterink [2017]]. Finally the weather data contains the most important weather parameters at the vessels location. The weather data is not measured on board but is provided by a weather provider. This weather data comes from a weather model, meaning that most parameters are calculated or estimated instead of measured. The names of all the parameters shown in table 3.1 are clarified for this report. The original parameter names or tagnames as they are named in the database are shown in appendix A.

Prime	**Noon**	**Norm**	**Weather**
Speed over Ground [kn]	Message Type	Normalised Thrust [kN]	True Wind Speed [kn]
Speed over Ground [m/s]	Berth Time	Normalised Fuel Consumption [t/day]	True Wind Direction [kn]
Speed Through Water [kn]	Draft Fore [cm]	Normalised Fuel Consumption [t/nm]	Wave Height [m]
Thrust [kN]	Draft Aft [cm]		Current Speed [kn]
ME Fuel Consumption [t/nm]	HFO on Board [t]		Current Direction [degrees]
ME Fuel Consumption [t/Day]	LSGO on Board [t]		Swell Direction [degrees]
Propeller Shaft Power [kW]	Luboil on Board [t]		
Shaftgen Power [kW]	Distance Berth to Pilot [nm]		
Break Engine Power [kW]	Distance Pilot to Pilot [nm]		
Specific Fuel Consumption [g/kWh]	Distance Pilot to Berth [nm]		
Latitude	Expected HFO Consumption [t]		
Longitude	Expected LSGO Consumption [t]		
Depth Under Keel [m]	Calculated Mean Draft [m]		
Shaft Torque [kNm]	Berth to Berth Fuel Consumption [t]		
Shaft Revolutions [Rev/min]			
Heading [Degrees]			
Prop Open Water Efficiency			
Main Engine Fuel Consumption [kg/h]			

Table 3.1: Available Data in the Dashboard Database

3.2. Method of analysis and visualisation

Determining the right method for performance analysis is very important. The final goal and the available data should be kept in mind while deciding on the analysis method. Firstly available performance analysis methods are researched. The decision for certain methods will then be explained.

Available Methods

Ship performance data analysis is described by different sources of literature. Aldous [2015] describes different methods for analysing ship performance. General methods like filtering, performance trials and normalising are named. The downsides to these methods are that normalising the data is difficult when accurate models are unavailable and filtering requires a large amount of data to be viable. Special performance trials might interfere with normal operation of the vessel. The generation of performance models is also discussed by Aldous [2015]. A distinction is made between theoretical, black box and hybrid models. Black box models are made with the use of statistical analysis like for neural networks. The advantages and disadvantages of the theoretical and black box models are specified by Aldous [2015] (figure 3.1). Hybrid models being a combination between theoretical and black box models should combine the best of both worlds. The hybrid model keeps the underlying relations of the theoretical models but corrects for the assumptions in these theoretical models with the help of black box predictions and real operational data. Aldous shows that hybrid models can reduce uncertainty in performance models. This hybrid method of modelling is interesting for this project since operational data is already available and in this way the physical properties of a relation can be maintained and reviewed.

	Theoretical Method	Black box Method
Positive	– Does not require historical data – Can evaluate new technologies – Can extrapolate beyond the given data range	– Can be more accurate as based on historical empirical data (i.e. neural networks have high prediction capability)
Negative	– Model structure and parameters are based on prior knowledge. – Require detailed ship information and large amount of input data. – Approximate as based on design condition – Trade-off: detail requires large number of parameters but fewer leads to a more robust model – Accuracy of prediction depends on assumptions and uncertainty implicit in the models – May lack predictability – Many of the theoretical assumptions are not validated with at-sea or sea trial data – Empirical assumptions are often based on old datasets and are not updated for modern ship types/hull forms	– Too high resolution for regression analysis to be applicable for different ships; poor extrapolation/scalability capacity – Co-linearity problems; it is unknown which independent variables impact the EC; improve by further distinguishing between types – Cannot evaluate new technologies – In NN particularly, the inputs have no physical significance – Statistical models cannot easily deal with non-linearities – There are strict rules concerning the error – Require prior knowledge of model functional form

Figure 3.1: Advantages and disadvantages of different modelling methods as defined by Aldous [2015] (EC: Expected Fuel Consumption, NN:Neural Networks)

Another way of analysis is benchmarking and KPIs [Bazari [2007]]. Bazari [2007] sees benchmarking as a vital part of an assets' energy management process. Figure 3.2 gives a schematic of how benchmarking is incorporated in the energy management process. Benchmarking can be used either to monitor a ships performance over time when a baseline has been established, or it can be used to benchmark different ships against each other. Important here is the selection of the right KPIs to do the benchmarking with. Bazari [2007] proposes the following minimum characteristics for KPIs.

- Be indicative of ship's performance
- Show appropriate and consistent variations with ship size
- Require minimal number of measured data for its estimation
- Be unambiguous and easy to understand

When benchmarking sister vessels the second characteristic is not as important since the size of the sister vessels are similar. An advantage of working with KPIs is that they show the performance in one view (if KPIs are chosen correctly). This means not much time is lost by the end-user interpreting the performance. A disadvantage is that a lot of information is also lost by just displaying a KPI. Also the cause for the performance is not always given by the KPI. This means that detailed knowledge is needed to correctly interpret the KPIs.

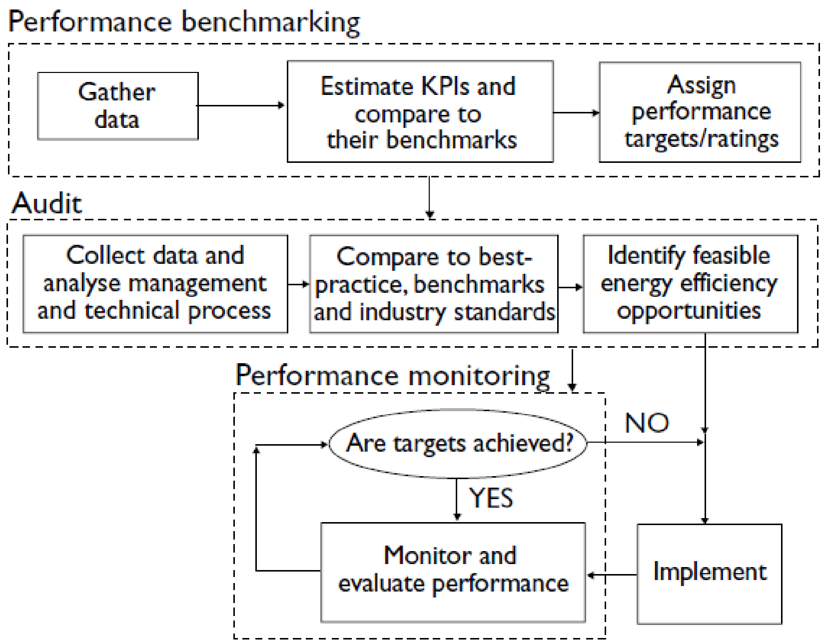

Figure 3.2: Main aspects of assets' energy management processes [Bazari [2007]]

Hasselaar [2011] indicates four main methods for performance data analysis used in literature: Methods using regression analysis over time (Trend analysis); Statistical methods using more sophisticated regression techniques to account for variations in weather conditions (Statistical methods); Deterministic methods using hydrodynamic relationships and lastly, system identification techniques. Of these four methods, the first one is making conclusions based on long term trends. This method could for instance be useful for determining the fouling of a hull. The downside to this method is that a lot of data is needed and poor data quality could produce poor conclusions. Filtering the data to eliminate the scatter induced by for instance weather effects is important here to increase accuracy. The second method uses statistical methods like multiple regression analysis to determine relations between parameters. This could be very helpful when trying to make predictions on performance but the physical characteristics of these parameters might get lost in the analysis. Meaning that the "why" might be hard to determine once the analysis is done. The third method uses hydrodynamic relationships to correct for the effect of wind, waves and other influential parameters. This method has already been applied to this data by Grutterink [2017]. Making good corrections proved difficult since detailed models of the vessel and its systems were missing. The last of the four methods mentioned by Hasselaar [2011] includes performing special periodic manoeuvres to determine the performance of a vessel. This sounds like an interesting option cause it eliminates a lot of the variance in the data but the problem here is that to do these manoeuvres the ship has to probably deviate from its day to day operation. This deviation is very costly since a time charter equivalent rate of 15000 euros a day is not uncommon in 2017/2018 and thus delaying operations by half a day could cost 7500 euro. This method is also not very suitable for this project since the data has already been collected. These special manoeuvres or trials could provide extra insight after a dry docking. In this case the vessel should perform well because of the clean hull and maintenance. This trial could then help provide a baseline which can be used to benchmark performance later.
If we have a more detailed look at the three methods: normalising, filtering and periodic manoeuvres, we see that they share the same end goal. The goal is to specify the performance for a specific operational conditions. Mainly this operational condition is calm water, but other operational conditions can also be analysed. Even though the goal is the same, the means to reach this goal is not. The different means each have their advantages and disadvantages which are discussed above. Dependent on the type of vessel and monitoring system a selection between the three has to be made. If sampling rate is high and a largely varying operational profile is present then filtering might be the best solution. When sampling rate is not that high and detailed theoretical models of the vessel are available, normalising might be the best choice. Special trials might be the best option for naval vessels. Which can easily perform special trials since they are not always on a mission. It should be noted that even though the goal is the same, the results might not be the same. Inaccuracy can vary for the different methods.

The used literature is very thin on how to analyse and monitor operational performance. Modelling human behaviour is also difficult to do. By researching the influence of operational parameters on the performance of the ship and by analysing the operational profile of the vessel we can still analyse the operational performance of the vessel when it comes to fuel consumption. This means that for example by analysing the weather effect on the ship and by analysing the weather along the sailed routes we can find the negative effects the weather has had during these routes. This information could help improve the weather routing strategy in the future. Conclusion about sailing at the correct speed can also be made when the speed versus consumption relation is determined and the operational profile is known. To analyse the commercial performance of the ship a different set of data is needed.
It can be seen that some of the sources have some overlap in the mentioned methods of analysis but some differences also exist. Important to take away from the literature is that there are different methods available and each has its advantages and disadvantages. A combination of methods to mitigate some of these advantages and disadvantages might be beneficial.

Selection of Methods

The main goal of the performance monitoring system is to create knowledge and to use this knowledge to optimise performance. The main question that has to be answered is: How should the data be analysed and presented to create the most knowledge? The answer to this question is very much dependent on the end user. It depends on the end users skill-set and preferences. Since performance management is very multidisciplinary[Johnson [2016]] and end users will be spread throughout the company, the information has to be presented as simple and clear as possible to fit everyone's skill-set and information needs.

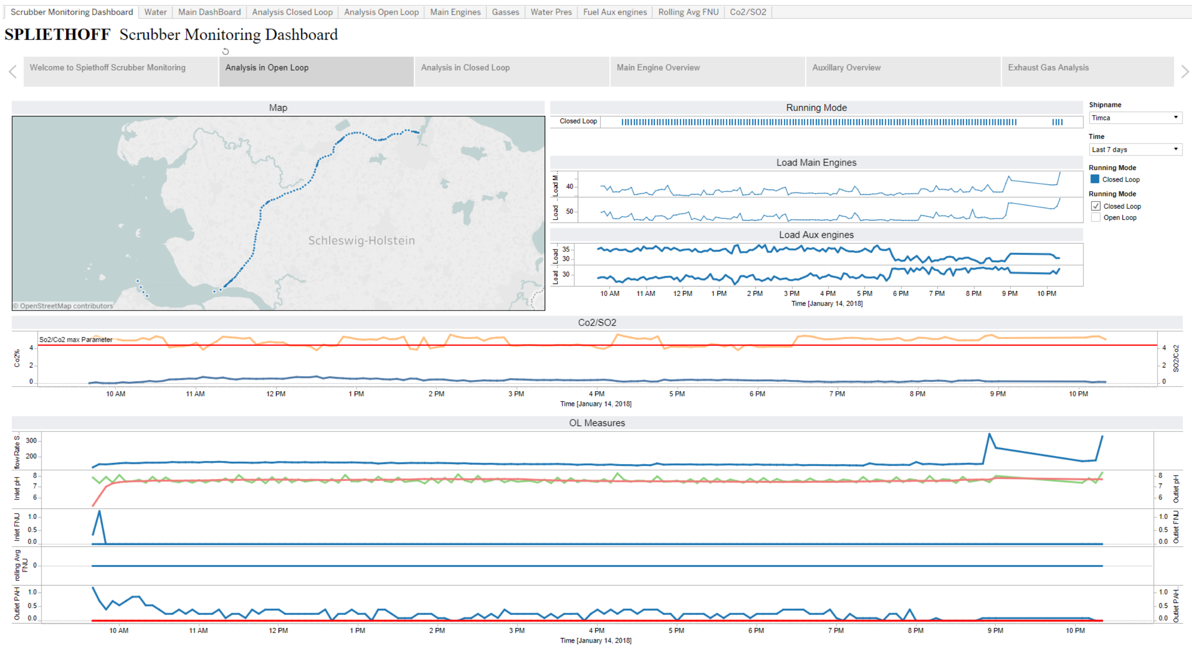

Figure 3.3: Business Intelligence Tool example of a clear representation of data

Business intelligence (BI) tools might offer a solution to this question. The strength of business intelligence tools lies in the ability to clearly visualise relations in large sets of data (see figure 3.3). Showing the relation of certain parameters in the form of visuals like graphs is a simpler way than displaying the relations in the form of equations that come forth out of model generation. On the other hand the equations generated by the model could also be plotted to show the relation but this might give a skewed picture of the reality due to inaccuracy in the model. Hasselaar [2011] bases his decision on the fact that the analysis has to show the performance in real-time on board of the vessel. This is already implemented for this project since there is already a life feed with KPIs to the bridge which is supplied by the sensor system supplier[VAF [2017]]. This system does need improvements since there have been some issues with the useability of this system. This means that some simple KPI's are made in real time on board of the vessel to give the crew the right tools to

optimise the ships performance.
This being said the largest part of the analysis is done on shore. This is where the data from different sources comes together to allow for more detailed performance analysis. Different ways of analysis will be applied to make a good indication of the ships performance. A first simple analysis will be done with linear regression in the from of trend lines. This type of analysis will be used to determine the fouling of the hull over time. The required shaft power to sail at a certain speed range will be filtered to calm weather and plotted over time to give an indication of increased required shaft power due to fouling of the hull and propeller. Filtering for calm weather is a viable method since there is a lot of data and filters can thus be applied to increase the accuracy of the analysis. Another method will be to visualise relations with the help of the BI Tool Tableau. Visualising for instance the effect of different wave heights on the required power or fuel consumption can already create a lot of knowledge that can for instance be used in voyage planning. A problem most BI tools have is that the option for making accurate fit lines are limited. These available fit models neglect the physical properties behind the data. This means that when the data is visualised with one of these BI tool fit lines an inaccurate relation is shown. To solve this problem single and multiple regression analysis is done by formulating simple models from theory and fitting them to the data. It should be said that this is different from standard regression since custom models are used to fit instead of standard regression functions. This way of analysis will also validate the correctness of the data and reduces the uncertainty as mentioned by Aldous [2015] since this is a form of hybrid modelling. These models can then be used to be plotted together with the data to give a more clear view of the relation between parameters which is also theoretically sound. These models can also be used in calculations in for instance business cases and simulations.
Benchmarking is also used to analyse the performance of the vessels. It is applied by benchmarking between sister vessels, benchmarking the performance against baselines and a benchmark between real life operation and the model scale tests. Deterministic data analysis (Normalising) is already done by Grutterink [2017] on a similar but slightly smaller data set. Normalising proved to not be a viable means of analysis for these vessels since due to a lack of information it was hard to make accurate models of the vessel. This means that normalising with the use of theoretical models is not done in this report.
It is clear that every method has its advantages, disadvantages and limitations. Combining the different available methods and applying them to their strongest areas will yield the best results. An example of this is the fact that baselines are very hard to determine for vessels that have been in service for a long time. Benchmarking between different sister vessels can still provide insight into the individual performance of a vessel. The combination of these different methods of analysis should provide a clear picture of the performance of the vessel. This information can then be used to find areas where the performance can be optimised.

3.3. Performance Data Analysis

In this section, the different relations between the performance of the vessel and the major influencing operational parameters are shown and discussed. These major influencing parameters are identified first.
During operation there are a lot of parameters that influence the required power needed for the ship to propel itself through the water. Since all these parameters work on the ship at the same time it is often hard to determine the exact contribution of a certain parameter. The major operational and environmental parameters influencing the required propulsion power are given in table 3.2 [Aldous et al. [2015]]. The list of parameters is no where near complete but it gives a good representation of the most influential ones. Also not all of the named parameters can be analysed. The analysis is limited to the performance data that is available. Manoeuvring (Rudder angle and Propeller pitch) cannot be analysed since there is no data available on the rudder angle and propeller pitch during operation.

Table 3.2: Most Influential Operational Parameters on Ships Propulsion Power

Operational Parameters	
Speed Through Water	Water Depth
Draft	Water Temperature
Trim	Hull and Prop Fouling
Wind Speed	Wind Direction
Wind Waves Height	Wind Wave Direction
Swell Height	Swell Direction
Rudder Angle	Propeller Pitch

Power Curve

The most characteristic graph that indicates the performance of a ship is the speed versus power curve. This curve gives a clear indication about the amount of energy needed to propel the vessel forward at a certain speed. The PMS has monitored the propeller shaft power and corresponding vessel speed for approximately a year. This means that a lot of data (one sample every five minutes) is available. This data can be used to produce the ships power versus speed curve. Figure 3.4 shows the visualisation of the power curve with the use of a BI tool for the vessel "Slotergracht". To get this overview the data has been filtered first. The filters are shown on the right side of the figure. The filters are set in such a way that the conditions are as close to design condition as possible with leaving enough data to give a good overview of the relation. In the map above the plot, the location of where the data has been acquired can be seen. A fit line is also drawn but this immediately indicates the limitations to fit line creation in the BI Tool. A limited amount of regression models can be chosen for these fit lines and these do not always represent the relation of the data correctly. Also the standard regression models which are used to make this fit curve do no always correspond to the physical models which describe the relation. Better fit curves can be made when a custom model is fitted to the data. A custom model which is derived from theoretical physical relations. The model is fitted to the data by minimising the sum of the squared error between the model and the measured values. This is also a type of regression analysis but it differs from the standard linear and multiple regression in the fact that is uses custom models.

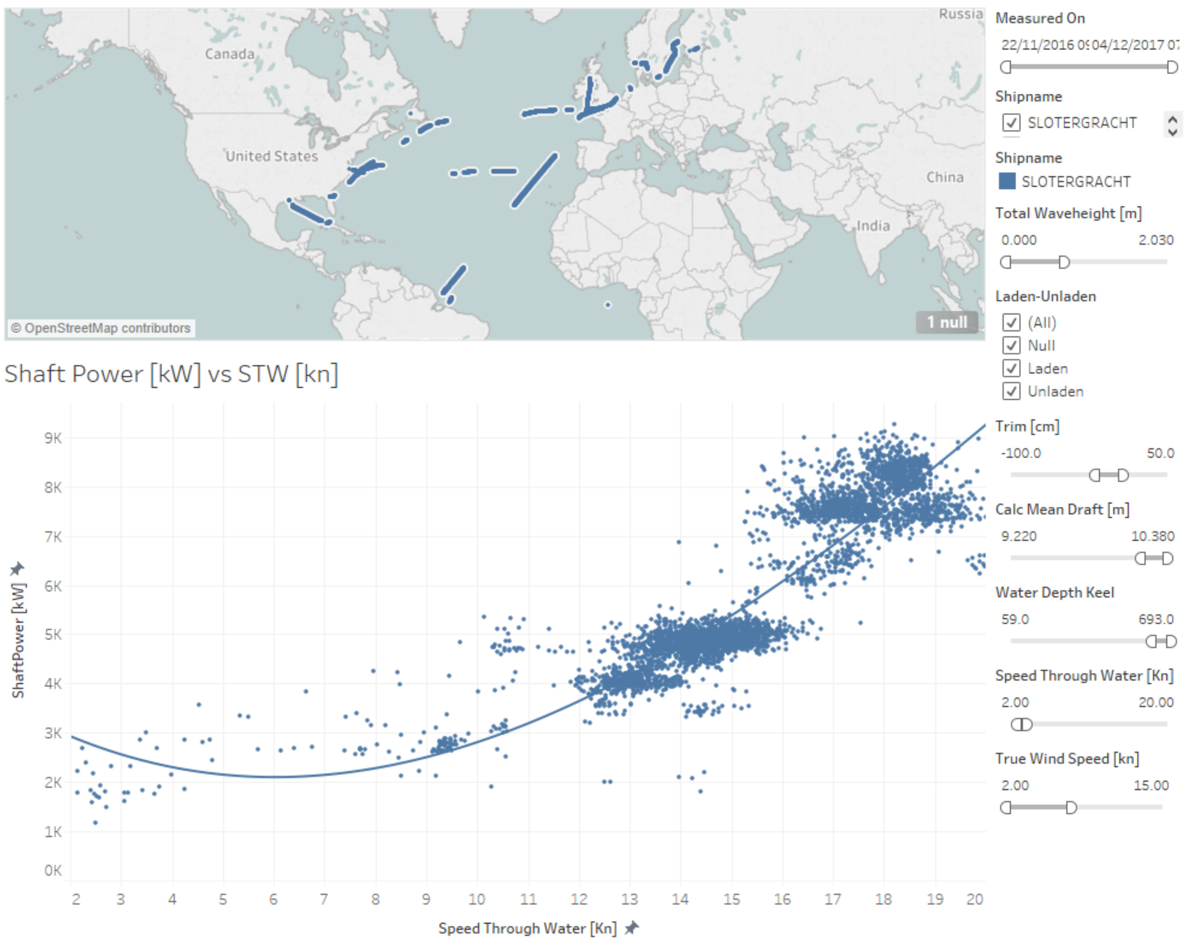

Figure 3.4: Shaft Power vs Speed through water for different waveheights

Holtrop and Mennen [1978] is considered as a way to model the required propulsion power since it is a widely used and accepted means of estimating the required shaft power. The downside to this method is that the equations used by Holtrop and Mennen [1978] consists of a lot of parameters and are not easily used in regression. Also Hoogenhout [2010] used the Holtrop and Mennen method in his research for determining the optimum trim for Spliethoff vessels and his estimations for propulsion power do not correlate with the data

found with the performance monitoring system. For these reasons the Holtrop and Mennen [1978] method is not used as a fit model but the method is used to give an indication of important parameters for the determination of required shaft power.
Klein Woud and Stapersma [2002] give the following relation in equation 3.1 between power and speed. This relation is derived from the frictional resistance relation. This means that the wave making resistance is not taken into account at first glance. This means that this equation is only valid for Froude numbers below 0.2. The wave making resistance can be taken into account if the term C_D increases with vessel speed.

$$P_D = C_D * \rho^{1/3} * \Delta^{2/3} * v_s^3 \tag{3.1}$$

Due to the position of the torque sensor we can assume that P_D is measured directly. C_D is a term which varies as well due to speed, fouling, waves, geometry and other operational parameters. In this case we have set filters for these parameters and the Froude number is low enough that it does not vary significantly with speed so firstly it is assumed that C_D is set to be constant first. ρ and Δ are also kept constant since their changes are very small and thus of little effect. We can thus rewrite this model to $P_D = C * V^3$.
If we fit this model to the measured data, we see that they do not match. The model is fitted with the use of regression in Excel. By using solver to minimise the sum of the squared error between the model and measured data the optimal fit is found. Figure 3.5 shows the measured data in blue and the model proposed by Klein Woud and Stapersma [2002] in orange. $P_D = 1.459 * V^3$ describes this model. This model will be referred to as fixed pitch model in the rest of this chapter.

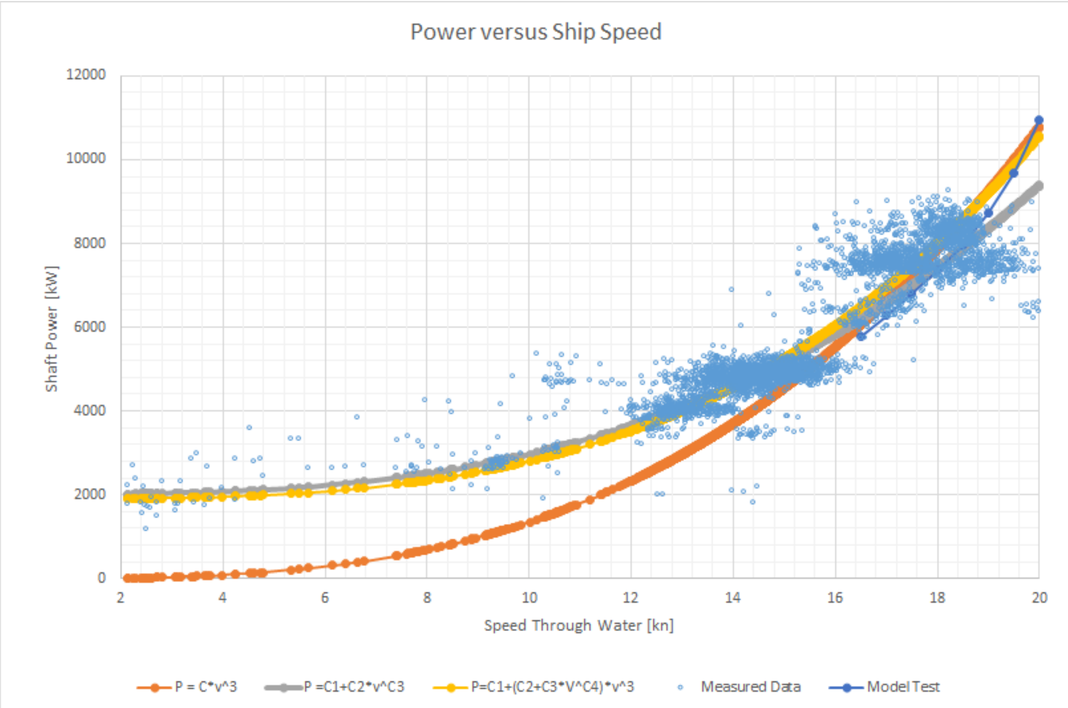

Figure 3.5: Model fits for Shaft Power vs Speed through water for the Slotergracht

What can be clearly seen is that the model does not fit the data at lower speeds. The performance of the real vessel is poor at low speeds compared to the imposed model. This can be explained if we dive deeper into the characteristics of the propulsion plant. The model described by Klein Woud and Stapersma [2002] describes a vessel with a fixed pitch propeller (FPP) which reduces shaft revolutions (referred to as rpm) when reduced speed is desired. The three Spliethoff vessels are equipped with a controllable pitch propeller (CPP) which operates in constant rpm mode. Meaning that the pitch is reduced when reduced speed is required. This is done because the vessel is equipped with a power take off (PTO) or shaft generator. To ensure the generator produces 60 Hz AC the shaft must be kept at constant rpm. Hollenbach and Reinholz [2011] describe the performance difference between fixed rpm mode and fixed pitch mode in their paper. Propeller efficiency is sub-optimal at speeds below the design condition due to the high rpm and low pitch of the propeller. Figure 3.6 shows the relation between fixed rpm, fixed pitch and combinator mode performance. Combinator mode varies both pitch and rpm to allow for a smaller sea-margin or is applied with engines that have a small power band.

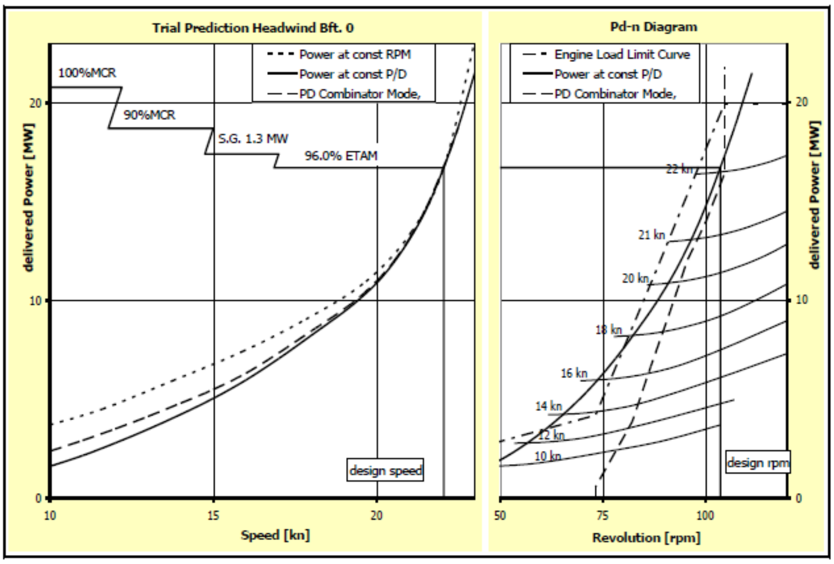

Figure 3.6: Performance difference between constant RPM and constant P/D [Hollenbach and Reinholz [2011]]

The fit model has to be adapted to account for this loss in propeller efficiency at lower speed. The shaft power will never go to zero, even at zero thrust, because the propeller is still turning at high speed and thus stirring up the water a lot. A new fit models is proposed. $P_D = C_1 + C_2 * v_s^{C_3}$ This model accounts for the loss in efficiency by simply adding a constant which represents the power required to spin the propeller in zero thrust mode. The term C_1 thus represents the shaft power at zero speed or zero thrust but at nominal revolutions per minute of the propeller shaft. This model fit is indicated by the grey line in figure 3.5. When the regression analysis is performed on this model to produce the fit with the smallest error score the resulting model fits the data at lower speed very well but at higher speed the relation does not really match. The power speed relation is expected to be steeper around design speed (19.5 knots) than the grey model depicts. At design speed the relation should behave the same or close to the same as the FPP model. This being said the fit is a clear improvement over the fixed pitch model.
A final model is proposed to better represent the relation between power and speed: $P_D = C_1 + (C_2 + C_3 * v_s^{C_4}) * v_s^3$. This model accounts for the change in C_D with increasing speed as described by Klein Woud and Stapersma [2002]. This changing C_D accounts for the influence of the wave making resistance which becomes dominant at higher Froude numbers. The constants in this last model are not all determined by regression but some are set manually in such a way that the model fits the relation better. This is done because when all constants are found by regression the line is less steep due to the high spread in the data. It results in a lower sum of the errors but it does not follow the relation of the data better. The fitted model is indicated by the yellow line in figure 3.5. It can be seen that the yellow line follows the relation better. An overview of the models with corresponding error score is given in table 3.3. The lower the error score the better the fit is to the measured data.

Table 3.3: Overview of fitted models to Slotergracht power curve

Model Name	**Model to fit**	**Model after fit**	**Error score**
Fixed pitch model (Orange)	$P_D = C * V^3$	$P_D = 1.398 * V^3$	215.601
Simple fixed rpm model (Grey)	$P_D = C_1 + C_2 * v_s^{C_3}$	$P_D = 2010.13 + 1.091 * v_s^{2.944}$	62.275
Fixed rpm adjusted fit (Yellow)	$P_D = C_1 + (C_2 + C_3 * v_s^{C_4}) * v_s^3$	$P_D = 1900 + (0.75 + 0.012 * v_s^{1.11}) * v_s^3$	73.683

Even though the last model has a lower error score it represents the relations better. The large spread in the data around 17-20 knots makes the regression flatten out the fit. The last model is also used to make fits for the other two vessels. Figure 3.9 shows all three models plotted in one graph. The fits for the Singelgracht and Schippersgracht with the measured data can be found in figures 3.8 and 3.7. The models corresponding to the three ships are also given in table 3.4. The models shown in this table will be set as the base power models for the three vessels. These will later be used to help identify the influence of the other operational parameters.

Table 3.4: Corresponding powercurve models for the three vessels

Ship Name	Model to fit	Model after fit
Slotergracht	$P_D = C_1 + (C_2 + C_3 * v_s^{C_4}) * v_s^3$	$P_D = 1900 + (0.75 + 0.012 * v_s^{1.11}) * v_s^3$
Singelgracht	$P_D = C_1 + (C_2 + C_3 * v_s^{C_4}) * v_s^3$	$P_D = 1900 + (0.70 + 0.012 * v_s^{1.2}) * v_s^3$
Schippersgracht	$P_D = C_1 + (C_2 + C_3 * v_s^{C_4}) * v_s^3$	$P_D = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3$

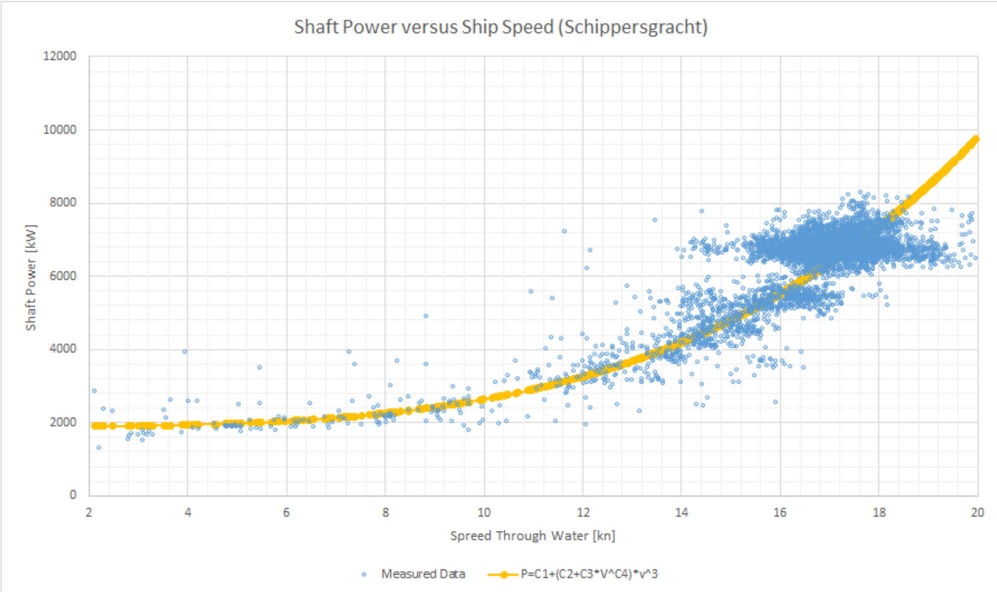

Figure 3.7: Power curve fit and measured data for the Schippersgracht

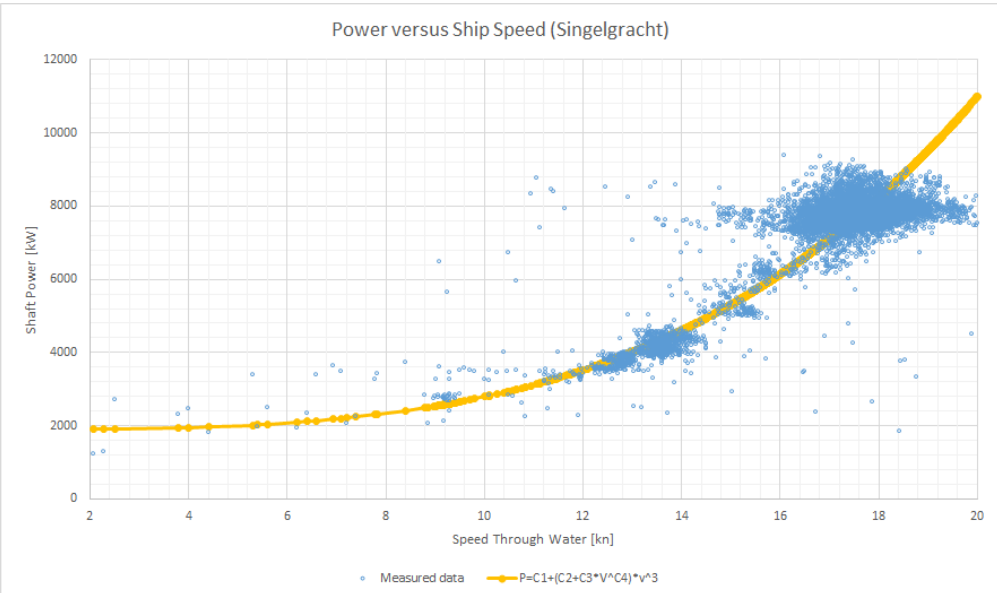

Figure 3.8: Power curve fit and measured data for the Singelgracht

It should be noted that the power speed relation fits the data well but that the result is unexpected at first sight. As mentioned before the relation does not show a steep curve at high speeds even though that is expected here since the vessels are fast for their size. This is explained by the fact that the hull is severally optimised for high speeds. The hull is very slender (based on high speed container vessels) and has an optimised bulb design. Another reason is the earlier named fact that the vessel sails in constant rpm mode and thus has a poorly performing propeller at lower speeds. All in all in can be said that the analysis succeeded in finding an accurate relation between the speed and required shaft power of the vessel.

The three vessels can be benchmarked against each other by looking at figure 3.9. It is clear that the Schippergracht performs significantly better than the other two when it comes to the required power needed to sail at a certain speed. Further research is needed to find the cause of this performance difference. This immediately shows the the downside to regression analysis with simplified models. It makes it harder to find the reason behind certain relations. The vessel performance when it comes to shaft power can also be benchmarked against the model scale tests of the vessels. The results of the model scale test are shown as the dark blue dotted line in figure 3.5. The problem with the results of the model scale test is that it also assumes variable shaft rpm. Meaning that a real benchmark can not be made. We can say that the vessel performs worse than the model scale tests indicates.

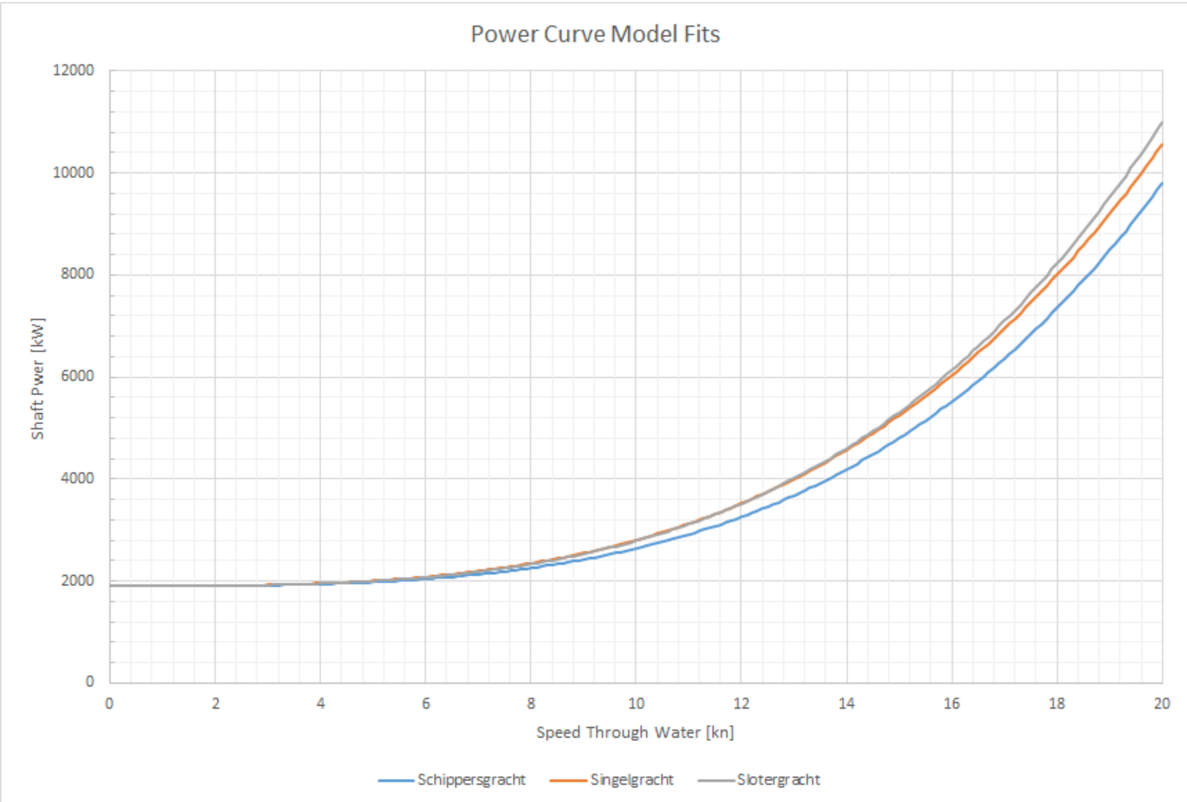

Figure 3.9: Power curve model fits for the three vessels

Two conclusions can already be drawn about the performance of the vessels from this initial analysis on the power curve of the vessels. Firstly the performance loss due to the ship operating at fixed rpm compared to variable rpm is large. The performance loss is due to the efficiency loss of the controllable pitch propeller turning very fast with low pitch at lower speed. The magnitude of this performance loss can be seen by looking at the difference between the yellow and orange line in figure 3.5. This is very valuable information for Spliethoff. Large savings in propulsion power can be achieved by installing a combinator mode on the vessels. This loss of required propulsion power has to way up against switching off the shaft generator at lower speeds and turning on the auxiliary engines. The auxiliary engines run on marine gas oil which is around 60 percent more expensive than HFO. Another option is installing a frequency converter. This has the advantage of not having to switch to the auxiliary engines but this installation is very costly to install. Now

that the data can be easily visualised and a fit model is introduced the business-case for this possible retrofit can be executed and can be more accurate since it is data driven.
The second conclusion is that the Schippersgracht outperforms the other two vessels when it comes to power needed for propulsion. The large difference is unexpected since the three vessels are identical and all have similar trades and hull fouling conditions. The large difference could indicate a sensor error but this has been ruled out by the sensor supplier. Deeper research into this difference in power has revealed that the engine of the Schippersgracht is tuned differently. The fuel rod position setting is different than for the other two vessels. Meaning that the maximum amount of fuel injection is limited for the Schippersgracht. This is also clearly illustrated if we lay the fuel consumption versus speed relation data over each other for the three vessels (See figure 3.10). It can be clearly seen that the maximum fuel flow lies eight tons per day lower for the Schippersgracht. There is a positive and a negative side to this. The positive side is that fuel is saved because the vessel is not able to operate above a certain fuel consumption where the other ones are. The downside is that the vessel is not able to operate at its full potential. The fact remains that until the data was analysed, it was unknown to the company that there was a difference in performance. Now that this is made insightful, research can be done to determine if the different fuel rod has a positive effect on the commercial performance of the vessel or not.

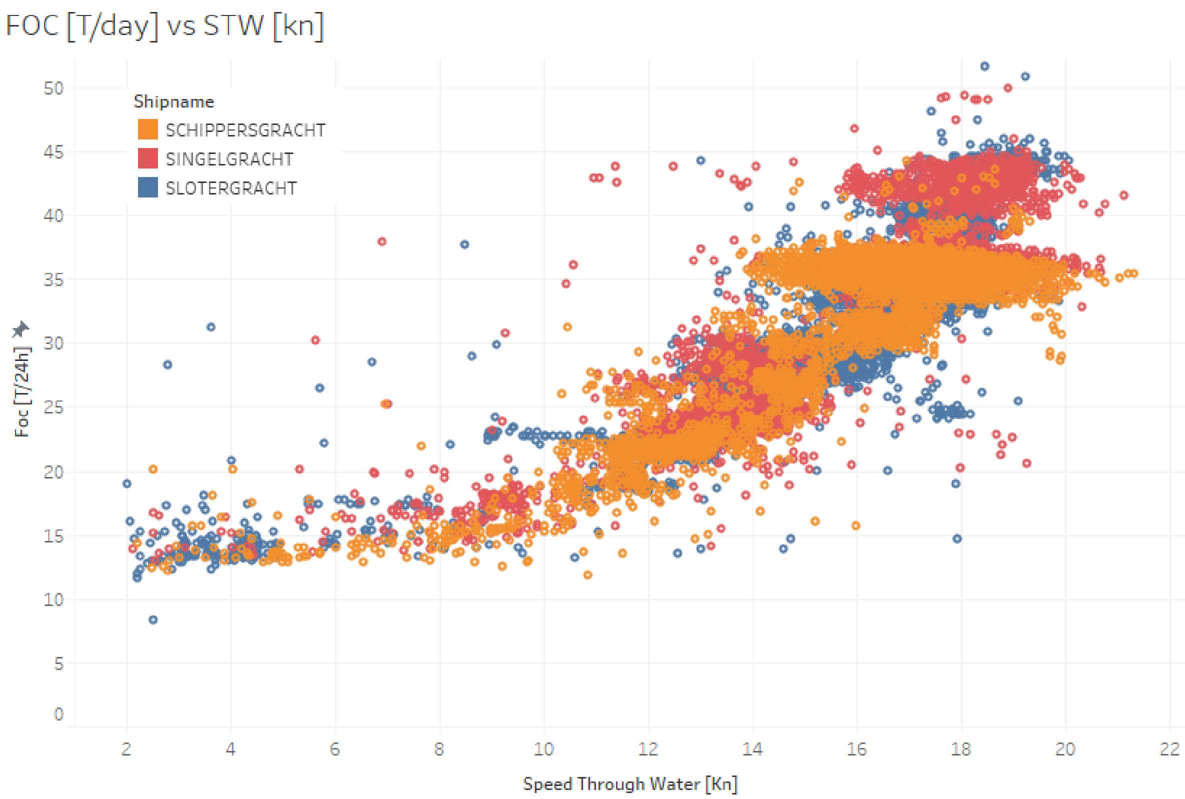

Figure 3.10: Fuel consumption in ton per day vs Speed through water for the three vessels

The proposed fit model for the relation between shaft power and vessel speed through water is based on theory but is very much simplified. It is simplified in the way that not every single component influencing the propulsion is modelled separately. Also the shaft power is not only influenced by vessel speed. Even though we have filtered out the influence of certain parameters as much as possible (Trim, Draft, Depth, Waves, Wind), their influence still remains in the form of the scatter shown in the measured data. There are advantages and disadvantages to this simplification. The advantage is that it simplifies the regression analysis and that the fitted model can be easily used in other calculations or decision support. The downside is that larger assumptions had to be made which could have a negative effect on the accuracy. The biggest simplification comes from the fact that the propeller is not modelled separately. By modelling the controllable pitch propeller separately more insight could be given into the performance of the vessel. This being said, we can also say that the combination of filtering, theoretic models and regression is a good way to determine

relations. The model shows a good fit to the data. The base models have now been calculated over the entire period of monitoring. The base models can also be used to benchmark different periods of operation and they should be revisited every few months.
Lastly, a note is made about the data quality and the effects of this on the uncertainty of the analysis. As said earlier a large spread in the data forced the regression analysis to show a more flat relation than expected. Corrections were made manually to counter this but this does cause uncertainty in the analysis. The fit model shown below was for this reason also not used for these vessels. The model has a separate term to account for the wave making resistance. This term is dependent of the Froude number (Fn) multiplied with the vessel speed till the power of four. Regression resulted in a C_3 of zero. This is caused by the large horizontal spread in the data and also partly due to the fact that the S-type vessels are optimised for high speeds.[1]

$$P_D = C_1 + C_2 * v_s^3 + C_3 * Fn * v_s^4$$

This is the first example which shows the importance of data quality but this will become more and more apparent throughout the data analysis. An increase in data quality could remove this spread and thus reduce uncertainty. This subject will come back at the end of the data analysis in section 3.4 where this subject is discussed.

Consumption Curves

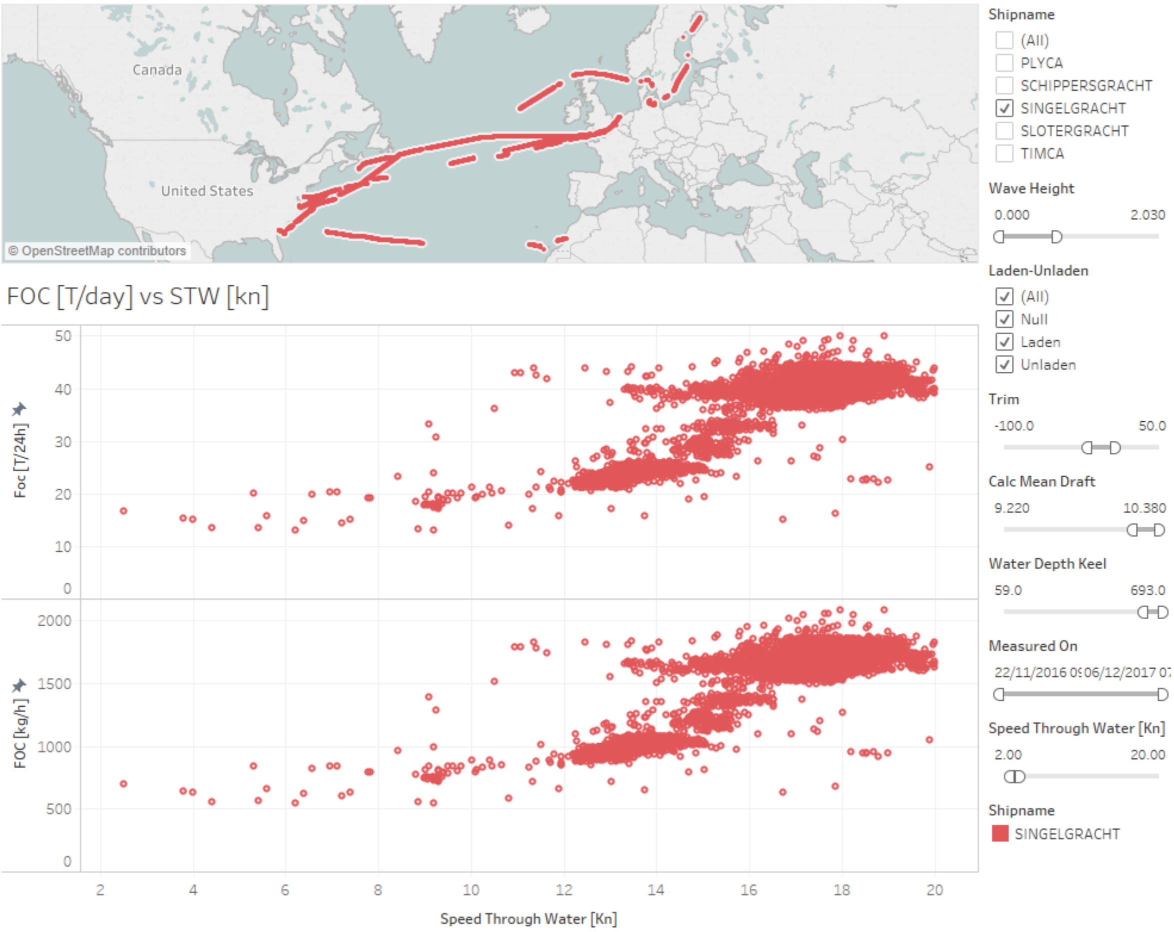

Figure 3.11: Fuel consumption in ton per day and kg per hour vs Speed through water for the Singelgracht

Another important performance relation for performance management is the fuel consumption per time and per distance compared to the vessel speed through water. Fuel consumption is so important because this di-

[1] This model is used for different vessel series which are not optimised for higher speeds and thus show a lot steeper relation at higher speeds. This analysis is not shown in this report.

rectly relates to costs through the fuel price. The fuel consumption per nautical mile versus the speed through water relation even gives an indication of the speed at which the least amount of fuel is consumed per nautical mile. The relations between fuel consumption and speed is researched in the same way as the power curve. Firstly, the data is visualised and filtered. After this, a fit model is proposed to represent the relations. The fuel consumption per unit of time versus the STW is analysed first. After this the fuel consumption per nautical mil versus the STW is analysed.

The PMS monitors the fuel flow of the three main consumers. The main engine (HFO), the diesel generators (MGO) and the boiler (MGO). Since the vessel has a shaft generator. The auxiliaries run only in port or when the shaft generator is defective. Boiler consumption and auxiliary consumption is not considered in this first analysis of performance during sailing. This means we will only consider the heavy fuel oil (HFO) consumption first. The fuel consumption per unit of time versus STW data is visualised and filtered as shown in figure 3.11.

It can be seen that this data very much follows the trend of the shaft power. This makes sense since the total fuel consumption consists of the break engine power (P_B) multiplied by the specific fuel consumption (sfc) of the engine at that load. In the case of these three vessels the brake engine power is built up from the propulsive power and the shaft generator power. The propulsive power is much larger than the shaft generator power (max.10000 kW versus max.800 kW) so it is expected that the fuel consumption follows a similar relation with speed as the shaft power. The difference is that at low loads of the engine the specific fuel consumption of the engine goes up. This thus lowers the performance at low loads and the relation will show a less steep increase with speed than the shaft power relation. This difference will be captured in different values for the constants but the same standard fit model as the speed versus power relation is used:

$$FOC_{kg/hour} = C_1 + (C_2 + C_3 * v_s^{C_4}) * v_s^3$$

The regression constants in this model are adjusted so it fits the fuel consumption data. The constants C_3 and C_4 are set at certain values to assure a better fit. This was needed in the regression process due to the large horizontal spread in the data. Due to this large horizontal spread in the data the regression pulls the fitted curve more flat than it should and thus causes C_3 and C_4 to be set to zero. By setting these values to a certain value and using regression to determine the other two values a better fit is realised. Regression analysis to fit the model to the data of the Singelgracht leads to the following model:

$$FuelConsumption[kg/hour] = 550 + (0.15 + 0.0013 * v_s^{1.3}) * v_s^3$$

The same process is repeated for the other two vessels. Which again allows us to have a quick benchmark between the three vessels. The three models together in one plot are displayed below in figure 3.12. Table 3.5 also gives and overview of the models. The fits and together with the raw data are shown in figure 3.13, 3.14 and 3.15. The fitted models show a good fit with the data even though a large scatter in the data is still present.

Table 3.5: Fuel Consumption models for the three vessels

Ship Name	**Model to fit**	**Model after fit**
Singelgracht	$FOC_{kg/hour} = C_1 + (C_2 + C_3 * v_s^{C_4}) * v_s^3$	$FOC_{kg/hour} = 550 + (0.15 + 0.0013 * v_s^{1.3}) * v_s^3$
Slotergracht	$FOC_{kg/hour} = C_1 + (C_2 + C_3 * v_s^{C_4}) * v_s^3$	$FOC_{kg/hour} = 550 + (0.15 + 0.00125 * v_s^{1.3}) * v_s^3$
Schippersgracht	$FOC_{kg/hour} = C_1 + (C_2 + C_3 * v_s^{C_4}) * v_s^3$	$FOC_{kg/hour} = 550 + (0.14 + 0.0012 * v_s^{1.3}) * v_s^3$

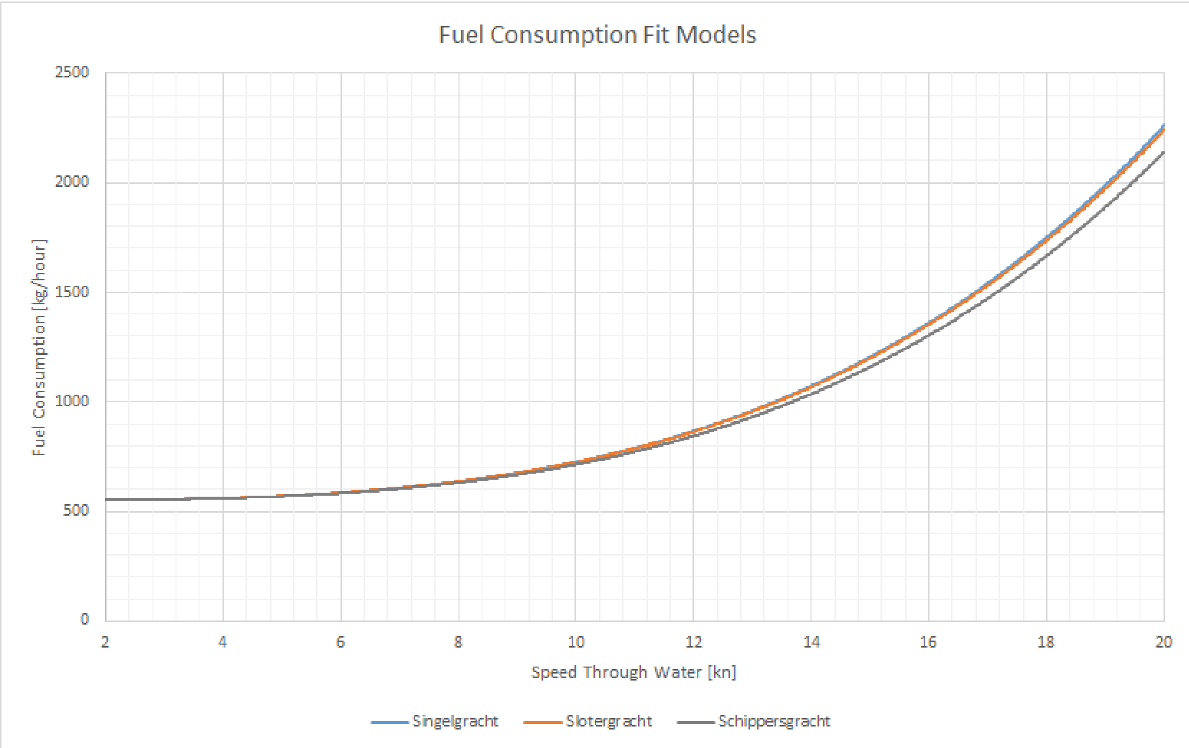

Figure 3.12: Fitted models for fuel consumption in kg per hour vs speed through water

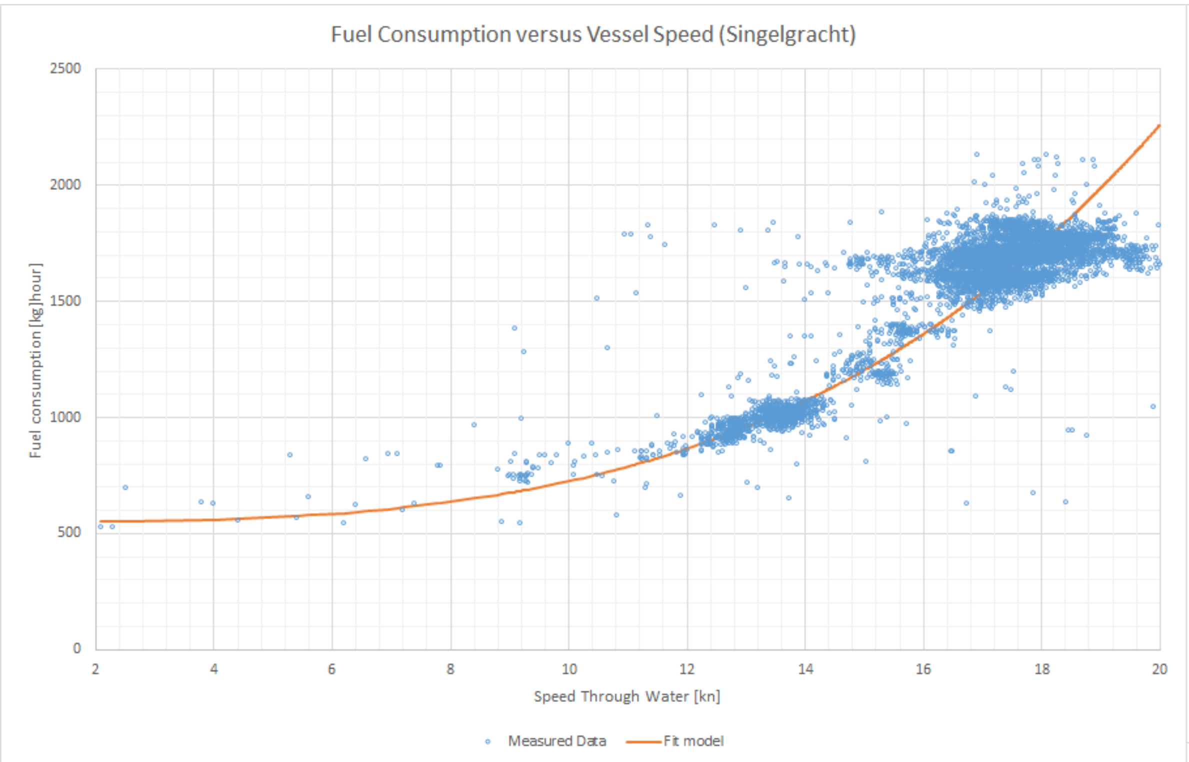

Figure 3.13: Fuel consumption fit Singelgracht

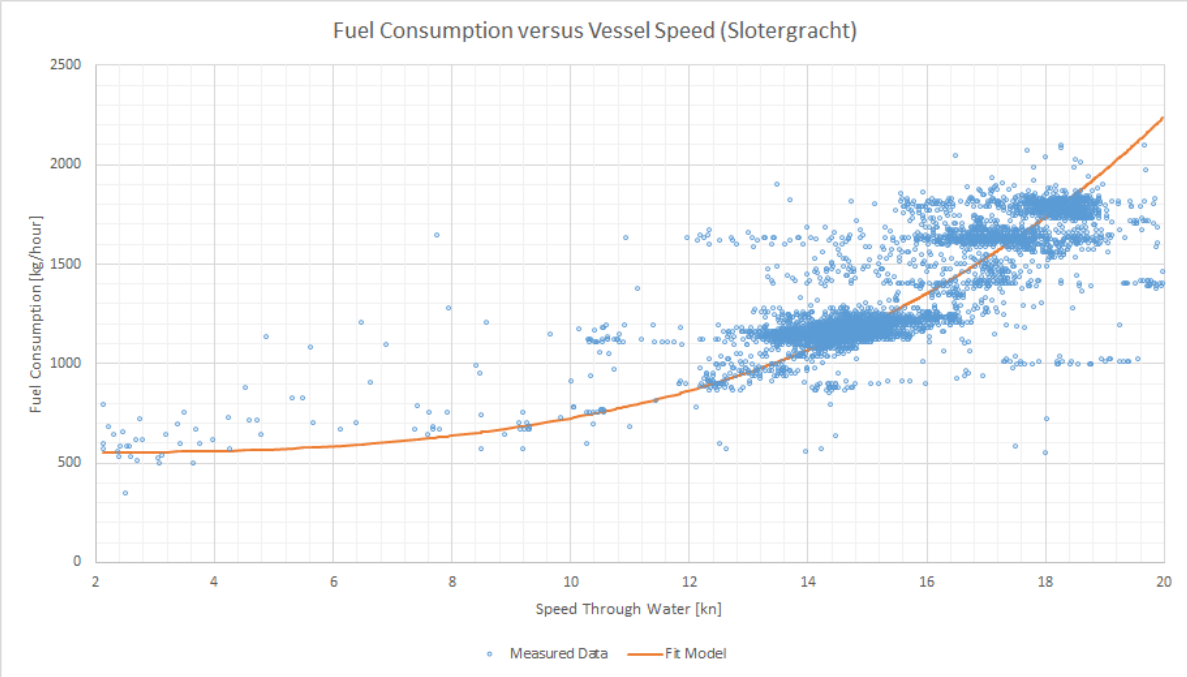

Figure 3.14: Fuel consumption fit Slotergracht

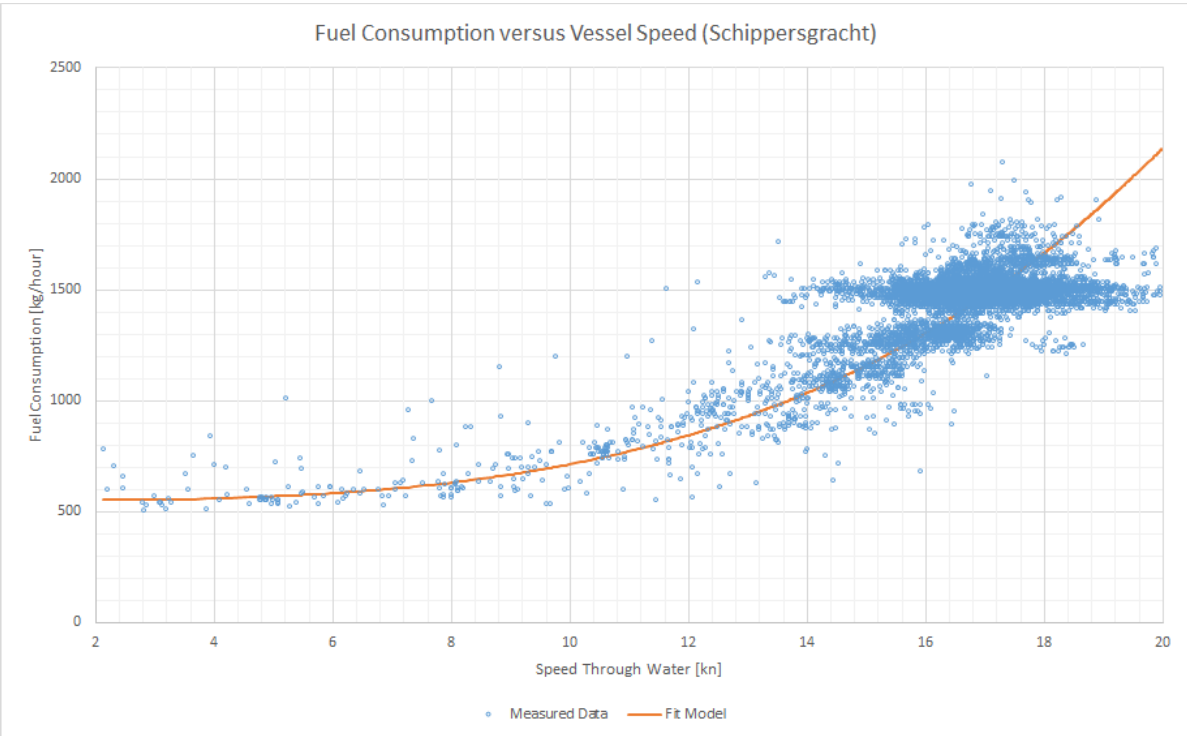

Figure 3.15: Fuel consumption fit Schippergracht

The fuel consumption per hour is an important KPI because it can be easily linked to costs. Fuel costs are the biggest operational cost for Spliethoff. The fuel costs have in 2016 an average share of around 27 percent of the total yearly vessel costs. We can again see the Schippersgracht has a lower fuel consumption than the other two vessels at higher speeds. This is again explained by the different fuel rod settings.

To further specify the fuel consumption versus speed relation, one last relation is formulated. This relation is the fuel consumption per nautical mile sailed through water. Fuel consumption per nautical mile gives the best insight into the fuel efficiency of the vessel. Nautical mile sailed through water is chosen because this eliminates the influence of current. The performance curve is based on the fuel consumption per unit of time but it is divided by the vessel speed through water. This means that the model for the fuel consumption in kg per hour can be used. These models simply have to be divided by the speed through water. An overview of these models is given below in table 3.6.

Table 3.6: Fuel Consumption per nautical mile models for the three vessels

Ship Name	**Model to fit**	**Model after fit**
Singelgracht	$FOC_{kg/nm} = \frac{C_1+(C_2+C_3*v_s^{C_4})*v_s^3}{v_s}$	$FOC_{kg/nm} = \frac{550+(0.15+0.0013*v_s^{1.3})*v_s^3}{v_s}$
Slotergracht	$FOC_{kg/nm} = \frac{C_1+(C_2+C_3*v_s^{C_4})*v_s^3}{v_s}$	$FOC_{kg/nm} = \frac{550+(0.15+0.00125*v_s^{1.3})*v_s^3}{v_s}$
Schippersgracht	$FOC_{kg/nm} = \frac{C_1+(C_2+C_3*v_s^{C_4})*v_s^3}{v_s}$	$FOC_{kg/nm} = \frac{550+(0.14+0.0012*v_s^{1.3})*v_s^3}{v_s}$

This relation is so insightful because it gives an immediate indication of the most fuel efficient speed. Spliethoff calls this "Eco Speed". Normally eco speed refers to the most economical speed (speed with best financial result [Stopford [2009]]) but Spliethoff has used this name to indicate the most fuel efficient speed. The speed with the highest financial result is named the "optimum speed" by Spliethoff.
The three model fits are shown in figure 3.16. We can see that according to the fit models the most fuel efficient speed lies between 11 and 11.5 knots. This relation can be used to calculate the optimum speed with the most profit or to give an accurate estimation of the expected fuel consumption on a certain voyage at different speeds.

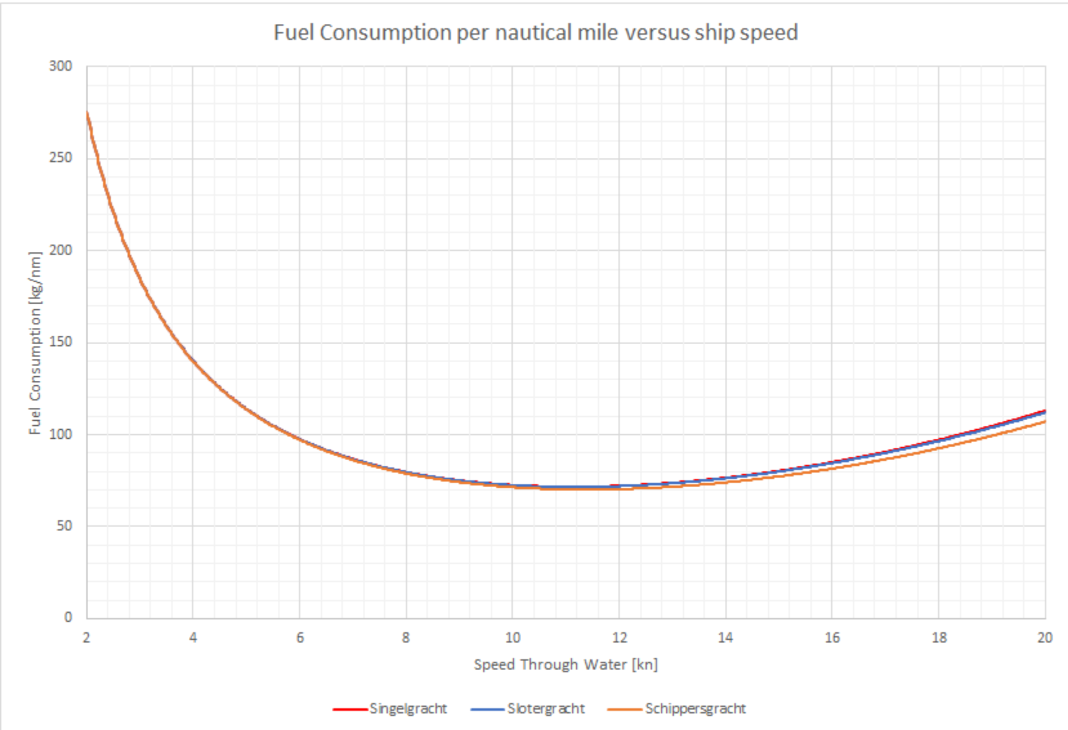

Figure 3.16: Fuel consumption per nautical mile fit models

The data of the three vessels is shown in figure 3.17. A graph with both the data and the fit of the Singelgracht can be found in figure 3.18. It is important when using regression to look at both the raw data and the fitted model when doing analysis. Hasselaar [2011] indicates that when only fitted curves or trend lines are shown without the raw data the accuracy and significance of the regression is often overestimated. Which could then lead to poor conclusions. It should thus be noted that data and trend or fit line should be shown together as much as possible. Transparency on how the fit lines are formed is crucial for the believabilty and accuracy of the performance analysis. If we look at the data in figure 3.17, it can be seen that a large spread is still present. Meaning that the above mentioned is extra important here.
This being said the proposed models do give an accurate representation of the relation between speed and consumption. The large spread is to be reduced by improving the data quality and setting stricter filters. Continual analysis is thus recommended in order to reduce uncertainty.

Now that the calm water baselines for fuel consumption and shaft power are defined, the analysis can turn to the effect of operational parameters on the performance of the vessel. This means that the influence of for instance waves can be determined in respect to these baselines.

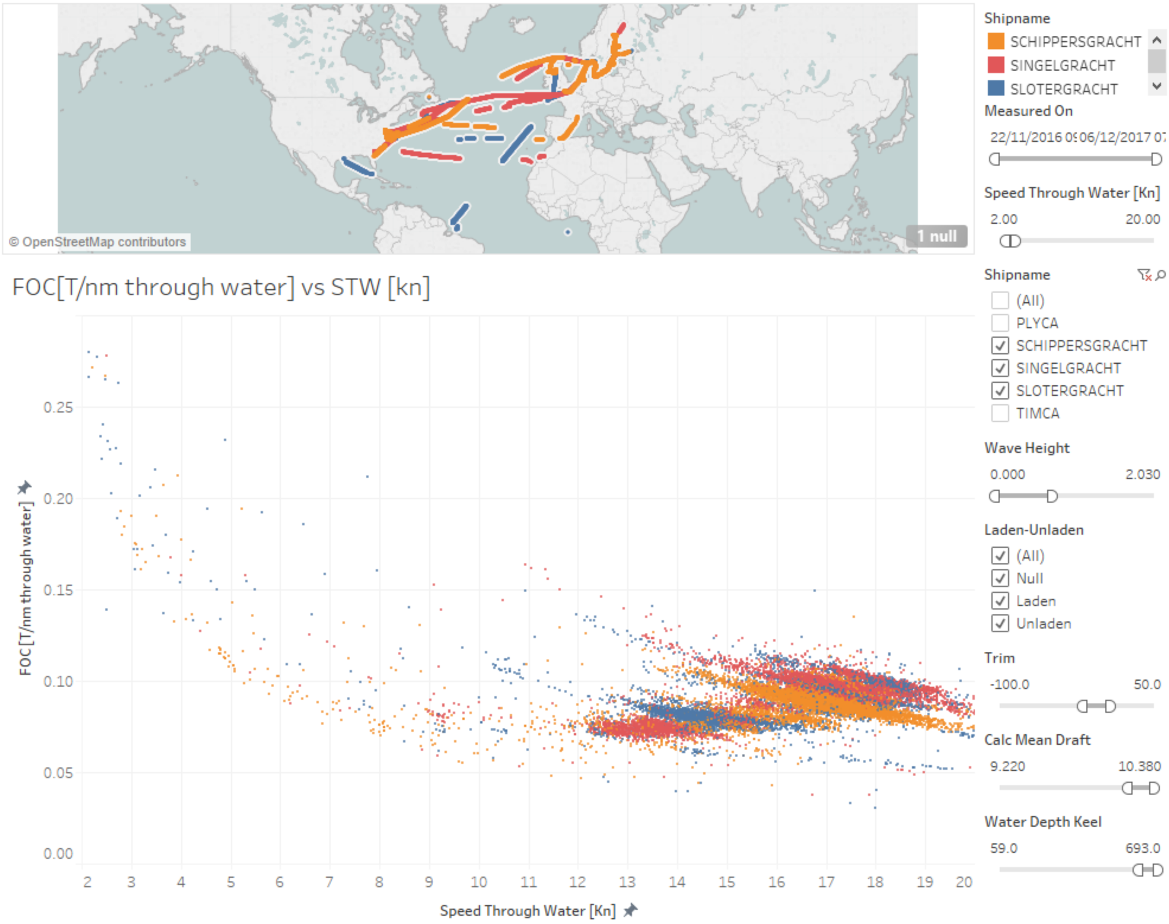

Figure 3.17: Fuel consumption per nautical mile data

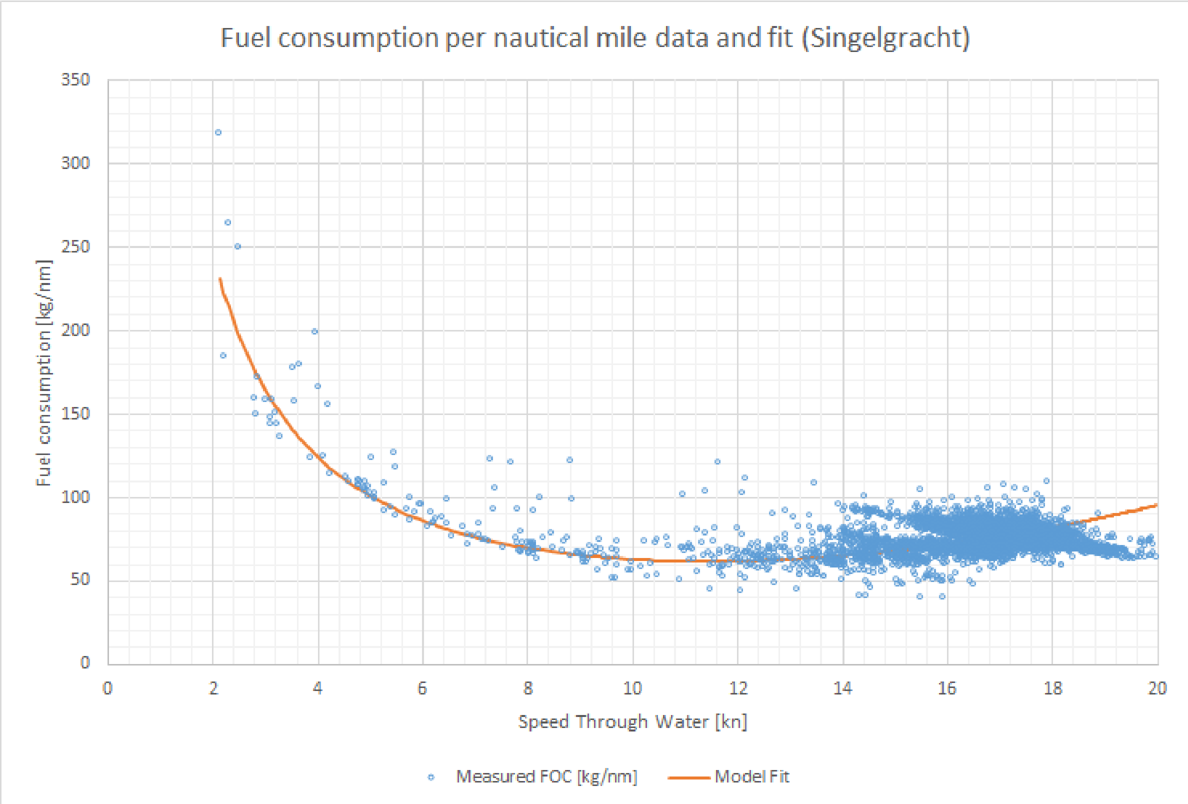

Figure 3.18: Fuel consumption per nautical mile data and fit Singelgracht

Effect of Waves

The effect of waves on the performance of the vessel is significant. Waves in this case meaning both swell and wind waves. These two are combined using Pythagoras's theorem into a total wave height. The two waves have been taken together to simplify the analysis. A better way to describe this might be to define it as the effect of a certain sea state and the sea state is defined by the total wave height. The total wave height is also a significant wave height. These sea states are called wave height categories in this chapter. These wave height categories have a range of half a meter of wave height (e.g. 0 to 0.5 meters or 4 to 4.5 meters). Figure 3.19 gives an overview of the data for the Schippergracht. It gives the shaft power versus speed data for the different wave categories and shows the frequency and the location of occurrence. The data is filtered on trim, wind, draft and operational mode (full sea sailing).

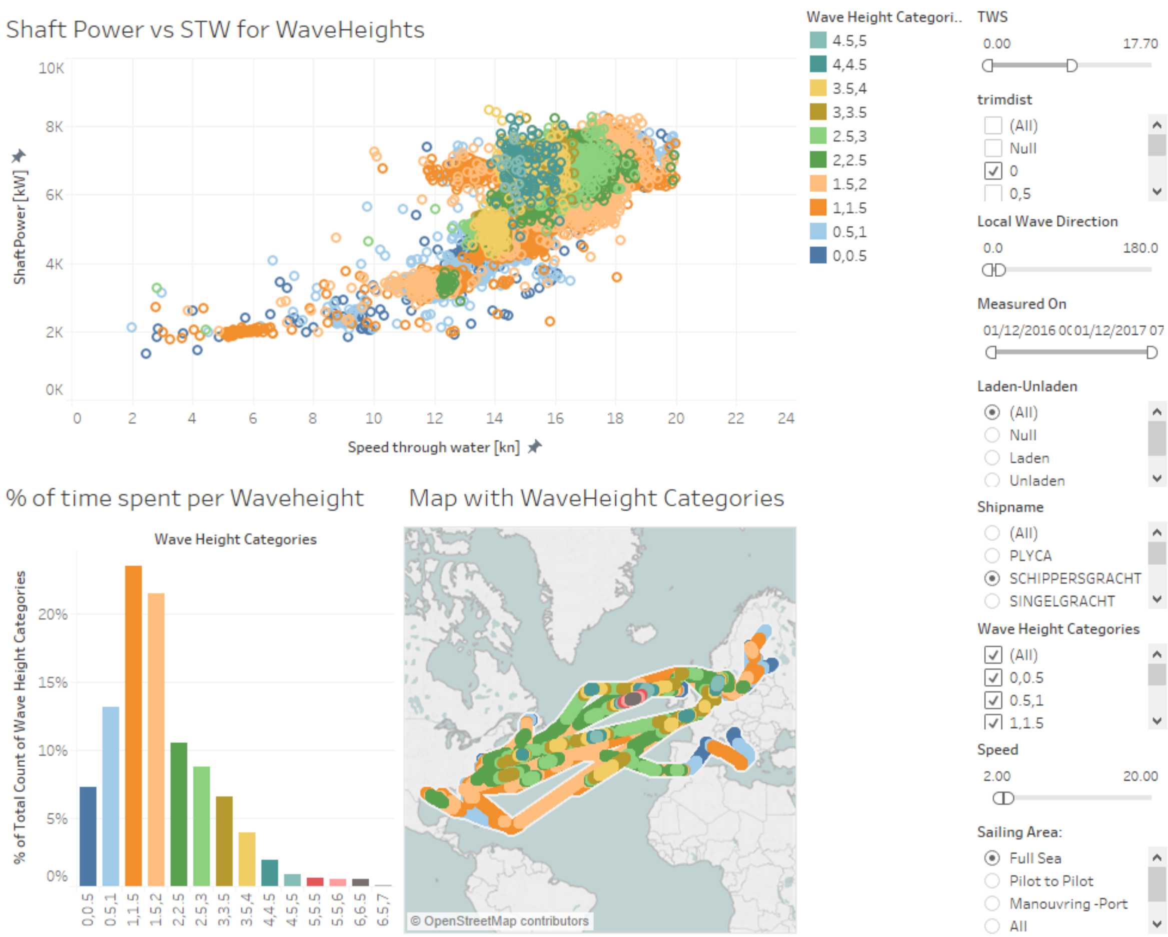

Figure 3.19: Effect of Waves Dashboard showing measured data

It can be seen that increasing wave height also needs a higher shaft power to sail a certain speed. This being said, from just the data it is difficult to see how big the influence on waves is. To give a better view of the relation between wave height and shaft power fit lines should be made. A proposed model is fitted to the data with the use of regression. A very popular model for the correction of wave added resistance is STAwave-1 and STAwave-2 [van den Boom et al. [2013]]. STAwave-1 is a simple theoretical model and STAwave-2 is an empirical model. Equation 3.2 shows STAwave-1. Besides the wave height the model is only dependant on constant parameters (ρ and g variations small so ignored). van den Boom et al. [2013] gives limitations to the model in that the wave height should be limited compared to the length of the vessel and is limited to wave directions +/− 45 degrees on the bow.

$$\overline{R}_{aw} = \frac{1}{16}\rho g H_s^2 B \sqrt{\frac{B}{L_b}} \tag{3.2}$$

For the fit lines, the model has to be adapted so it can be used in a regression analysis to make it fit the data. Since shaft power data is available and not resistance data, the resistance is multiplied by the speed (in m/s) of the vessel. To determine the added shaft power we also have to account for the propulsive efficiency. The following model for the added wave power is proposed for the regression analysis:

$$P_{aw} = C_{aw,p} H_w^2 V_s$$

The correction for the difference between knots and m/s is enclosed in $C_{aw,p}$. This model will be added to the base model which has been formulated in the section "Power Curve" above. During the regression analysis we will vary the $C_{aw,p}$ so it best fits the data. This $C_{aw,p}$ can then also be compared to the products of the constants in equation 3.2 as a validation. When this is done we again have to correct for the propulsive efficiency and the different between knots and m/s.
The analysis is done for the Schippersgracht data. The regression is done for every wave height category with sufficient data. For $C_{aw,p}$ it is then verified if it is constant for the different wave height categories. The following model below is thus used for regression analysis of the added wave power for the Schippersgracht:

$$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} H_w^2 V_s$$

For the wave height in this equation, the average of every wave height category is taken. The resulting fit lines are shown in figure 3.20. An increasing shaft power can clearly be seen for increasing wave heights. The fit lines also fit the data well. This can be seen in figures 3.21 and 3.22 where a visualisation of the regression for the different wave height categories is given.

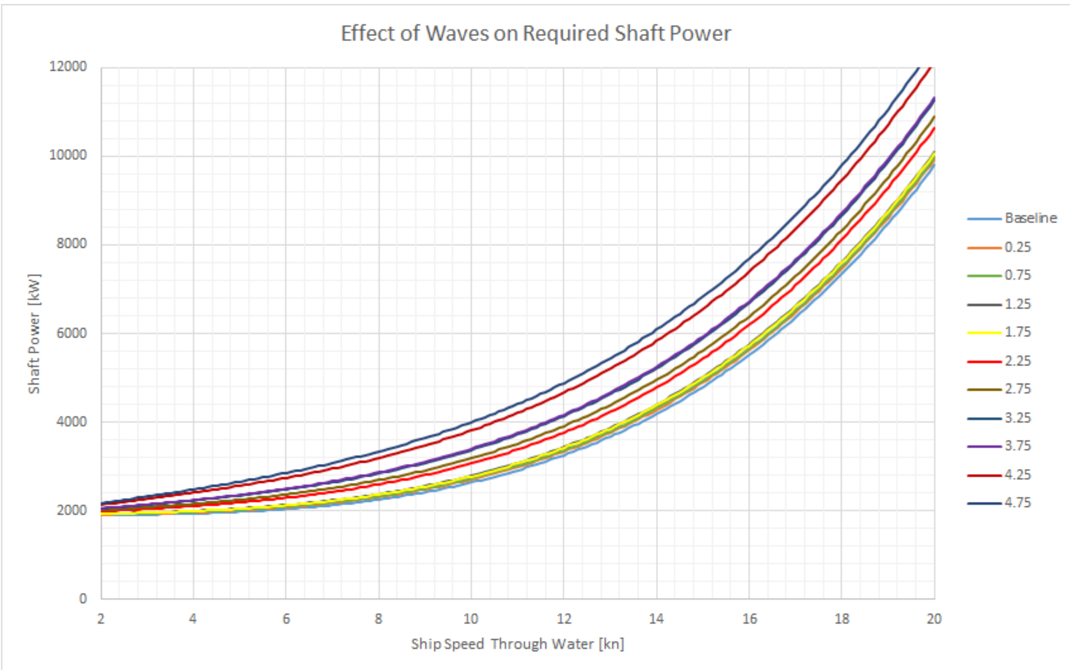

Figure 3.20: Fit curves for required shaft power at different wave height categories

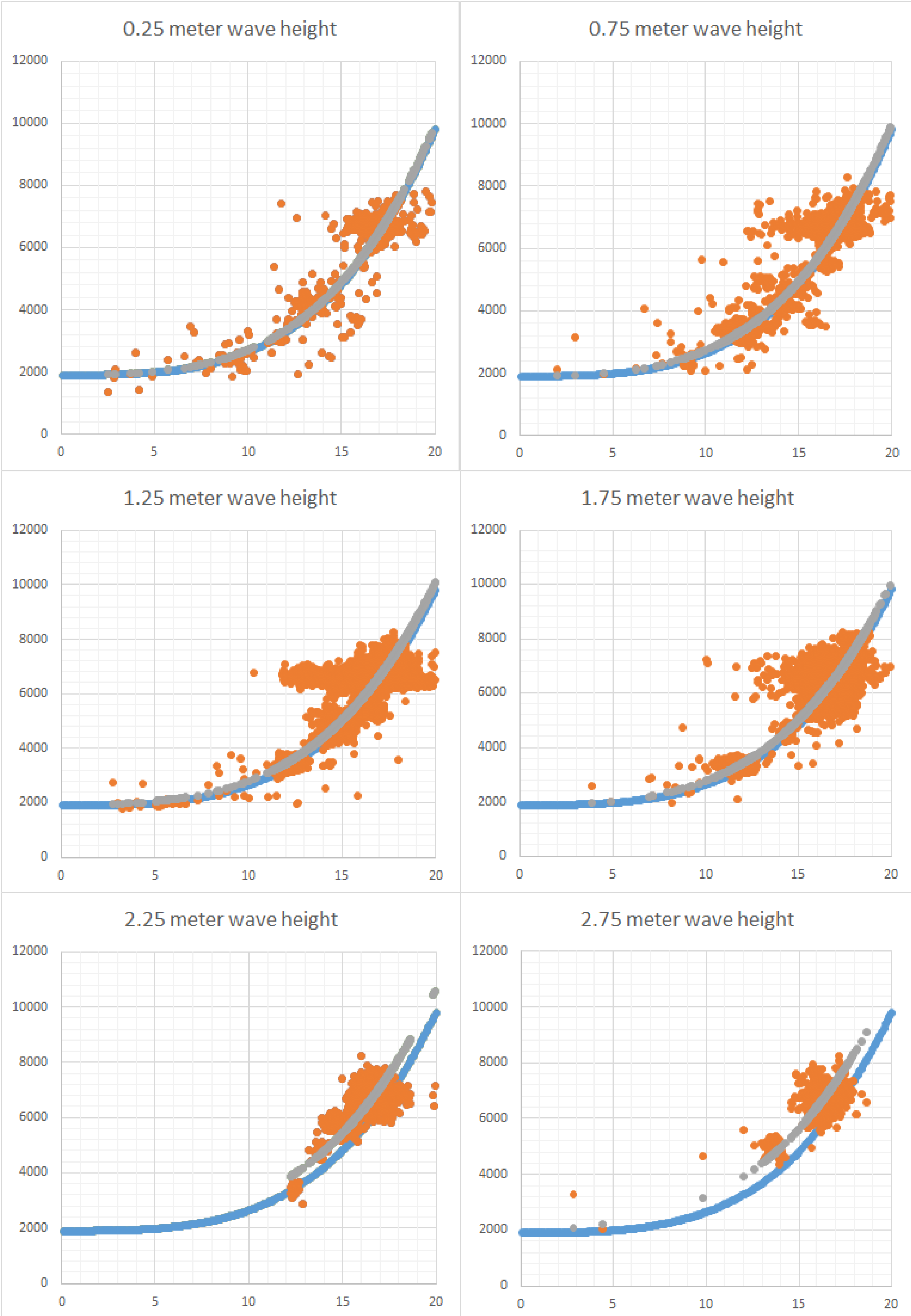

Figure 3.21: Fit curves with measured data and calm water baseline (Blue=Baseline,Orange=Data,Grey=Fit models)

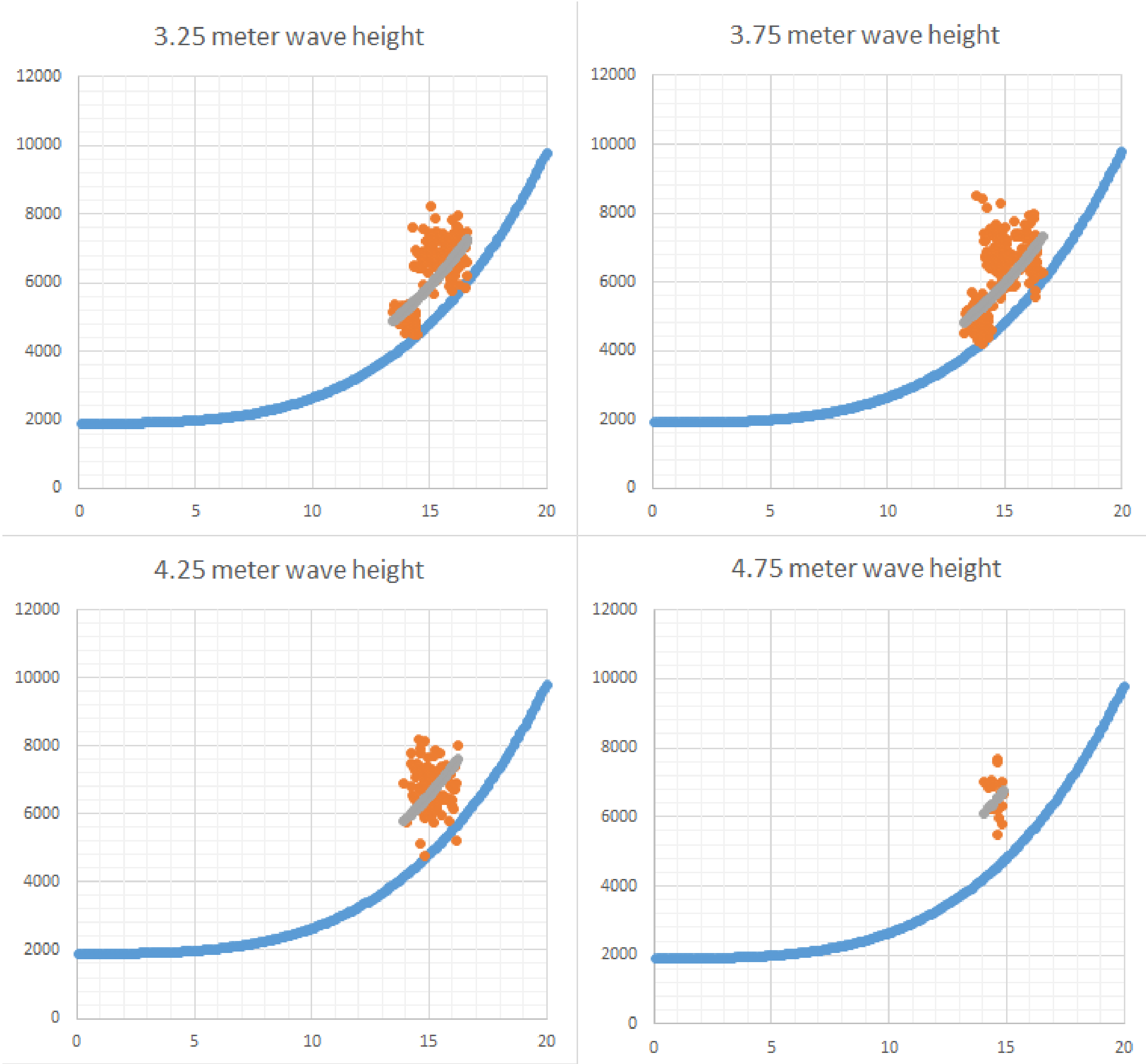

Figure 3.22: Fit curves with measured data and calm water baseline (Blue=Baseline,Orange=Data,Grey=Fit models)

We can now analyse the values of $C_{aw,p}$. An overview of the fit line models and the $C_{aw,p}$ that result from the regression analysis are shown in table 3.7 below.

Table 3.7: Fit line models with corresponding $C_a w, p$ for the Schippergracht

Wave Height Category	**Model to fit**	$C_{aw,p}$
0,0.5 meters	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} * 0.25^2 * v_s$	109.00
0.5,1 meters	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} * 0.75^2 * v_s$	16.33
1, 1.5 meters	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} * 1.25^2 * v_s$	9.55
1.5, 2 meters	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} * 1.75^2 * v_s$	4.47
2, 2.5 meters	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} * 2.25^2 * v_s$	8.41
2.5, 3 meters	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} * 2.75^2 * v_s$	7.23
3, 3.5 meters	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} * 3.25^2 * v_s$	6.95
3.5, 4 meters	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} * 3.75^2 * v_s$	5.42
4, 4.5 meters	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} * 4.25^2 * v_s$	6.51
4.5, 5 meters	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw,p} * 4.75^2 * v_s$	6.02

If we look at the values of $C_{aw,p}$ in table 3.7 we see that for the first few wave height categories $C_{aw,p}$ shows some weird values. The relation in the first few categories does show an increase in power with increasing wave height but this increase is higher than expected from theory. After the first three categories the value of $C_{aw,p}$ seems to hover around 6.5. If the equivalent of $C_{aw,p}$ is calculated from the theory of STAwave-1 (eq. 3.2), the following is found:

$$\frac{1}{16}\rho g B\sqrt{\frac{B}{L_b}} = \frac{1}{16} * 1.025 * 25.2 * 9.81 * \sqrt{\frac{25.2}{168.21}} = 6.13$$

For ρ, 1.025 t/m^3 is used instead of 1025 kg/m^3 because we calculate in kilowatt or kilonewton instead of watt or newton. As said earlier we have to account for the difference between knots and meter per second and compensate for the propulsive efficiency. Speed in meter per second has to be multiplied by 1.943 to find the speed in knots. Almost a factor of two. The difference between the propulsive and effective power also lies in this same range. A propulsive efficiency of 50 percent is in the right range. This means that the two corrections cancel each other out. We can thus conclude that the values 6.13 and 6.5 lie close to each other and this thus is a good validation. The difference between the two is expected since the wave direction is not filtered to waves only 45 degrees on the bow and also higher wave heights are analysed than the limit of the model specifies. Also influences of other parameters are not completely filtered out.
All in all it can be said that the influence of the waves follow an expected relation from basic theory and that the fit lines that have been made give a good view of the relation between the wave height and the shaft power of the vessel. These fit models can be used to optimise weather routing because the increase in power for certain wave height is now clearly defined. This increase in required power and thus fuel can then be compared against an alternative route with lower wave heights but a longer sailing distance. The relations can also be an input for the weather routing software which is already used within Spliethoff. This software currently uses empirical data to determine the influence of weather. These can now be replaced by the more accurate relations created by this analysis.

Influence of Wind

Similar to waves, wind can also have a large effect on fuel consumption of a ship. A similar method of analysis as the influence of waves is applied to determine the influence of the wind of the required shaft power of the vessel. It should be noted that wind also generates waves. Analysing wind and waves separately is thus challenging because when there is wind there are almost always waves. For this analysis, data where the wave height was higher than two meters is filtered out. The data is also filtered to be between 9 and 10.5 meters and the trim is filtered to lie between 0 and -1 meters. The dashboard in the BI tool and the data used for this analysis is shown in figure 3.23. From a quick look at the data a relation can already be seen between increasing wind and required power.

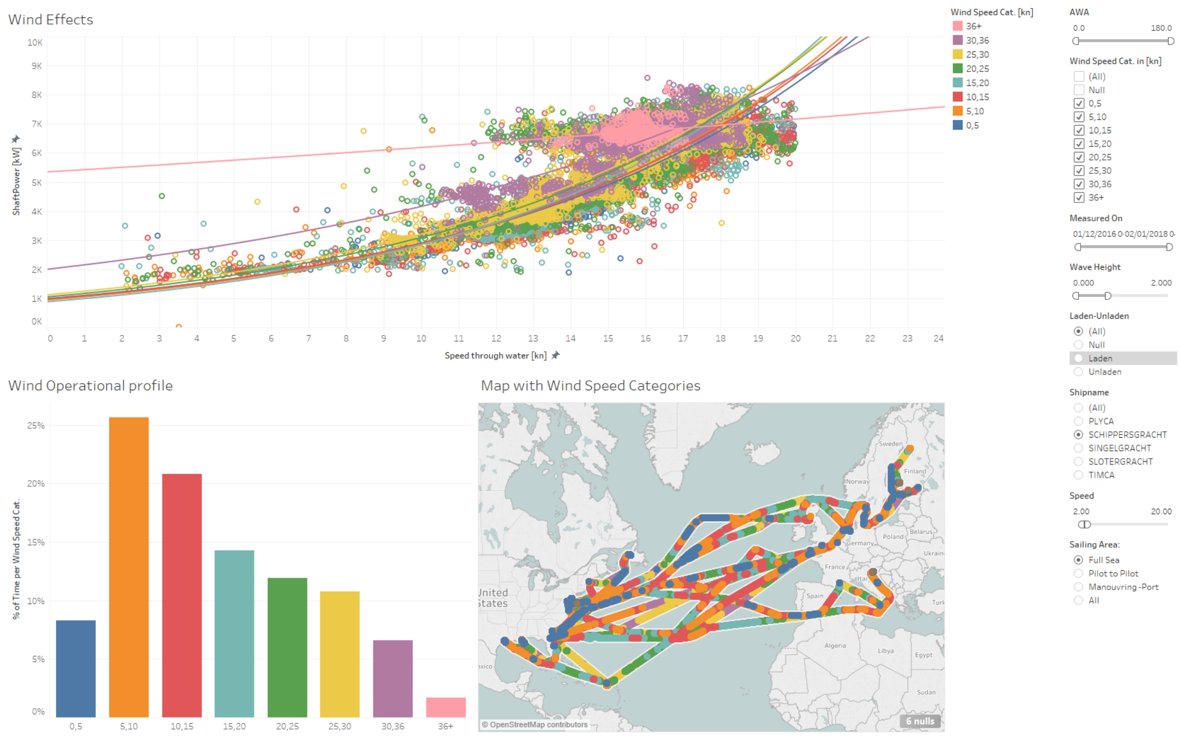

Figure 3.23: Data visualisation for the effect of wind on the performance in BI tool

A well known simplified model to describe drag is given below. In this equation C_D is the drag coefficient that is dependent on the shape of the object, the angle of incidence and the Reynolds number. A is the frontal surface area of the object.

$$R_{air} = \frac{1}{2}\rho v^2 C_D A \tag{3.3}$$

This relation is adapted to model the added resistance due to wind. First of all the wind speed has to be taken relative to the ships movement. This is called apparent wind. The apparent wind speed is measured on board of the vessel but these measurements are inaccurate due to the location of the anemometer on the ships. The apparent wind will be derived for the vessel speed and heading and the true wind speed and direction provided by the weather model. This conversion is done in the following way:

First, the local angle between the wind direction and the vessel heading is determined. This angle will be limited to a range of 0-180 meaning that no differentiation is made between local east and west.

If $|TWD - Heading| <= 180$ then:

$$LWA = |TWD - Heading| for |TWD - Heading| < 180$$

else

$$LWA = ||TWD - Heading| - 360|$$

Where LWA is the local wind angle and TWD the true wind direction. The LWA together with the vessel speed over ground (SOG) and the true wind speed (TWS) now form the input to calculate the apparent wind speed (AWS).

$$AWS = \sqrt{TWS^2 + SOG^2 + 2 * TWS * SOG * \cos(LWA)}$$

The apparent wind direction (AWD) can then be determined with the following equation:

$$AWD = \arccos\left(\frac{TWS * \cos(LWA) + SOG}{AWS}\right)$$

These calculations are made in respect to the speed over ground. This means that if we want to analyse only the effect of the wind we have to filter out the current speed. It would be preferable to analyse the effect of the wind in respect to the speed through water so we do not have to filter out the current. This is done ny firstly correcting the wind speed for the current and then replacing SOG by STW. The following equations illustrate the taken steps:

If $|TWD - CurDir| <= 180$ then:

$$CWA = |TWD - CurDir| for |TWD - CurDir| < 180$$

else

$$CWA = ||TWD - CurDir| - 360|$$

Here CurDir stands for the current direction and CWA is the angle between the current and the wind direction. With this information we then calculate the Corrected Wind Speed (CWS) with the following equation:

$$CWS = \sqrt{TWS^2 + CurrentSpeed^2 + 2 * TWS * CurrentSpeed * \cos(CWA)}$$

The final step is to calculate the Corrected Apparent Wind Speed (CAWS) in regards to the Speed Through Water (STW). This is done with the following equation:

$$CAWS = \sqrt{CWS^2 + STW^2 + 2 * CWS * STW * \cos(LWA)}$$

The Local Wind Angle (LWA) is used istead of a corrected wind angle because the wind speed is always much higher than the current speed so the change of direction due to the current is always small enough to neglect.

The model which is used for the regression analysis can now be derived from the relation of the air resistance or drag mentioned earlier (eq. 3.3). The following model is proposed for the added wind resistance and power (eq. 3.4).

$$R_{added,wind} = C_{aw} v_{aws}^2 \rightarrow P_{added,wind} = C_{aw} v_{aws}^2 v_s \tag{3.4}$$

In this model all the physical parameters have been lumped together in the regression parameter C_{aw}. The speed is changed to the apparent wind speed. Both the corrected apparent wind speed (CAWS) and the apparent wind speed (AWS) can be used depending on if the calculation is done with the speed over ground or the speed through water of the vessel. v_s thus represents both the speed over ground and the speed through water of the vessel. This model is then added to the baseline model by summation to give the final model which will be fitted to the data. In the case of the Schippersgracht this is:

$$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw} * v_{aws}^2 * v_s$$

For the initial analysis it is chosen to analyse the effects of the wind with an apparent wind angle range between 0-15 degrees. This means head wind between -15 and 15 degrees from the bow of the vessel. This wind is assumed to have the largest negative effect on the performance of the vessel. The resulting model fits for the different wind speed categories with an apparent wind direction between 0-15 degrees are shown below in figure 3.24. In the plot it can be seen that until an apparent wind speed of 15 knots there is no significant negative effect on the performance of the vessel. The fact that the wind does not have a negative effect to the performance until 15 knots compared to the baseline can have several reasons. The first reason can be that the data which was used to determine the baseline was not filtered strictly enough to give a pure baseline of no influencing weather conditions. It can indeed be seen in figure 3.4 that some weather effects are still included in the filtered data. The data used for the baselines still includes true wind speeds of up to 15 knots. If the effects at lower wind speeds are to be determined a new baseline should be formed in a later stage when more data is available so the filters can be stricter.

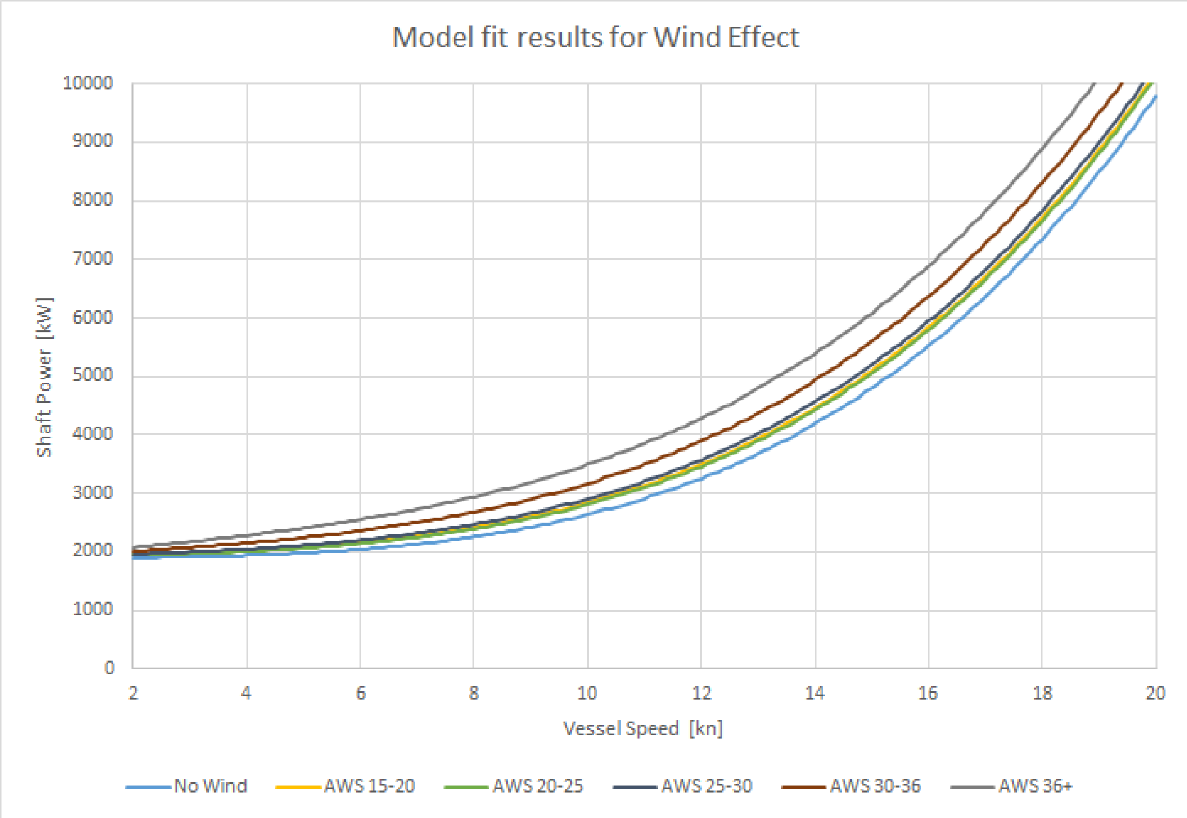

Figure 3.24: Wind Effect model fits for different wind speed categories (Schippersgracht)

The results of the regression analysis are shown in table 3.8 below. In the table the models with the found C_{aw} per wind speed category are shown. In figure 3.25 and 3.26 a visualisation of the fit models with the raw data and baseline is given.

Table 3.8: Fit line model results for added wind resistance

Wind Speed Category	**Model to fit**	C_{aw}
0,5 knots	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw} * 2.5^2 * v_s$	0
5,10 knots	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw} * 7.5^2 * v_s$	0
10, 15 knots	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw} * 12.5^2 * v_s$	0
15, 20 knots	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw} * 17.5^2 * v_s$	0.085
20, 25 knots	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw} * 22.5^2 * v_s$	0.0335
25, 30 knots	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw} * 27.5^2 * v_s$	0.0352
30, 36 knots	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw} * 33^2 * v_s$	0.049
36+ knots	$P_s = 1900 + (0.55 + 0.012 * v_s^{1.2}) * v_s^3 + C_{aw} * 37^2 * v_s$	0.063

It can be seen that C_{aw} after apparent wind speeds of 15 knots varies between 0.085 and 0.0335. A comparison of the physical parameters that have been comprised in C_{aw} and the value of C_{aw} after regression can be done to serve as a validation of the resulting values of C_{aw} after the regression. C_{aw} is comprised of four parameters. These are found in equation 3.3 and are $\frac{1}{2}, \rho, C_D and A$. For ρ we take $1.225 kg/m^3$, $A = 25.2 * 37.8 = 952.56 m^2$ and $C_D = 0.75$. These values are multiplied to find the value of C_{aw} in SI units. We have to correct this value for the fact that we use kilowatt and knots in our calculations. First $C_{aw,SI}$ has to be divided by 1000 to compensate for using kilowatts and it then has to be multiplied by the cube of the ratio between knots and meters per second.

$$C_{aw,SI} = \frac{1}{2} * 1.225 * 0.75 * 952.56 = 437.58$$

$$C_{aw} = \frac{C_{aw,SI}}{1000} * (\frac{1852}{3600})^3 = 0.0596$$

It should be noted that the calculated value of C_{aw} is an estimation because there has never been a windtunnel test to determine the coefficient of drag (C_D) and thus is estimated following the guidelines of the ITTC. This being said the calculated value of $C_{aw} = 0.0596$ lies right in between the range that was found with the use of regression. This gives us a validation of the found values with regression. Wind from other directions than the ones analysed in this report will also be analysed in a similar fashion but this is not worked out in this report.

The found relation between shaft power and wind speed can now also give input to the weather routing tool similar to the influence of waves and can be used to make better estimations of the expected fuel consumption. It can also be used to calculate back to a no wind situation in which other parameters or components can be tested for performance.

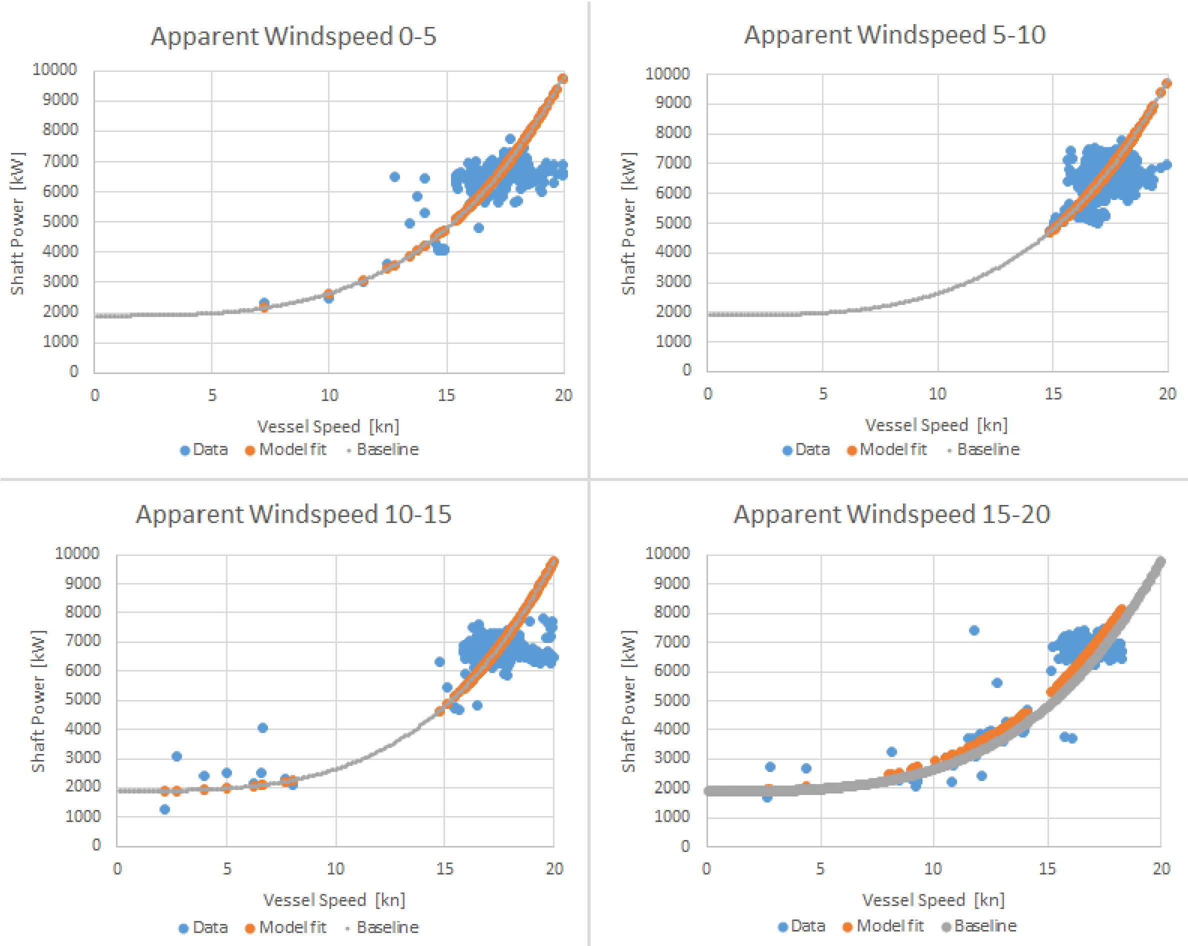

Figure 3.25: Fit curves for added wind power with measured data and baseline

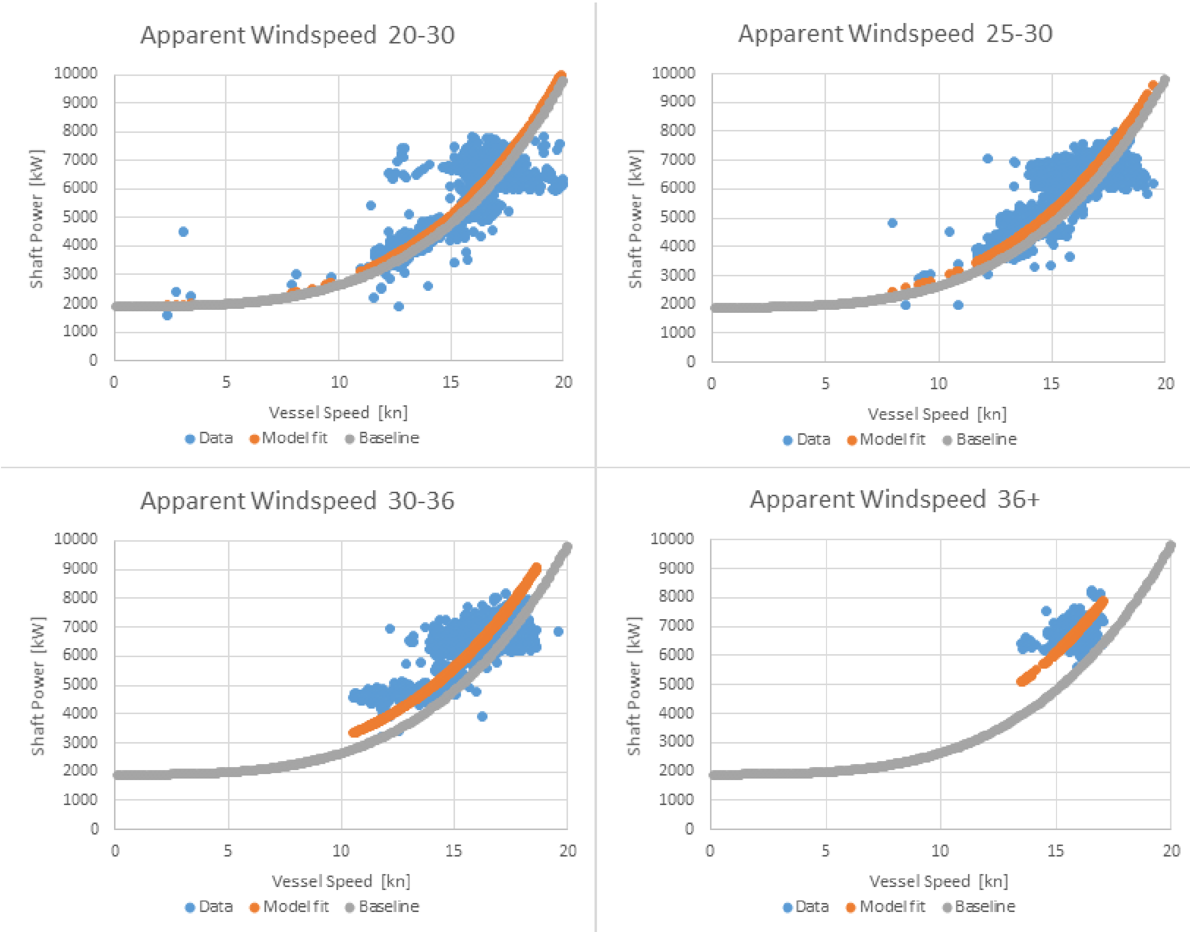

Figure 3.26: Fit curves for added wind power with measured data and baseline)

Influence of Draft

The influence of draft on the performance of the vessel is important because when comparing the performance between vessels or between different trips the draft will most likely vary. This would make comparing them difficult. It is also important for ballasting because we can then judge if it is worth it to take on extra ballast to optimise the trim of the vessel. The analysis of the influence of draft has been proven difficult during this research. Because of this two different methods of analysis have been applied. The difficulties were caused by both data quality and the method used to analyse the effect. Both methods are described in this chapter.

Firstly, the method that was least successful in determining a relation between the draft of the vessel and the required shaft power is discussed. The data used to find the relation is shown in figure 3.27. This data is filtered to fair weather conditions and a trim between 0 and -100 centimetre (100 cm by the aft). In the data it can already be seen that the relation goes against the intuition of the people that have studied the hydrodynamics of a ship. The highest draft seems to be performing very well compared to other drafts. This is unexpected because pushing a larger volume through water means more wetted surface so more friction and also more water needed to be displaced. Of course there are many different effects that are at play at the same time. Examples of this are bulbous bow submergence and varying wake numbers which could explain these initial results. The data set for certain drafts also seems very small which also causes some uncertainty. Despite these observation the analysis was still carried out. The method of analysis is similar to the other operational parameters that were analysed. Firstly, a theoretical model to describe the relation between draft and power is found and adapted to use in the regression analysis. The model that was chosen is the admirality coefficient:

$$A_c = \frac{\nabla^{2/3} * v^3}{P}$$

The displacement term which gives a representation of the wetted surface is simply replaced by the draft of the vessel. This assumes that the water line stays similar over the analysed draft range which is not the case especially because of the presence of a bulb. It should also be noted that the admirality coefficient only accounts for the frictional resistance. Wave making resistance is not taken into account. It does not account for design influences, meaning that for instance design optimisation at a certain draft or at certain speeds is not reflected in this model. The relation of the draft till the power of two over three is still used to determine a model for regression due to its simplicity. It can be easily used in regression.

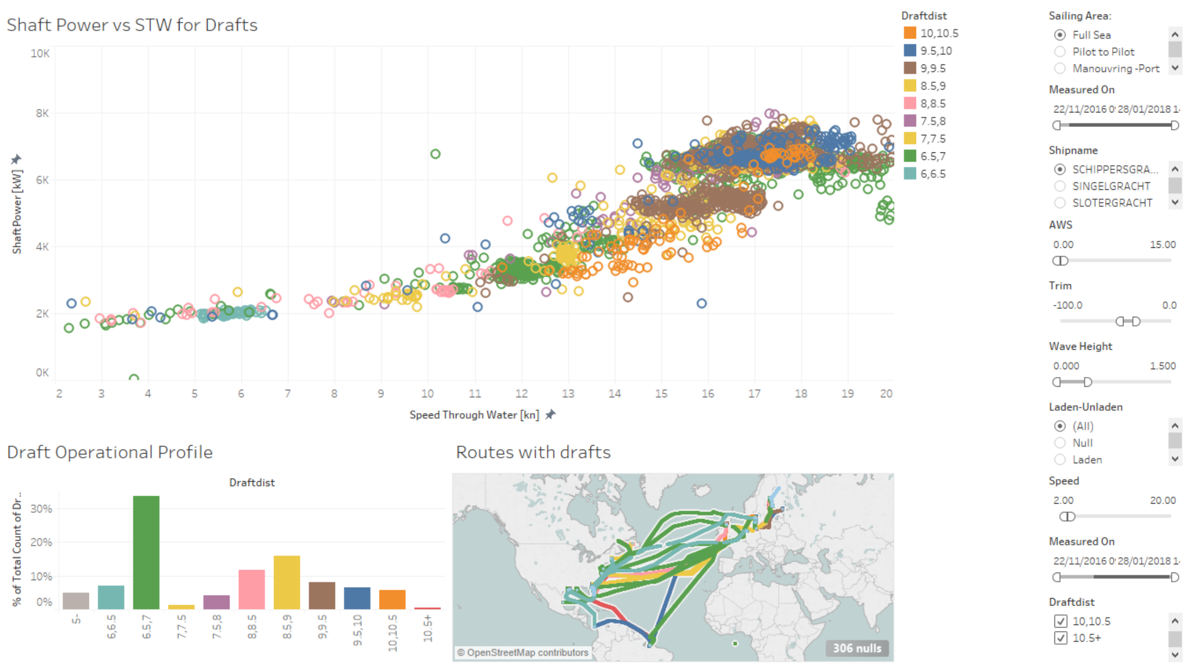

Figure 3.27: Data visualisation for the effect of Draft on the performance in BI tool

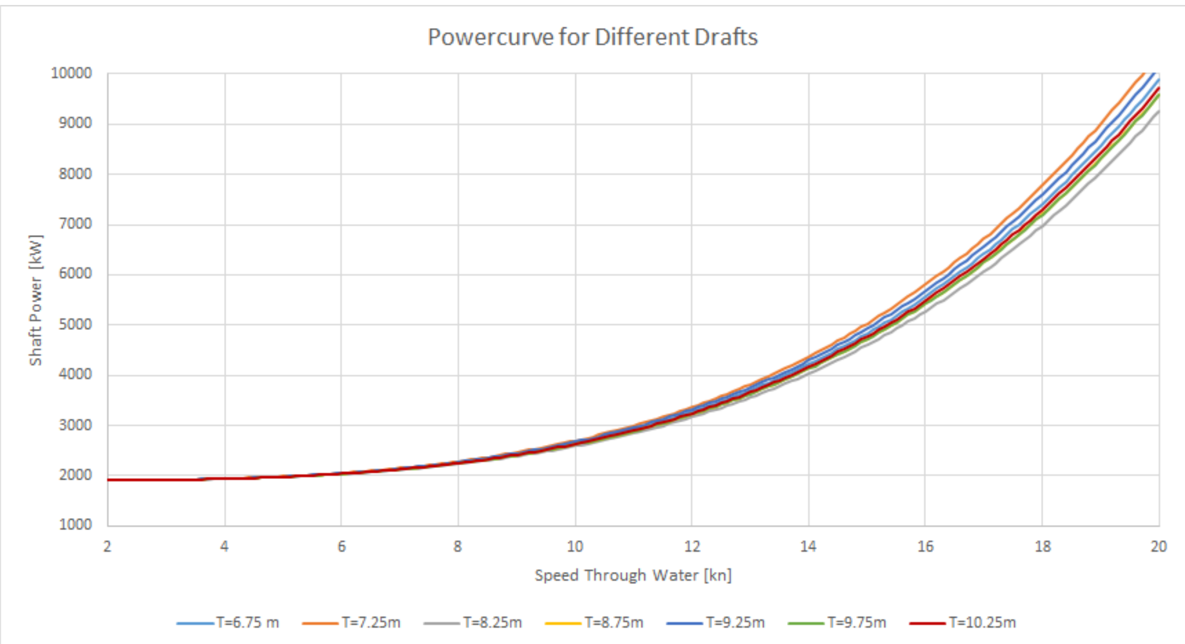

Figure 3.28: Powercurve fits at different drafts

The following model is proposed to use for the regression analysis of the Schippersgracht data:

$$P_s = 1900 + ((0.55 + 0.012 * v_s^{1.2}) * (C_{draft} * T^{2/3})) * v_s^3$$

The model consists of the previously determined power curve with to added term to account for the different draft which was derived from the admirality constant. In this fit model C_{draft} serves as the regression constant and is multiplied with the draft relation derived from the admirality constant. This model is chosen because it there is only one simple component with the draft relation that has an influence on the required power making the regression analysis simple while still being based on the theory of the admirality constant. The fitted curves with their corresponding data are shown in figure 3.29. The resulting fit curves for all drafts are shown together in figure 3.28.

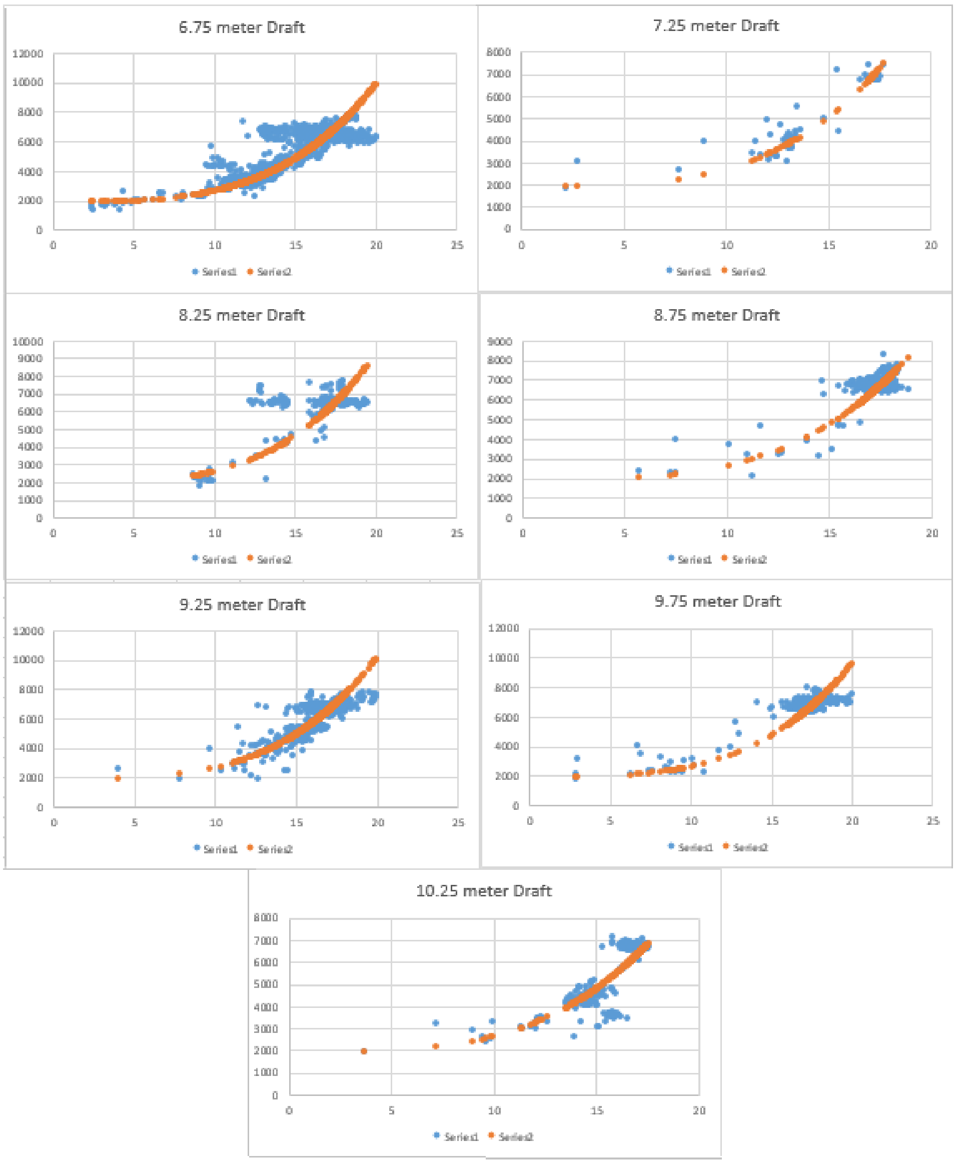

Figure 3.29: Fit curves at different drafts for the first iteration of the analysis

The results in figure 3.28 are unexpected. What the admirality coefficient tells us is that the required power should increase with increasing displacement. The results of this first analysis do not show this same behaviour. It shows that the power curve of the highest draft of 10.25 meters only lies in the middle of all analysed drafts while it is expected to have the highest required power.

There are several reasons that could explain these results. One of these is the fact that a bulbous bow is present on this vessel. The bulbous bow only reduces wave making resistance when operating at design draft. This

could explain the sudden drop in required power at this high draft. Another issue can be seen in figure 3.29. The curve does not seem to fit the data of the 10.25 meter draft well. Also the curve for a draft of 7.25 meters seems to have the highest required power.
Another reason for the unexpected results can be the data quality. Drafts are entered by hand by the crew of the vessel and it has shown that these are very prone to errors. Also there are doubts about the method used to link the correct noon messages which contain the drafts, to the correct data. Data quality is essential in data analysis. Due to this it was decided to put the analysis on hold due to the many uncertainties connected to this analysis and the results and to firstly further improve data quality. During this time a new database was developed which improved the data quality significantly. For the analysis of the draft this meant that the available amount of data increased and that far less errors were made in the drafts themselves. The data quality was improved by changing the ETL processes which corrected the errors which were introduced by the manual input of the draft data. Also rounding off errors were eliminated from the ETL processes which made the vessel speed through water more accurate. The sampling process was changed to include averages over five minutes instead of point samples every five minutes which reduced the scatter in the data and weather data was enriched with apparent wind speed to better account for the influence of wind. With this improved data another method of analysis is performed.

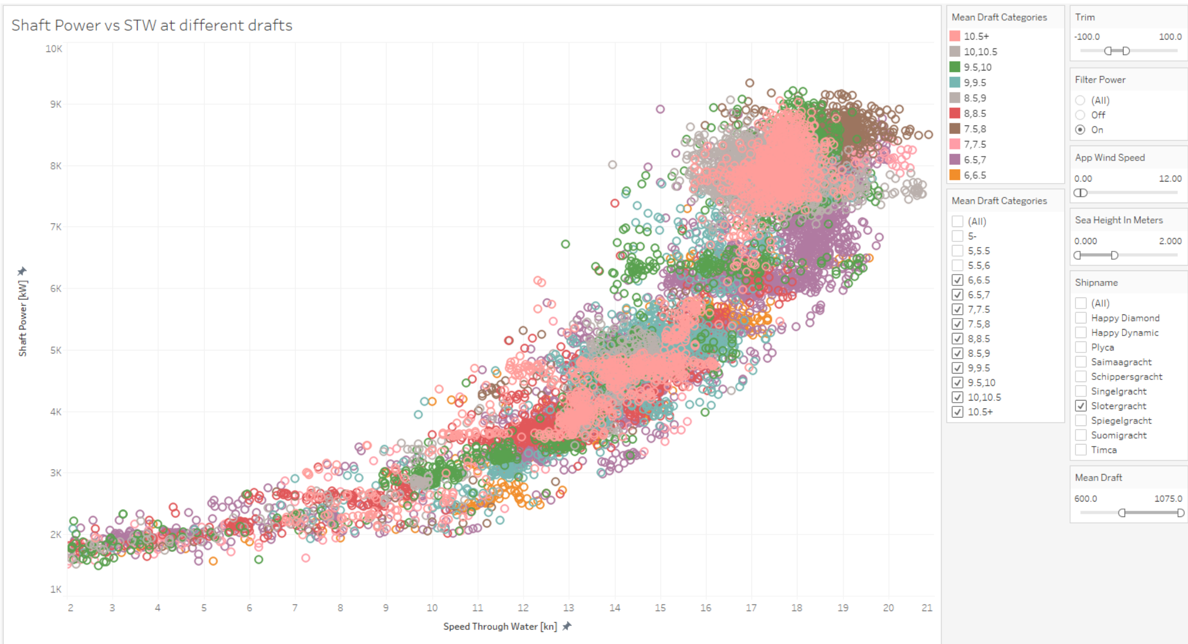

Figure 3.30: Shaft Power vs Speed through water data of the Slotergracht used for the second method of analysis

In figure 3.30 the data used for this second method of analysis is shown. Several things are to be noted about the data. Firstly, all outliers have been filtered out so that only steady sailing is analysed and measurements errors are discarded. This was done by defining a lower and upper border around the main cloud of data and discarding all data beyond these borders. Similarly to the previous method the weather and trim have been filtered out so only the effect of the draft is analysed. Meaning that only fair weather conditions and a trim range between 1 meter by bow and 1 meter by stern is analysed. Here it should be noted that at a draft between 7.5 and 8 meters the data has not been filtered on trim since this would not leave any data to analyse at this draft. Despite of the similar filtering method as the first analysis it can immediately be seen that a much larger data set is available in this database compared to the data used in the first analysis. This is mostly due to the data quality being higher in this database which causes a much larger part of the data being usable.
The relation between the data of the different drafts seems to be much more consistent at first glance. It seems like until 15 knots the draft does not have a significant influence on the required power of the vessel. What can be seen is that the maximum achievable speed of the vessel seems to decrease with an increasing draft and thus that at higher speeds the draft does have the expected effect on the required shaft power. It seems that the added resistance due to the draft at lower speeds is made insignificant due to the low efficiency

of the controllable pitch propeller at low speeds.
Instead of defining a separate model to describe the relation between draft and required shaft power the base power model will be fitted to the data at each different draft (see section 3.3.Power Curve). This means that a baseline power model will be created for each draft. In hindsight this should have been done as a starting point of the data analysis. By using the base power model more freedom is given to the regression analysis to give a better fit to the data at different drafts. It also makes more sense to determine a new baseline power model for every draft since in essence the whole submerged part of the ship changes and thus different characteristics van be expected at different drafts. The downside is that the draft parameter is no longer present in the equation. The following model is thus fitted to the data:

$$P_D = C_1 + (C_2 + C_3 * v_s^{C_4}) * v_s^3$$

The resulting fit models from the regression analysis are shown in table 3.9. The resulting fits on top of the data are shown in figure 3.31 and 3.32. All the fits together are shown in figure 3.33. It can be seen that the models fit the data well. There are two drafts which cause an unexpected result. The first one is the draft between 7.5 and 8 meters. The required power is similar to the required shaft power at a draft of around 9.25 meters. From figure 3.31 we can see that there is a large cloud of at very high speed and power. Also as said earlier the data at the draft of around 7.75 has not been filtered for the trim. The trim at connected to this data is either 1.2 meters by the stern or 2 meters by stern. Combined with the high speed this could explain the high required power. The result for this draft will not be used. In a later stage stage when more data is available the analysis will be done again.
The second draft that shows unexpected results is a draft of 8.25 meters. The required power seems very low for this draft. The fitted curve follows the data well but there is no data at higher speeds. A good representation over the entire speed range of the vessel can thus not be made. The bulb does not fully submerge until a draft of 8.7 meters meaning that the bulb could also not have caused this seemingly large drop in required power. The results at this draft are not considered for now due to the uncertainties. It is recommended to analyse this draft at a later point in time when a larger data set is available.

It can be said that determining the relation between the draft of a vessel and its resistance or shaft power is not easily determined. There are effects that are not easily modelled due to the complex shape of ship hulls. This being said conclusion can still be drawn from this analysis. Firstly, it can be said that the draft only has a significant effect at higher vessel speeds. A clear reduction in top speed at higher drafts is the effect of this. The found relations can be used in further analysis and should serve as baselines in the next run of the data analysis.

Table 3.9: Fit Model results with R-Squared

Draft range [m]	**Model from regression**	**R-Squared**
6,6.5 meters	$P_s = 1900 + (0.85 + 0 * v_s^1) * v_s^3$	0.873
6.5,7 meters	$P_s = 1900 + (0.73 + 0.008 * v_s^1) * v_s^3$	0.876
7, 7.5 meters	$P_s = 1900 + (0.73 + 0.008 * v_s^1) * v_s^3$	0.945
7.5, 8 meters	$P_s = 1900 + (0.8 + 0.003 * v_s^{1.4}) * v_s^3$	0.765
8, 8.5 meters	$P_s = 1900 + (0.8 + 0.001 * v_s^{1.4}) * v_s^3$	0.852
8.5, 9 meters	$P_s = 1900 + (0.8 + 0.0015 * v_s^{1.4}) * v_s^3$	0.956
9, 9.5 meters	$P_s = 1900 + (0.7 + 0.006 * v_s^{1.32}) * v_s^3$	0.768
9.5, 10 meters	$P_s = 1900 + (0.75 + 0.006 * v_s^{1.35}) * v_s^3$	0.901
10, 10.5 meters	$P_s = 1900 + (0.6 + 0.008 * v_s^{1.43}) * v_s^3$	0.618
10.5+ meters	$P_s = 1900 + (0.4 + 0.011 * v_s^{1.46}) * v_s^3$	0.896

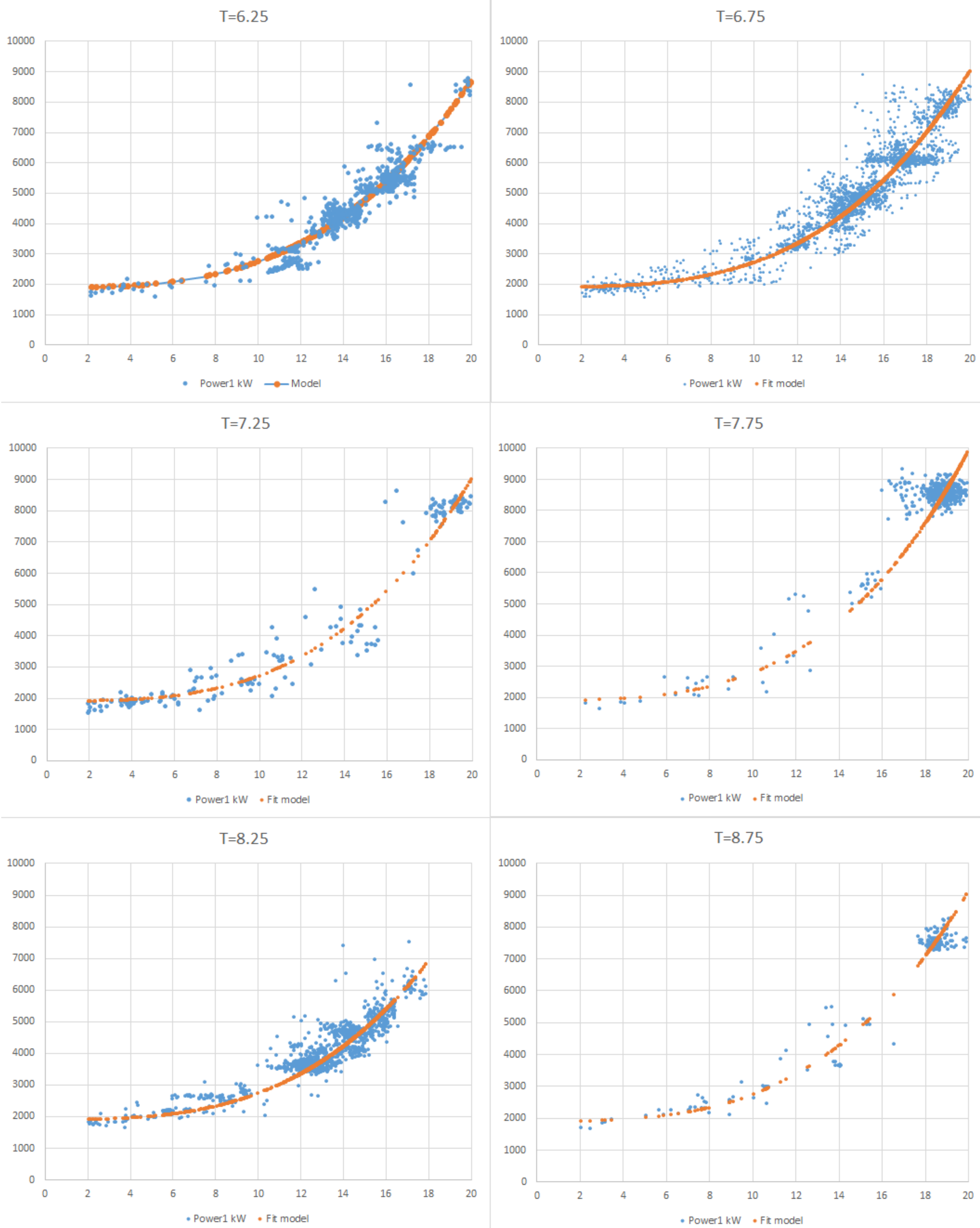

Figure 3.31: Fitted model with data for the Slotergracht

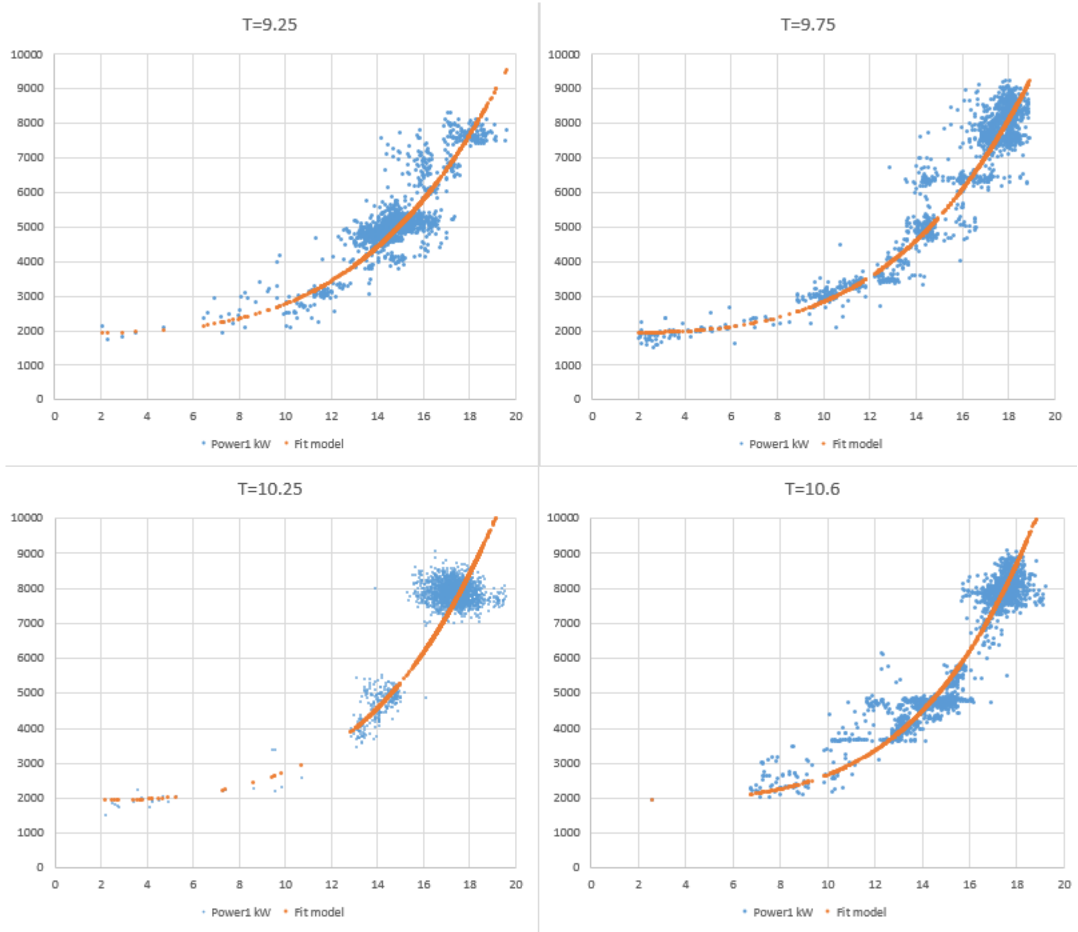

Figure 3.32: Fitted model with data for the Slotergracht

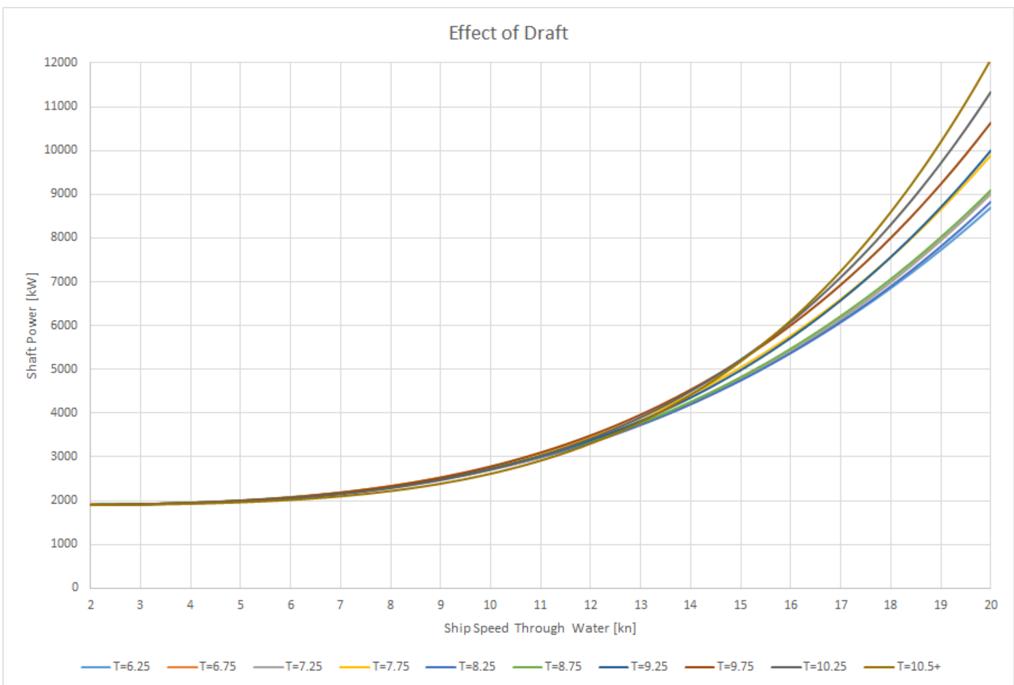

Figure 3.33: Fitted curves for the shaft power vs speed at different drafts

In the analysis of the draft it has again become clear what the effect of data quality is on the data analysis. The analysis was only successful after a new database was set up which improved the data quality. The large scatter in the data was also reduced which in turn reduced the uncertainty in the analysis. The data quality is to be improved continuously to further improve the data analysis. One way to do this is to remove the need for manual input.

Influence of Trim

The goal of the trim analysis is to determine how the trim of the vessels influences the performance of the vessel. This could then give insights on the optimum trim of the vessel at certain drafts and even at different weather conditions. This means that the optimum trim is very much dependent on the draft and the weather conditions. The trim is also dependent on the cargo and the way it is loaded. This means that the same conditions are almost never seen twice which greatly increases the uncertainty of this type of data analysis. For this reason it has been decided that the influence of trim is not researched in this project.

It should be said that future research should be done to find the relation between the trim and the required shaft power. The trim can be researched in the future in a few different ways. It can be done using the same method as the data analysis above when more data is available so that the uncertainty can be reduced. A second method is to perform special trials with the vessels which focus mainly on finding the optimum trim at different drafts. This eliminates the waiting time for the right amount of data to be available for the other method. The downside is that the vessel will not be able to produce revenue at the time of these trials which could make them costly. Another option might be to perform a Computational Fluid Dynamics (CFD) analysis to determine the optimum trim for a certain vessel series. This analysis is also costly eliminates the other two downsides mentioned above.

The trim analysis will be done in the future because value is to be created here with the reduction of fuel consumption but it is not published in this report.

3.4. Data analysis conclusion and discussion

The goal of this chapter was to find a suitable way of analysing the data and to perform the data analysis to determine whether the data provided by the performance monitoring system could be used to optimise the performance of the vessels. For the first part of this goal it is determined that a combination of several analysis methods are beneficial to give the most complete view of the vessel's performance. A form of hybrid modelling was chosen to both verify the data and to form fit curves which can serve as baselines or assist in calculations. This hybrid modelling fits theoretical models to the filtered data using regression. These fit lines can also serve as a visualisation aid to make relations more clear. Benchmarking between sister vessels and the made baselines is seen as a good means to find performance deficits. An example of this benchmarking between sister vessels can be found in appendix B.

The second part of the goal is to analyse the data and to determine whether the information created is useful for assessing the performance of the vessels. In short the analysis proved that the performance of the vessel can be specified with the methods used. Baselines are specified and relations between operational parameters are determined and partly verified by theory.

What also came forward during the analysis is that the data quality is very important and that several methods had to be used to come to the desired results. Because of this project it became clear that a high data quality is of the utmost importance to make accurate conclusions about performance. This led to actions being taken to actively improve the data quality. As mentioned before this also led to the creation of a new database. This had several positive effects. Firstly, it drastically increased the speed of the ETL processes. This allowed us to have a close to live data stream (One hour delay). It also improved on the accuracy of the ETL processes by removing large rounding errors and incorrect data coupling. Manually introduced errors which are introduced into the raw data by manual input are also largely corrected by the new ETL processes. These errors were mostly generated by people entering data in different units like meters instead of centimetres.. Also a part time employee was taken on to actively improve data quality by identifying and correcting errors. It can thus be said that the realisation of the importance of data quality when trying to find performance relations has risen due to the data analysis.

The downside of this was that the data analysis took far longer than expected. Delays were cause by having to set up and wait for the new database. It also caused uncertainty during the analysis due to the large spread in the data. The largest part of the data analyses documented in this report has been done on the old database but it should be said that the analysis has been done again for the new database. If not mentioned the same methods were used with the new database. The uncertainty in the analysis was greatly reduced but most of the new results are not documented. This is not done because the goal of this chapter is to define the method of analysis and not the final fit curves. It should be said that the results of before and after the new database do not deviate largely but the uncertainty in the results has been significantly reduced. This can be seen from the large difference in spread between the two different analysis attempts when analysing the influence of draft. It is recommended to further work actively on the improvement of data quality and to repeat the data analysis process when more and more data is collected. This is recommended because without the data it is nearly impossible to make conclusions about the performance. The accuracy of these conclusions drawn from analysis are heavily dependent on the data quality and the quality of the data only comes forward while analysing. This means that a spiral like improvement process is needed which keeps circling through analysis and data quality improvement to keep increasing the value that can be created by the data.

II

Part 2: Performance Management

4

Analysing the current Performance Management System

The goal of this chapter is to establish an overview or baseline of the performance management system and processes before the use of the performance monitoring system. This means that the performance management that is in place at the time of this research project is analysed. This is referred to as the current performance management system. Weaknesses of the current performance management are identified so that they can be improved upon. Also barriers which block the efficient implementation of performance management are identified. The analysis will focus on the knowledge about optimising performance throughout the company and on the information or data available within the company needed to optimise performance. This performance management audit as it can also be called will be performed in the office and on the vessels.

Before the analysis of the current performance management can start we have to give a clear definition for what performance management is. There are two separate terms which are mentioned frequently in recent literature related to shipping which together form performance management. These are performance optimisation and energy management. Performance management in the shipping context is not mentioned often in recent literature but performance management can be seen as a mixture of performance optimisation and energy management in this research project. Performance optimisation and energy management share a lot of common ground but there are some differences. Performance optimisation is often focused on theoretical ways to optimise performance without specifying the practical implementation of the found ways to do so. Energy management also focuses on the implementation, monitoring and corrections of the optimisation possibilities. Another difference is that energy management only focuses on energy. Performance envelops a wider scope which can apply to several parameters. This means that instead of energy management which offers a complete system but addresses a small scope and performance optimisation which addresses the correct scope but does not offer the total management system needed for successful implementation, performance management is defined from the combination of the two. This performance management addresses a complete management system with the correct scope.

In the case of Spliethoff performance management is defined as maximising profit by improving the operation of the vessels as a primary goal. Secondary goals are reducing fuel consumption and creating knowledge. Reducing fuel consumption does not always lead to increased profits. This is why it is set as a secondary goal, increasing profit will almost always have priority over reducing fuel costs. This being said in an ideal market reducing costs will result in an increased profit. Even though the ideal market does not exist in practise it can be assumed that reducing costs will lead to increased profit in most cases and can thus be seen as a viable step to increase performance.

In this chapter, firstly, the method of analysis is discussed. This is followed by the findings of the analysis for the different departments. Lastly, a conclusion is given on the performance management in place at Spliethoff before the implementation of the performance monitoring system.

4.1. Performance Management audit

As said earlier the performance management in place before the start of this project has to be mapped. Semi-structured interviews have been performed to do this. These interviews have taken place in two departments of Spliethoff and with officers and engineers on board of vessels. The two departments are the commercial department and the technical department. This group of people together is responsible for the operations and maintenance of the vessels. Supporting departments as for example accounting have been left out of this initial audit since they do not have a direct influence on the operational performance of the vessels. Firstly, the commercial department will be discussed. Secondly, the technical department. Thirdly, the vessels are analysed and lastly, the previous research done at Spliethoff on performance optimisation.

Commercial department

The simplified goal of Spliethoff is to maximise profit with the operation of the Spliethoff fleet. This goal is carried throughout the whole department. To this goal some subgoals are attached. Spliethoff strives towards having the reputation of being a high quality shipping company. Quality is defined in the following way: To always comply with contractual agreements and to provide more service than minimally required. Being on time with minimal delays and being capable of short lead times due to a large fleet. Also the vessels are of high quality with ice class and often with heavy cranes or other special loading equipment to be able to handle every general cargo in every region of the world. Another subgoal that is becoming more and more important, is being environmentally friendly. This goal is mostly derived from regulations which are sharpening but also because of a growing demand of the sector for environmentally friendly transport. Being environmentally friendly is often defined as having a high transport efficiency with regards to emissions and with metrics which are often defined by regulations from the IMO or the EU MRV regulations. Metrics like the mass of CO_2 emitted per tons of cargo moved over one nautical mile are commonly used to measure environmental performance of vessels. The EEDI and EEOI are also examples of this. While this subgoal is not as important at the moment, expectations are that it will be in the future[1]. What can be seen is that the subgoals might interfere with the main goal of Spliethoff. Having vessels with ice class, large engines for high speeds and expensive auxiliary systems might not provide the highest profit in all scenarios. The same goes for being environmentally friendly. Finding ways to comply with all goals is on the top of the list. The head of the department shares the idea that operational data is important to finding these ways but that at the moment this data is not available or not easily accessible. The same goes for optimising the general performance of the company.
This is a common theme throughout the commercial department. Spliethoff has a good idea in which ways it can optimise operations due to its highly experienced people but the needed information to make this optimisation is not always easily available. This causes the potential results to not be accurately specified in a business case and the change is thus not implemented. This is a problem throughout the industry when it comes to performance management or energy management [Johnson [2013]]. This problem is slowly fading away since the use of performance monitoring and data is becoming more and more popular in the maritime industry.

This being said, optimising performance is a known topic to everyone spoken to about the subject. The commercial department also has several tools to help them in optimising their performance. There is a decision support tool which helps find the optimal time charter equivalent (TCE) rate for a certain voyage. This tool takes into account all operational costs and revenues to determine the optimum planning and speed. They also have good knowledge on how to minimise waiting and port times to increase performance. The operators tell the vessel to slow down when time becomes available due to waiting times or tell the vessel to speed up to save for instance extra stevedore costs due to weekend fees. These are always weighed against the extra fuel costs this might bring. In figure 4.1 a schematic of the decision model is given to determine the optimum speed in voyage planning.

[1] Expectations were met since IMO introduced their emission target to reduce the emission of maritime transport by 50% by 2050 in April, 2018

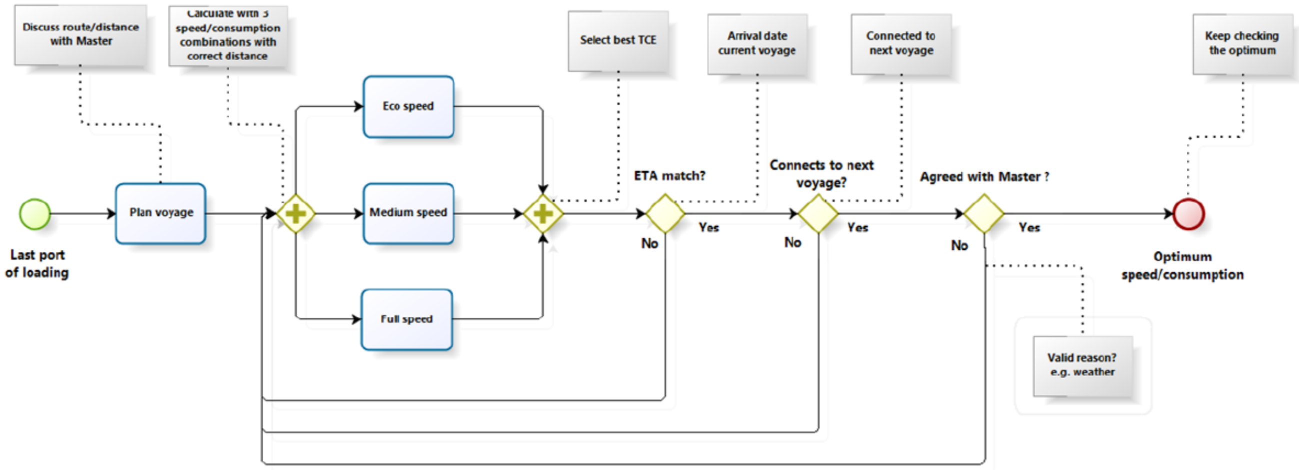

Figure 4.1: Decision model for optimum speed [Grutterink [2017]]

Improvements to this system can be made by increasing the accuracy of the prediction and data used in this tool. Often the ship has to be consulted to give an estimate of the fuel consumption on a certain route at a certain speed. They often ask the consumption of the vessel on this route at two or three different speeds. If accurate consumption models were to be available for the operators they could investigate more speeds easily without have to consult the vessel. Also an insight into the influence of weather on the consumption and an overview of the weather along a route could help them in making more accurate estimations of the performance of a certain trip and help them to make better predictions on the ETA of a vessel.

It is also important to test the performance after a voyage is complete. Analysing the performance after every single voyage can create a lot of knowledge. This learning process is very important for increasing the performance of any operation. From the interviews it became clear that even though an eye is kept on the results, the results are only examined in more detail when the performance has been extremely bad. When this happens, finding the reason for this poor result is also challenging since detailed performance data was not available before the PMS. This means that the learning process is almost impossible at the moment. Also there is no follow up because there is no hard proof on how the poor performance could have been avoided or how much value can be created by changing operations. An overview of voyage performance at the end of a voyage which is based on detailed performance data could boost knowledge creation significantly. Having a clear picture of the performance of the vessel at every stage of the voyage is very important for this learning process.

A note should be made here in that not all of the operators view performance monitoring as something that could benefit them in optimising their performance. Meaning that for some implementation of performance monitoring will ask an unwanted change in their daily operations and might thus not be a hundred percent effective. Some operators do not see optimising fuel consumption as a part of their job description. They think the vessel and technical department have these responsibilities. This is not an unfair assumption since it is not their field of expertise but if everyone uses their knowledge of their field to work towards a common goal and fills in the blanks for the other parts of the organisation, it could help optimise performance a great deal. An example of this is that if the operators can inform the vessel if a large delay is to be expected in the next port the vessel can decide to slack off and save some fuel until it arrives at this port.

This communication between vessel and operator is very important with regards to performance management. The operators have an understanding that good communication between the vessel and the operator is important and is essential in reducing waiting times and improve voyage planning overall. This being said the communication between vessel and shore can still be improved significantly. The improvements can be mostly made in information sharing. At the moment it is hard for the operators to know where the vessel is situated and what the conditions are in which the vessel is sailing. This makes it hard to make a good estimation on the ETA and the delay the vessel might experience. This means it is hard for the operators to give a good speed advise in order to reduce delays or safe fuel. Providing an accurate overview of the current location of the vessel and the weather conditions it is in can improve this significantly and will potentially reduce the frequency at which the vessel is forced to anchor or drift because it cannot enter port. This communication also goes the other way. Giving the captain of the vessel more insight into the voyage plan and what can be expected on a voyage operational is equally as important. Also giving the captain insight into the costs of operating a vessel can create awareness.

Lastly, the availability and use of commercial data is discussed. Business intelligence tools like the one used in this project are designed to work with commercial data. Vessel performance monitoring is not one of its intended uses. There lies a big opportunity to also include the commercial data into the performance monitoring system and being able to link commercial performance to vessel performance more easily. Adding commercial data to the system also gives the added benefit of being able to use the business intelligence tool for its intended use and even enriching it with the vessel performance. Giving a clear overview of what trades and trips have been successful over the years and what has influenced profitability could also create a lot of knowledge for Spliethoff. Giving a clear picture of how much and what type of cargo has been transported from where to where is invaluable information. Making this information easily accessible could be very valuable. Business Intelligence (BI) tools like the ones used in the data analysis are made to work with commercial data. The tools assist in creating usable information from large amounts of data. There is a big opportunity for Spliethoff to use these tools to give a clear overview of the commercial performance of the company. For the total performance management it is also of the utmost importance to have this data available in the same performance monitoring system because this would enable to optimise the performance on more than just reducing operational costs. Since the data is already collected it will only require a small amount of resources to group the data in a structured way in a database.

To conclude the audit of the commercial department, it can be said that there is a general understanding of how to optimise performance. It is also known what is needed to do so but this information is often missing or difficult to obtain. The performance monitoring system could create a lot of value here by simply filling the information needs of the operators. This could help voyage planning significantly and the learning process could be greatly improved. It could also fill the information sharing gap between the vessel and operators and improve communications in this way. The follow up of the upper management has to also be improved when it comes to improving the performance. When performance deficits are found and solutions are presented, the solutions have to be implemented and applied with the support of upper management. This is lacking at the moment at Spliethoff.

Technical Department

The technical department at Spliethoff has two main departments. It provides the engineering and project management needed for the newbuild projects and retrofits. The other department is responsible for the maintenance of the vessels. Both the planning and the maintenance tasks itself are carried out by the people in this department. Different views about performance management are present within this department. The difference mainly comes from the different sub-goals that are present throughout the department. One sub-goal that is strongly present in the technical department is an environmental sub-goal. This sub-goal evolves around the philosophy of reducing emissions by 50 percent before 2050. This follows the target set by the IMO to reduce CO_2 emissions from the maritime sector by 50 percent before 2050. This means that for this part of the department reducing emissions is a part of increasing performance. The environmental sub-goal could go in against the main goal of Spliethoff which is to maximise profit from transporting goods with the Spliethoff fleet. A 50 percent reduction in emissions asks for major changes to the commercial operations of Spliethoff as well. Meaning that a 50 percent emissions reduction can most likely only be achieved by reducing the sailing speed of the fleet. This might reduce the speed to below the most economical speed and could thus damage the profit made.
This emission reducing sub-goal is not yet shared throughout the entire department. Others see investing in improving maintenance as a higher priority and do not see that reducing fuel consumption and thus emissions could also lead to increasing profit. Their sub-goal is to reduce the downtime of the vessels and to limit the breakdowns that bring high maintenance cost. This difference in philosophies also comes from the different type of people in the technical department. The largest part of the department has a very practical mindset. This is due to the fact that they also perform the maintenance on the vessels themselves and almost all are ex officers or engineers that sailed on the ships. They believe a more hands on approach would be more beneficial than looking at data. A hands on approach is important when it comes to the maintenance of ships but the data can offer an extra source of information to support this hands on approach. A transformation in culture is needed here before performance monitoring and data based decision making are part of the daily

routine.
The newbuilding department has a different view on performance management and performance monitoring. They see a lot of value in having accurate operational data which can assist with making business cases and can help identify weaknesses in performance of the vessels. Many questions about operational profiles of the vessels have already come forward and these can be easily produced with the help of the performance monitoring system. An example of this is given in figure 4.2. For them the knowledge contained in the data of the performance monitoring system has the highest value. How to extract the knowledge from this data is not yet clear to them but this is why time and resources are invested in researching performance monitoring. They already have a strongly performance oriented attitude at this department and the addition of the performance monitoring system will only give them more tools to apply their performance management.

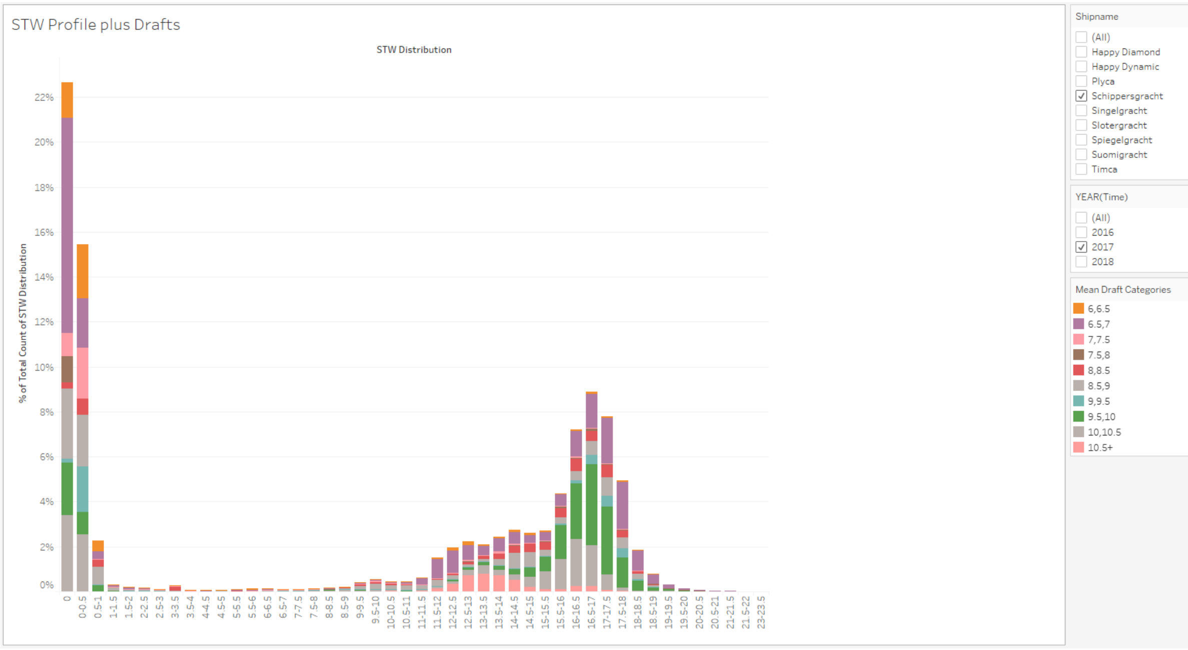

Figure 4.2: Visualisation of the operational profile with regards to speeds and drafts of the Schippersgracht

The maintenance system should also be addressed. Since this is one of the core tasks of the technical department and is certainly an important part of performance management. The current maintenance system is mostly based on experience and maker specifications. This means that almost all preventive maintenance is based on maker specification or relies on the expertise of the superintendents in the office and mechanics/engineers on board of the vessels. Corrective maintenance also has a large role in the current maintenance system. Condition monitoring is not yet applied in a systematic way. One of the things that came forward during the interviews is that the condition monitoring data that is being collected at the moment is not being used because the data is not collected in a way so that it can be showed together with other data or see its development over time. The current machinery condition reporting is done in weekly spreadsheets. These spreadsheets only show the data for that week and do not show trends. These trends are essential in determining the need for maintenance. Finding a way to show these trends and to enrich the data with other operational data is seen as potential value by the superintendents.
Implementing a more data driven maintenance strategy such as "Reliability Centered Maintenance (RCM)", could improve the performance of the maintenance at Spliethoff. The current maintenance system at Spliethoff relies heavily on experience. This experience is not shared or documented in a correct way, meaning that the knowledge often stays at one person. There is data being collected that could be used for data driven maintenance but this information is not processed in such a way that it is usable. This being said the possibilities with regards to RCM are currently being researched internally. If RCM is seen as something that could optimise performance it could be integrated with the performance management system.

Onboard the vessels

Spliethoff policy is to let the people with the most applicable knowledge make the operational decisions. This means that it wants to leave most operational decision making to the master and officers on board of the vessel. Spliethoff has a well trained crew and they intent on using this in-house knowledge as much as possible. This means that instead of giving orders from the office, tools are developed for the crew on board to use and to provide training that leads to more efficient operation. Most of the operational decision making is thus done on board. Creating an overview of how the people on board of the vessels strive towards high performance is thus very important. An overview of performance management is created with the helps of visits to the vessels and sailing along for a short period of time.
The first thing that was noticeable is that the opinions, motivation and general operations varied a lot between different vessels and different people. Meaning that on board of one vessel they were more than interested into developing and using certain performance tools and dashboards and others might see it as an extra unwanted workload. This is important because it reflects the fact that improving performance is not as simple as providing a tool. The human factor has a large effect on the effectiveness of implementing performance management. It is not as simple as one solution fits all. This being said there is a good general understanding on board of what influences the performance of a vessel. What is often not known is what the best operational point of the vessel is in a certain situation. Again there seems to be a barrier between knowing how to optimise performance and the information needed to make this possible, or that the information is there but the knowledge of how to interpret the information is not there.

Figure 4.3: Old ECO sailing instruction above performance indicating system

In figure 4.3, a memory aid is placed above the performance indicating system on board of a vessel. This memory aid should represent sailing ECO, meaning that when the fuel consumption is less than 30 t/day or 1250 $kg/hour$ the vessel is sailing ECO. The problem with this is that this instruction is incorrect. ECO sailing is defined as the speed at which the lowest consumption per nautical mile is attained. The performance indicating system above which this sticker was placed even contains the fuel consumption per nautical mile as seen in figure 4.4 at "Ship Efficiency". This indicates that when it comes to sailing ECO sailing, some instruction is still needed on board of some vessels
When discussing the various tools which are available on board of the vessels to optimise performance the feedback is also mixed. The ship has two mayor tools which can assist in optimising performance of the vessel. The first tool is SPOS which is short for Ship Performance Optimisation System. This tool is actually a weather routing service which helps optimise the vessels route with regards to weather. Even though the tool is viewed as useful, it is not yet used to it full potential. Routes are often still plotted by hand on paper charts. After this the routes are copied into the computer based tool SPOS. The captains then use this to monitor the expected weather along the route but they do not often use the optimisation capabilities. The tool might be more effective if SPOS is consulted before a final route is charted.

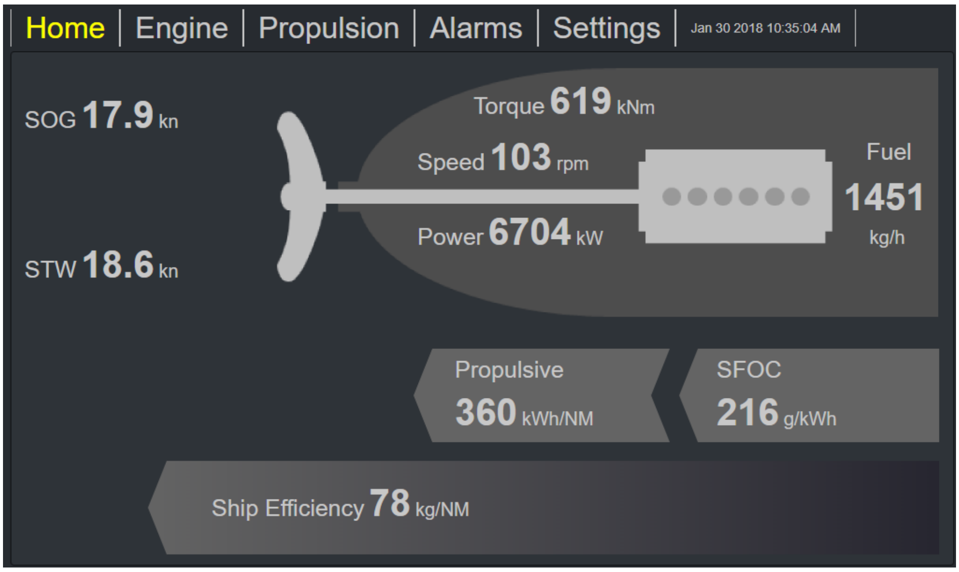

Figure 4.4: Home screen of performance indicating system on board of some vessels

Another tool is the performance indicating system which is present in the bridge console and the engine control room. This system integrates data from on-board sensors to KPIs which can be used to monitor the ships performance. A tool like this is very useful and is one of the most important measures to create awareness on board about performance. This being said, there are some issues with the current tool. First of all, the accuracy of the used data. The ship efficiency is calculated by dividing the fuel consumption in kg/hour by the ship speed through water (STW) in knots. The problem is that the STW comes from the speedlog. This sensor has proven to be inaccurate throughout the industry. This means that on this screen the valuable KPI of the fuel consumption in kilograms per nautical mile is inaccurate.

Figure 4.5: Bridge of the MV Schippersgracht with Performance Indicating System boxed in red

Another issue with this system is obvious when looking at figure 4.5. The performance indicating system which is boxed by the red rectangle is placed very inconveniently. The poor viewing angle makes the screen

unreadable from almost all normal operating positions. This means that when an officer wants to use the system he has to lean over the bridge console. This is everything but inviting for the users. Also the user interface itself is not the most inviting and user friendly. Important KPIs are shown on the screen but their development over time are not visualised. This means that it is hard to see the effects of a certain change in operation. It is clear that a large improvement can be made to the performance indicating device. Having clear and accurate performance data on the vessel is one of the most important aspects of the performance management since the crew of the vessel make most decisions about the operations of the vessel.
Lastly, the ship has a SEEMP (Ship Energy Efficiency Management Plan) on board. This is a compulsory document introduced by the IMO. In this document instruction made by Spliethoff are given which help in saving energy on board of the vessels. In this document it is specified for example that certain type of equipment is to be switched off when not in use and even gives instruction on how to trim a vessel and use SPOS. This document is used by the vessels but the document has to be updated to better serve the crew. The SEEMP is also criticised in literature on its effectiveness. The SEEMP is mostly used to raise awareness about best practises but it does not specify how to monitor or review the efficiency [Johnson et al. [2013]]. Meaning that there is little to no follow up on the implementation of this document. It is still believed that the SEEMP can be an effective document for practical instructions if the crew can be motivated to use it.

In conclusion the crew has good general and practical knowledge of how to optimise performance of a vessel. They do this now with practical experience as a basis. For example, the vessel is trimmed just slightly to the aft because it has proven to not give bad performance. Heavy weather is avoided because it is known to cause poor performance. Thanks to the well trained and experienced crew of Spliethoff this has been going quite well. This being said, an increase in performance is certainly to be gained when the decision making is fortified by real performance data and when the available tools are used in the day to day operations. A practical example of how weather routing can be optimised is given with the help of figures 4.6 and 4.7. In figure 4.6 a few ships with their sailed tracks are shown. In figure 4.7 the fuel consumption, speed and wave height over time are shown of the grey and pink vessel. The grey and pink vessel are both on their way to the east coast of the United States of America. The pink vessel passed the English Channel one day after the grey vessel. The grey vessel was planning upon exiting the English Channel to move in a South-Westerly direction. The vessel had not noticed the large depression moving South-Easterly which would cross the planned route when these plans were made. This meant that the vessel had to drastically deviate its course and was experience heavy swells. The pink vessel which followed a day later did notice the depression and decided to keep a Westerly route first. This caused the pink vessel to experience far less swell and was able to come aside the grey vessel. If the grey vessel had used the weather routing tool upon crossing the English Channel the large delay might have been avoided. The delays are very costly. A day of delay can easily cost the company €15000 due to extra voyage costs and loss of income.

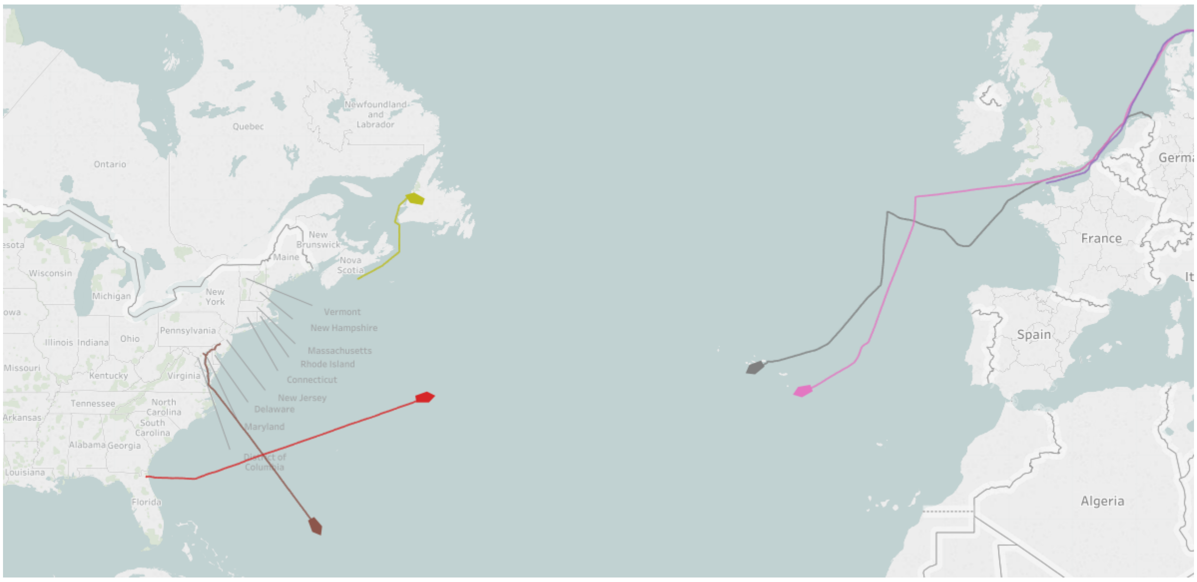

Figure 4.6: Effects of heavy weather on routing

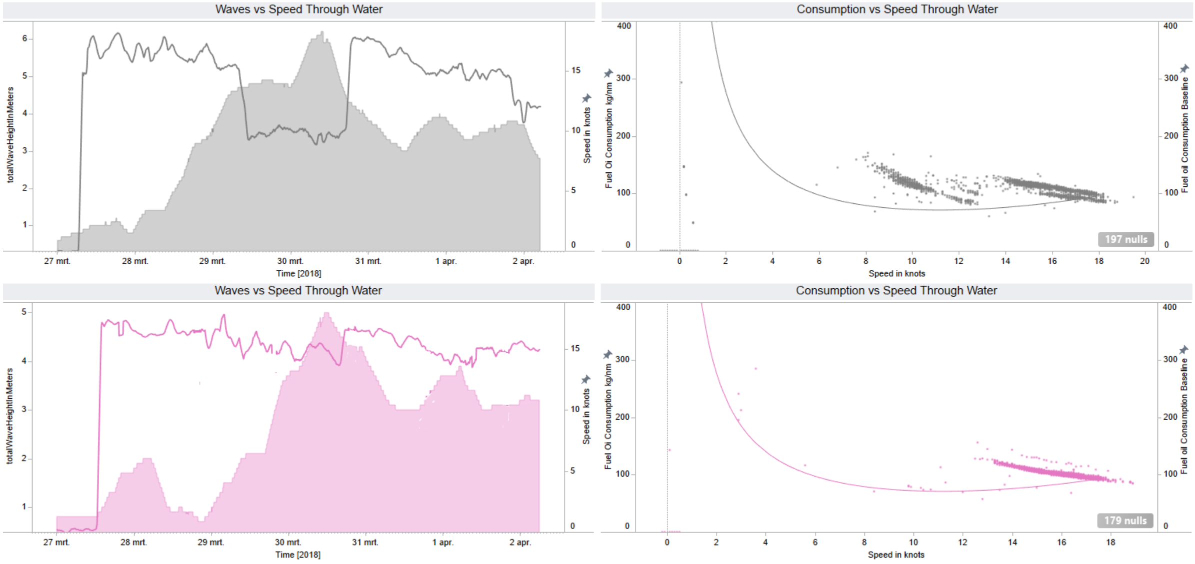

Figure 4.7: Effects of heavy weather on consumption (Left: Area plot is significant waveheight and line is speed, Right:Fuel Consumption in kg per nautical mile vs speed together with a fair weather baseline)

The use of the weather routing tool has to be promoted to reduce the negative effects of weather on the performance. Instead of using the tool as a simple forecast the vessels should optimise their route with the tool. To do this it is important that the vessels also get a clear overview of the effects the weather has on performance when not using the weather routing tool. The dashboards as shown in figures 4.6 and 4.7 could already give great insights to the personnel on board. Finding a means to share this information with the vessels over the limited internet bandwidth is important. One way could be to share reports of the performance instead of giving the entire tool and data. By showing the vessels the result of poor weather routing instead of just telling them to use the weather routing tool will motivate the crew more to use it because they can see the rewards from using the tool. This is a very important aspect of performance management, the ability to see the rewards of making changes to operation.

The performance indicating device also has to be improved. Having a tool that shows the performance of the vessel in real time and in a clear way is very important in creating awareness and knowledge. The performance indicating device should be located in such a way that it is always visible on the bridge without blocking the view outside. Implementing some sort of competition element into this device like for instance between the different shifts could motivate the users to increase performance. Having a clear overview of how their decisions influenced the fuel consumption over time should also be included on the performance indicating device. This could be done by simply showing the trend of fuel consumption over the last few hours.
Lastly, following up on the performance management on board in the form of performance audits and performance monitoring will ensure a better implementation. Training the vessels in the use of these tools should continue.

Performance optimising research at Spliethoff

The main part of the research done on performance at Spliethoff before this project and that of Grutterink [2017] comes from Hoogenhout [2010]. The subject of his work was to optimise liner performance for the ConRo vessels on two different trades. Even though his research only focuses on the liner service of the ConRo vessels it did lay the ground work for performance optimising measures within Spliethoff group. Measures like optimising the trim of the vessel or vessel speed are well discussed in this research and are said to have significant cost savings when optimised. Added wind resistance and effects of trim have also been researched separate from the previously named research. In both cases the influence of trim has been analysed by using the power estimation method of Holtrop and Mennen [1978]. The added wind resistance due to stowage has also been analysed with theoretical models. The same theme comes forward in the performance optimising research as throughout the departments at Spliethoff. The theoretical knowledge is there but it has not yet been or only partly proven by actual data. Meaning that the positive effects of these strategies have not been

registered in real operation. The effect of this is that it has formed a small barrier for implementing performance optimising strategies. The company has become slightly sceptical of implementing new strategies because they have not shown a proven return.
The performance monitoring system can really offer more insight here. Strategies and other performance optimising measures can be tested and based on real data. This should increase the efficiency of these measures and also give the company more confidence in implementing new measures.

4.2. Overall conclusions

From the interviews, analysis and audit, one common theme keeps coming forward. That is that throughout Spliethoff there seems to be a common understanding of how to increase performance but there are certain barriers that stop Spliethoff from implementing these performance optimising measures effectively.
The first of these barriers rests in the upper management of the company. They have not yet seen the desired returns in any of the performance management projects until now. The results have been also disappointing to them due to the under involvement and the lacking follow up with improvements when poor performance is found or when ways of improving performance are specified. Also, there does not seem to be a large drive to research the lacking performance. It is said by upper management that performance should be optimised but the way in which this should be done is not specified. Successful performance management relies heavily on the involvement of upper management and their willingness to make changes to company culture and operations. This means that before implementing a new performance management plan the dedication of the upper management is required to increase the chance of success. Spliethoff culture includes not giving feedback or orders from the office to the crew on their vessel operation. This makes it nearly impossible to make changes to operations if these come from the office. Upper management should recognise this and specify clearly when changes in operations are to be made. The crew and office personnel are to work together towards a common goal and not see feedback as an attack on their skills. Communication and information sharing between vessel and office improvements are essentials to this as well.
The second barrier is the (partial) unavailability of the data or information needed to make decisions that optimise performance. Even though there is a general understanding of what should be done to optimise performance it is often based on theory and not on real operational data. Examples of this are the optimum trim of the vessel and the influence of weather on the vessel. Also the determination of the eco-speed has been based on theory before the implementation of the performance monitoring system. This means that a good start has been made in reducing fuel consumption of the vessel but that the performance monitoring system could provide that last optimisation step and could provide more accurate knowledge to the company. The knowledge and information contained in the operational data will ensure a higher efficiency in the performance management.
Lastly, it is noted that Spliethoff has certainly not been operating blind. They have a good idea of how to optimise performance but the final steps have been missing to implement a fully successful performance management. This means that there is space left to optimise the performance but these might not be as big as starting from scratch. The new performance management plan should focus on using the information provided by the performance monitoring system. It should also focus on follow up and measuring the effects of certain changes. This is important to show the positive effect of performance management. Showing the effects of performance changes is of the utmost importance when implementing new tools and strategies. Without visible rewards the change in operations and possible extra workload do not seem worth it. This means that the performance monitoring system is as important as a performance optimising tool as it is important as a verification and implementation tool.
The possible added value that can be created by removing these barriers is specified in chapter 6. The costs of the performance management system needed to remove these barriers is also specified. A structured plan to remove these barriers is given in chapter 5.

5

New Performance Management Plan

The goal of this chapter is to propose a new performance management plan. This plan is to fill in the missing links in the performance management at Spliethoff which were identified in chapter 4. The plan will also give some performance optimising strategies. This new performance management plan which utilises the performance monitoring system can then be tested for added value in the chapters following this one.
It is important to firstly define a structure for the performance management plan. Some existing management systems are analysed to see if these can serve as a template for the new performance management plan. Secondly, a new performance management plan is proposed. Lastly, the role of the performance monitoring system is discussed to see what part of the added value can be contributed to it.

5.1. Analysis of management systems/plans

A management plan provides the structure and framework of tasks and procedures to fulfil a certain goal or perform certain tasks. A management plan can be applied to almost every process. A well structured management plan is important if you want to be successful in achieving and maintaining these goals. The effectiveness of the plan is logically very much dependent on the quality of the management system. Management plans for various applications have been standardised by the international organisation for standardisation (ISO). Examples of this are ISO 9001 quality management, ISO 14001 environmental management plan and ISO 50001 energy management. These standardised management systems are widely used throughout several industries. These management systems are often based on a PDCA (Plan, Do, Check, Act) structure. An example of such a structure is given in figure 5.1 from ISO 50001:2011. The check and act steps of the management structures is something that could improve the performance management at Spliethoff.
The SEEMP (Ship Energy Efficiency Management Plan) is another management plan which could serve as a template for a performance management plan. The SEEMP is a compulsory management plan which has to be present on board of every ship because of IMO regulations. The SEEMP's main goal is to raise awareness about fuel efficiency and best practises that reduce energy consumption. It does specify that the energy consumption has to be monitored but it does not follow up on that in the regulations. For this reason the SEEMP is often criticised as an effective means of reducing energy consumption [Johnson et al. [2013]]. The International Maritime Organisation (IMO) itself does specify that the SEEMP can be more effective if it is used as a subset in another energy management system like ISO 50001. The SEEMP can then be used as a ship specific framework which addresses the best practises on board of a certain vessel to reduce energy consumption. The SEEMP seems to be most effective at eliminating the waste of energy by creating awareness about energy consumption.

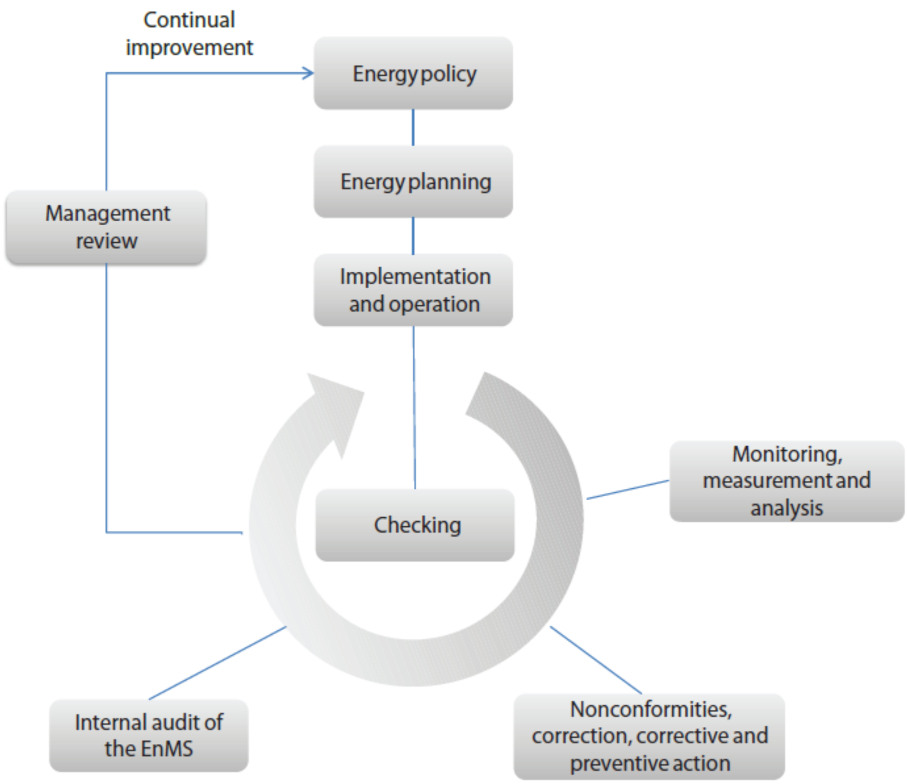

Figure 5.1: Plan, Do, Check, Act structure as defined by ISO 50001 [ISO 50001:2011]

Spliethoff already has a certificate for their ISO 14001 environmental management plan. This means that the company has experience with implementing these standardised management plans and has even gone through the certification process. The process of certification has not been experienced as an easy one. It is a time consuming process which cannot be rushed due to the dependency on third party auditors. This being said, the experience will certainly make implementing another standard much easier than the first. The environmental management plan in place at Spliethoff is not suitable to be adapted into a more performance oriented management plan due to its focus on waste management. It would risk including too many goals in one management plan. Goals that do not directly relate to each other or that might interfere with each other.

Performance management is the most closely related to energy management in this case because fuel costs are the biggest operational cost for the company and reducing fuel and thus energy is important in performance management. Meaning that ISO 50001 would be most suitable to serve as a framework to base the management system on. Adaptations have to be made depending on the desired focus on performance versus energy savings. Implementations at other shipping companies of ISO 50001 often have a clause in the management plan which states energy saving strategies are only implemented if they also have a positive effect on the financial result of the company. By doing this the scope of energy management is narrowed. This means that it is not as effective as it could be and thus not pure energy management. The clause causes it to be a narrow scoped performance management plan which only focuses on business optimising strategies which also results in a savings of energy. Narrowing down the scope of the management plan in such fashion does not have to be a bad or negative thing. It could make the project more manageable and if successful produces both energy savings and an increased profit, thus achieving two goals at once. Also, for total performance management data or information is needed from all corners of the organisation. To prevent barriers from rising up due to lack of information it is important to set a scope and only analyse the parts of which data and information is available. This being said, it should be noted that the performance monitoring system, at the time of this project (2017/2018) mainly focuses on the fuel or energy consumption of the vessels. The fuel costs have by far the largest share in the total vessel costs. This share is around 25 to 30 percent. Meaning that focusing on the energy management part of performance management seems like a suitable scope.

Jafarzadeh and Utne [2014] also offer a framework to overcome barriers in energy management. In the paper, information barriers also cover the largest share of the named barriers which complies to what is found at Spliethoff during this research. Jafarzadeh and Utne [2014] together with Johnson et al. [2014] show the importance of removing these barriers before performance or energy management can be successful. Figure 5.2 gives a simplified overview of the framework provided by Jafarzadeh and Utne [2014]. This "barrier management process" should run parallel to or should be part of the performance management plan. This will increase the efficiency of the performance management.

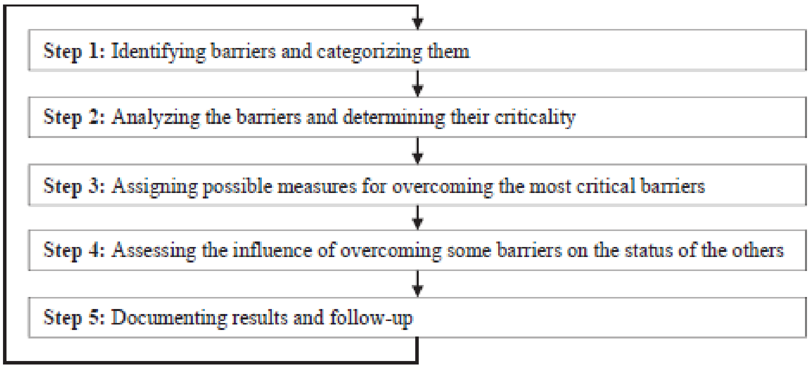

Figure 5.2: Simple overview of framework to bridge barriers [Jafarzadeh and Utne [2014]]

It has been determined that there are several well set up frameworks to tackle a performance management project. Using a predefined structure has many benefits. It can reduce the time needed to set up a plan and it makes sure that important steps are not overlooked. A separate process that analyses barriers in the project and eliminates them is crucial for the success of the performance management.

5.2. Proposed Performance Management Plan

In this section an initial draft of the proposed performance management plan is worked out. This will include the structure of the management plan and the main activities. The goal is to identify the steps in performance management and which part of these are enabled by the performance monitoring system. This will assist in estimating the value that the performance monitoring system can create. It will also serve as a start to the performance management plan for Spliethoff.

As stated earlier in 5.1, it is beneficial to use a well tested framework when setting up a new management system. ISO 50001 is selected as the most suitable for this purpose. This because this is closely related to performance management in this case. It is also important to define a scope within the performance management plan. With this it is important to realise what data is available. You can not manage what you can not measure. The performance management system mostly monitors fuel consumption in relation to the operational parameters of the vessel and some simple maintenance indicators like hull fouling and specific fuel consumption. The initial performance management plan will thus focus on this. When commercial data and more detailed condition monitoring data becomes available, the scope can be widened to also incorporate this and form a more complete performance management plan. The ISO 50001 standard provides the structure and requirements for the content of the management plan. It does not provide the contents itself. Small adaptations have to be made to the framework of ISO 50001 Energy Management to shape it into performance management. Figure 5.3 gives a visualisation of the framework of the ISO 50001 standard with its continual improvement cycle [IMO [2016]]. In this figure index number 1, 2 and 3 are missing. Especially index one is important to include in the continual improvement cycle in the case of this project because this is where the scope is defined. This scope will have to be adjusted as more data becomes available over time. Not all bullet points as shown in figure 5.3 for the performance management plan will be worked out in this chapter. Instead the main line and most important parts will be given.

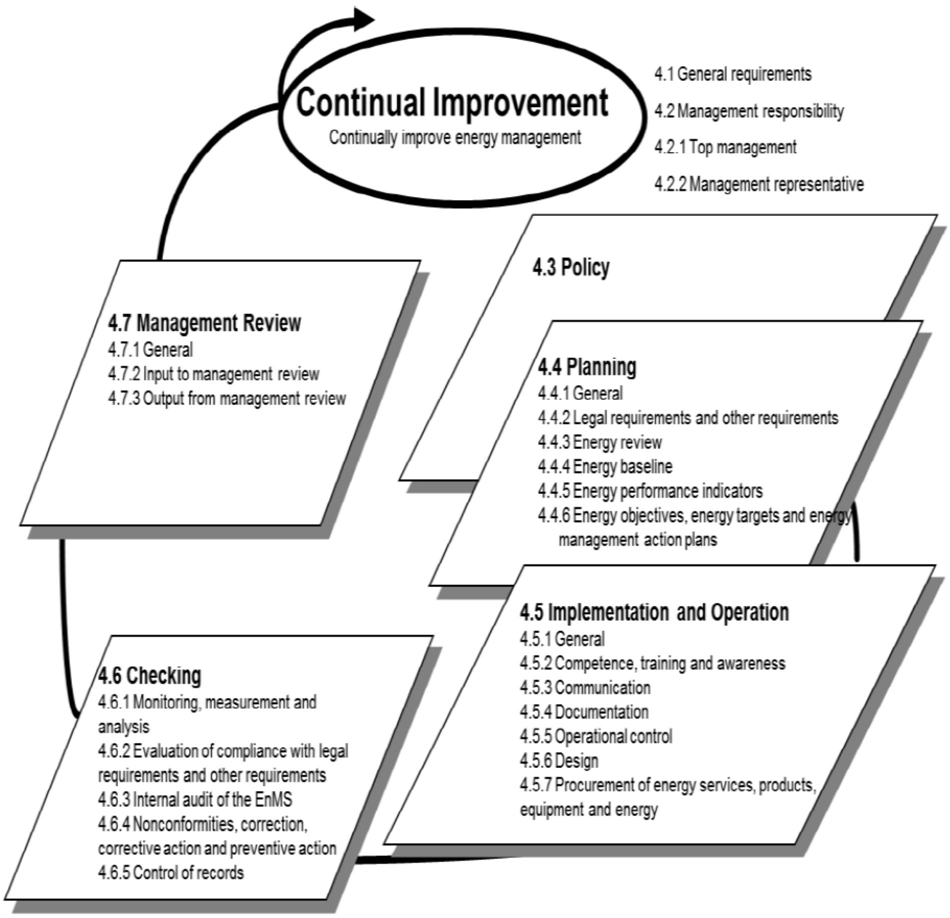

Figure 5.3: Overview of ISO 50001 framework [IMO [2016]]

Scope

Firstly, it is important to define the scope of this performance management plan. The goal of the performance management plan is to optimise profit obtained with the Spliethoff fleet. There are three main areas the performance management will focus on to achieve this goal. These are the operation of the vessel, the maintenance of the vessel and newbuilding or retrofits. These three areas need to be specified by a scope as well since they are limited by the information and data needed to provide good performance management. The extend of the information is limited to what can be provided through the performance monitoring system.

The operational performance management will focus itself on reducing fuel consumption by using the information provided by the performance monitoring system. Reducing wastage of fuel by creating awareness and optimise planning by improving communication and information sharing between crew and shore.

The maintenance performance management will focus on hull and propeller fouling and main engine performance loss. This means that the focus here will also be on reducing fuel costs.

For newbuilds and retrofits the goal is to improve business cases by using the operational data provided by the performance monitoring system.

Even though a focus will be on reducing fuel cost it should be said that the total cost package should be monitored. Fuel cost reductions will only be implemented if they result in a net gain in total profit or when the benefits outweigh the costs. All implementations will thus have to be financially viable or have significant non monetary benefits before implementation.

The scope of the project also contains finding and implementing more information sources during the project to expand on the performance management system. The performance management will for now not focus on market analysis and the reduction of non operational costs.

Lastly, the performance management plan shall only focus on the vessels which have been implemented into the performance monitoring system. The implementation of vessels into the performance monitoring system is also part of the scope and will be carried out over time.

Performance Policy

The performance management will strive towards optimising fleet performance within the predefined scope. A performance team is to be appointed to achieve this goal. The performance management system is to be verified on a yearly basis by testing its financial benefit. This means that the earnings/savings or potential earnings/savings have to way up against the costs associated with the performance management system. The collection of performance data and the expansion of this data is to be continually improved upon to support the performance management. The biggest changes should come forth from awareness and knowledge creation. The performance team is not to give orders to the entire organisation on how to improve their performance but to educate, train and inform about performance optimisation. Meaning that the performance management system will not just be a decision making system but also a knowledge providing system. The decision making will be adapted downstream due to this knowledge creation. The performance management will carry on until proven that it is not profitable or if it goes in against other more prominent policies. In such a case the performance management plan has to be adapted. The performance management plan will also be continually improved upon.
It is vital that more data and information is implemented into the performance monitoring system over time. Especially commercial data is important. If the goal is to steer or control on financial performance, it is important to have the data to do this. Implementing commercial data should thus have a high priority in the development of the performance management system.

Performance Planning

In figure 5.4 a concept diagram of the planning process is seen as given by ISO 50001:2011. An overview of the inputs and outputs of the energy planning is given. It should be said that this is a repeating process. For the purpose of performance management the planning has to be adapted but since the main focus is on reducing fuel consumption it is only slightly.

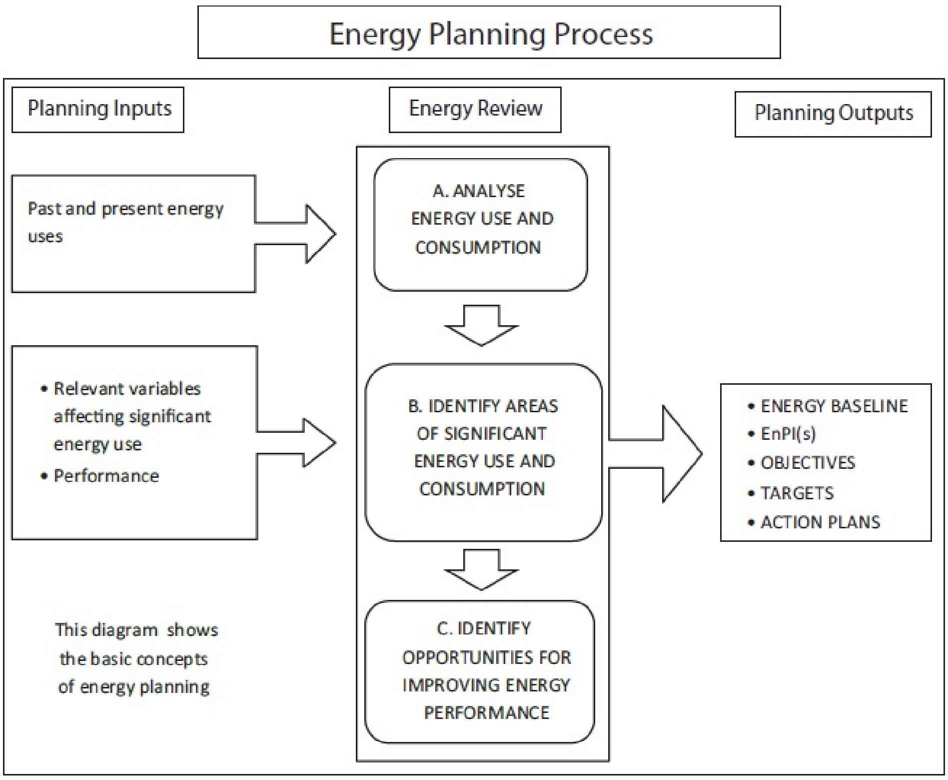

Figure 5.4: Planning concept as given by ISO 50001 Energy Management [ISO 50001:2011]

The performance planning process starts with information and data gathering. The information and data is needed for the performance audits or reviews. During these audits the performance is tested. The initial performance audit at the start of the project is different from the ones throughout the performance management's lifetime. In the initial audit it is important to analyse the performance data and to set up baselines.

In this initial audit the first areas of improvement are also identified. The audit for the S-type vessels and the office has already been performed in section 4.1 and the data analysis and baseline creation has been done in section 3.3. Certain parts have also been performed for other vessels in the fleet but these will have to continue when expanding the performance management over the entire fleet. In figure 5.5 an overview of the entire fuel consumption and sailing distances of the whole fleet is given. From this the largest consumers can be identified. The totals have been removed but it can be seen that the Conro and the S-type vessels share the largest part of the HSFO (Heavy Fuel Oil) consumption. HSFO also is by far the most used fuel. Even though the S-Types have sailed a lot more distance than the Conro vessels, the total consumption of the Conro vessels is still higher. This is due to the higher operating speed and size of the Conro vessels. Focusing on these two vessel classes in the beginning of the project has the highest potential of reducing fuel costs.

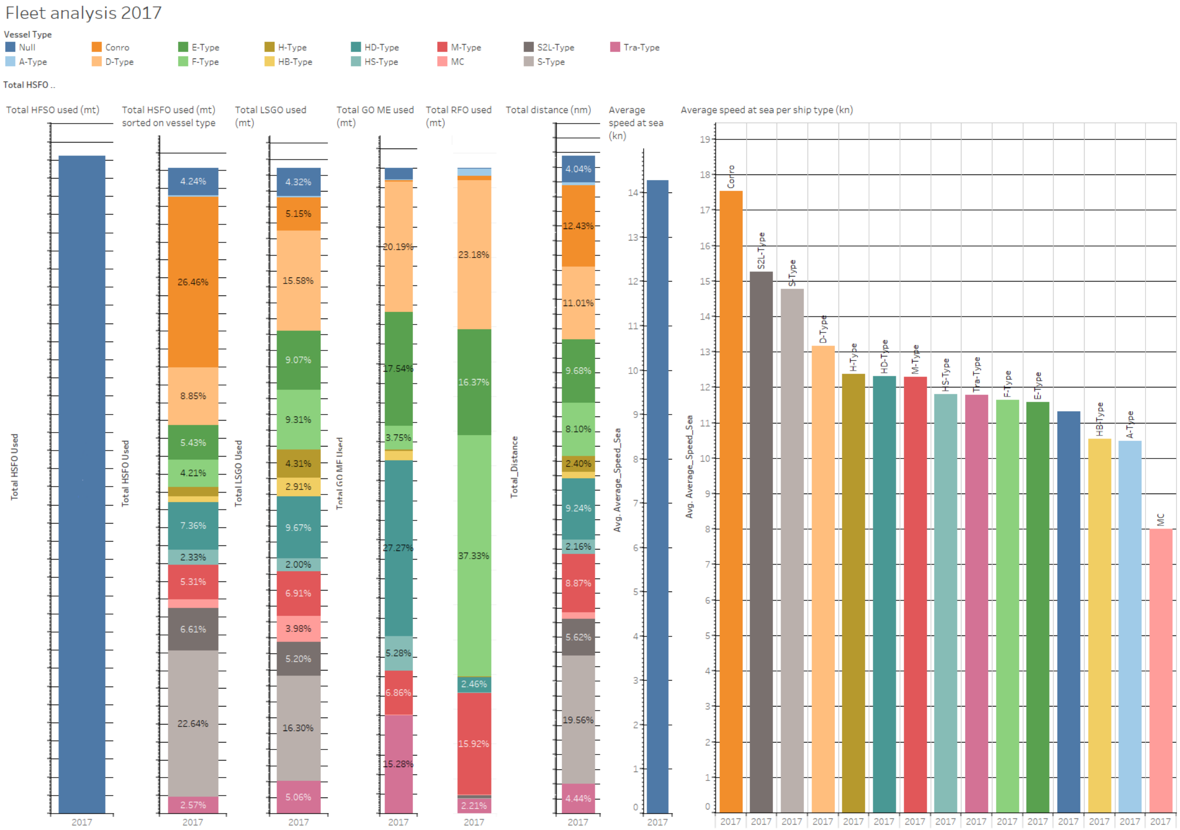

Figure 5.5: Overview of fleet consumption and operation (Totals removed)

Identifying areas where the performance can be optimised is also important in the performance planning. As mentioned in this report, creating awareness and knowledge is very important. It is believed that providing information and creating awareness about performance will already cause an increase in performance. This because it has been identified that often information or data is missing that is needed to make performance optimising decisions. Creating knowledge will thus be one of the largest action plans. Eliminating wastage of fuel will also be part of this. Fuel wastage that comes forth from negligence like for example not turning off the hold or deck lighting when not used is another area of where performance can be gained.
Another area where performance management can make a difference is newbuilding design and retrofitting of performance optimising technologies. Using the performance data provided by the performance monitoring system can support businessescases and optimise design. The data analysis in chapter 3 showed that the vessels without combinator mode have poor performance at speeds lower than the design speed. The data also showed that the vessel almost never sail at design speed meaning that they perform far from optimal. Optimising a design for part load or equipping vessels with frequency converters might be beneficial.

The outputs of the performance planning process are: Baselines or KPIs, Objectives and Targets and Action plans. The baselines have been determined in chapter 3 but the development of these is to continue. The

objective of the performance management plan is to realise added value for Spliethoff. This is initially done by optimising fuel consumption and reducing delays. The target for the first year is to have proven that the performance monitoring system can create added value within an acceptable time period. This means that there should be a return on investment within 5 years. The target after this year is to realise this return on investment and to keep on improving the performance monitoring system.
The action plan is to create awareness and provide the employees of Spliethoff with the knowledge to optimise performance. This will be done by creating and implementing performance dashboards in the office and on the vessels. Articles and reports are to create the awareness on performance management. Performance data analysis is to be performed by a designated person which will steer the direction of the performance management. In the implementation more details are given about these plans.

Implementation

The implementation of the performance management will be done with the help of several means. Firstly, awareness about the performance management system has to be created. This will be done with and official statement of the upper management and quarterly articles in Spliethoff Group's monthly magazine. In this quarterly article cases will be described so that the staff can see the effects of their performance optimisation. The SEEMP will also be upgraded to include the performance optimising strategies and give a general overview of the performance management system. Further awareness will be created with presentations at the officers meetings.
Secondly, performance optimising tools will be implemented within the performance management system. There are the existing tools like the weather routing tool of which the use has to be promoted and for which training will be given to further increase the use of this tool. Tools will also be made by the performance management team itself. The first tools will be performance dashboards for in the office as well as on board the vessel. The dashboards are to be tailored to the information needs of the different departments and the vessels. This means that at first, three main dashboards will be developed. One for the operators in the commercial department, one for the superintendents in the technical department and one for on board of the vessels.
Where the dashboard for the operators and on board of the vessel will be more focused on the operational performance of the vessel, the dashboard for the technical department is focused on the maintenance of the vessel. The performance dashboard of the operators will include a map with the current position of the vessel, its sailed track and planned track. Over these tracks the performance and conditions are shown. There will also be the possibility do dive deeper into the performance and compare the performance to established baselines and to see the causes of this performance. This will allow the operators to make better estimations about the ETA and fuel consumption and to provide the vessel with a second opinion on their chosen route. It also helps them to create knowledge about the parameters that influence performance. The first implementation of the operator dashboard is shown in figure 5.6 and 5.7.

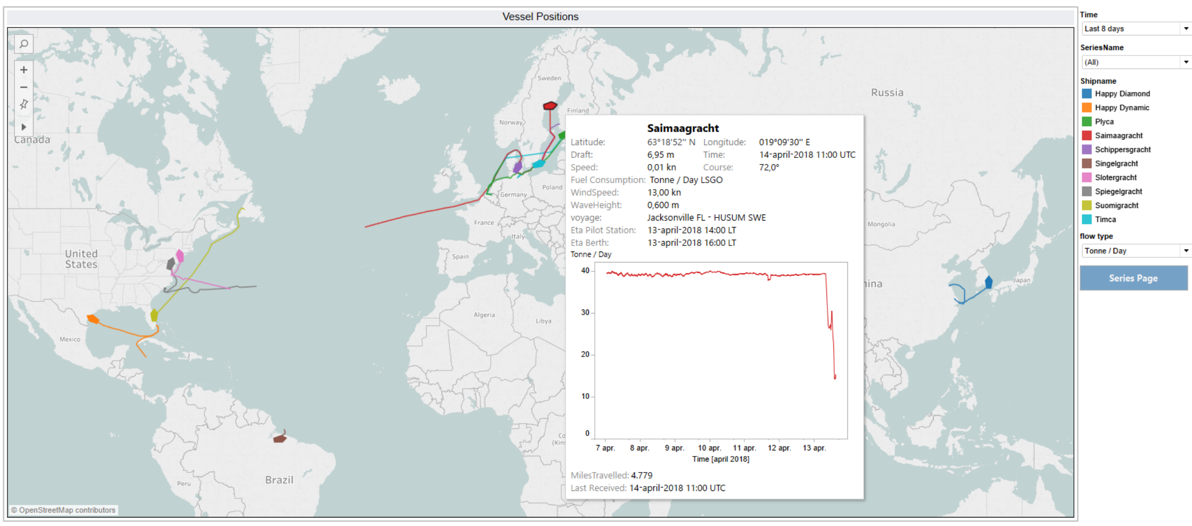

Figure 5.6: Home screen of operator dashboard concept (Missing planned track and weather overlay)

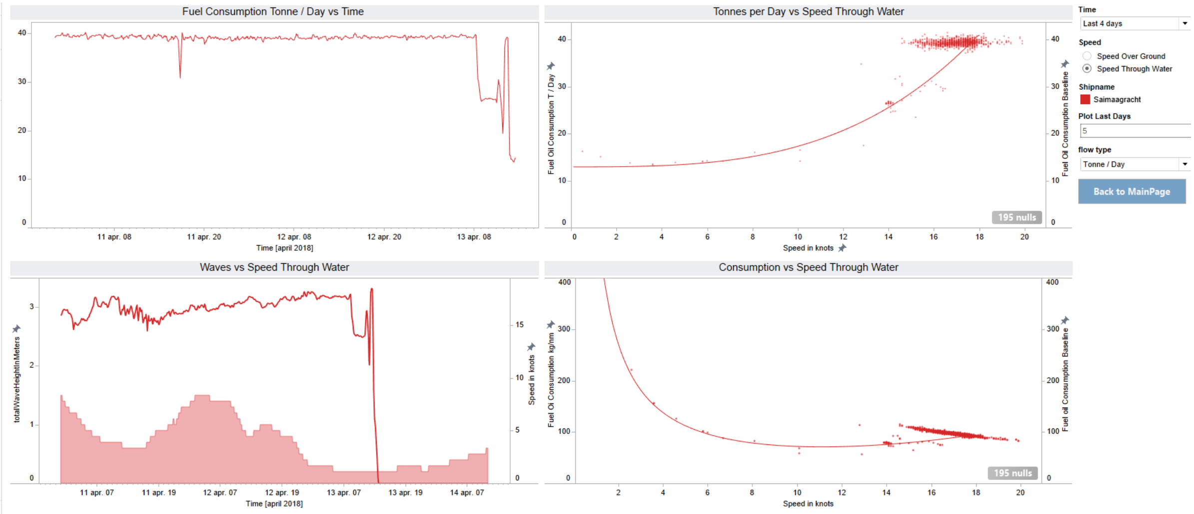

Figure 5.7: Trip performance analysis page of operator dashboard (Top two graphs: fuel consumption over time (left) and fuel consumption vs speed and baseline (right), bottom two graphs: significant waveheight (area plot) and speed (line plot) over time (left) and fuel consumption per nautical mile vs speed with baseline (right))

The dashboard on board of the vessels will serve as a replacement for the performance indicating device currently installed on the vessels. This dashboard is to display the current performance of the vessel compared to a certain baseline and to show the development of the performance over the past hours. This will enable them to show the influence of their operational decisions on the performance of the vessel and also gives them the information needed to optimise this performance. This will create the awareness on board and introduce an element of competition between different watch shifts. A concept of this dashboard is given in figure 5.8. The dashboard has the same layout as the dashboard in figure 5.7. The difference is that the dashboard on board will show live data and the current operational point.

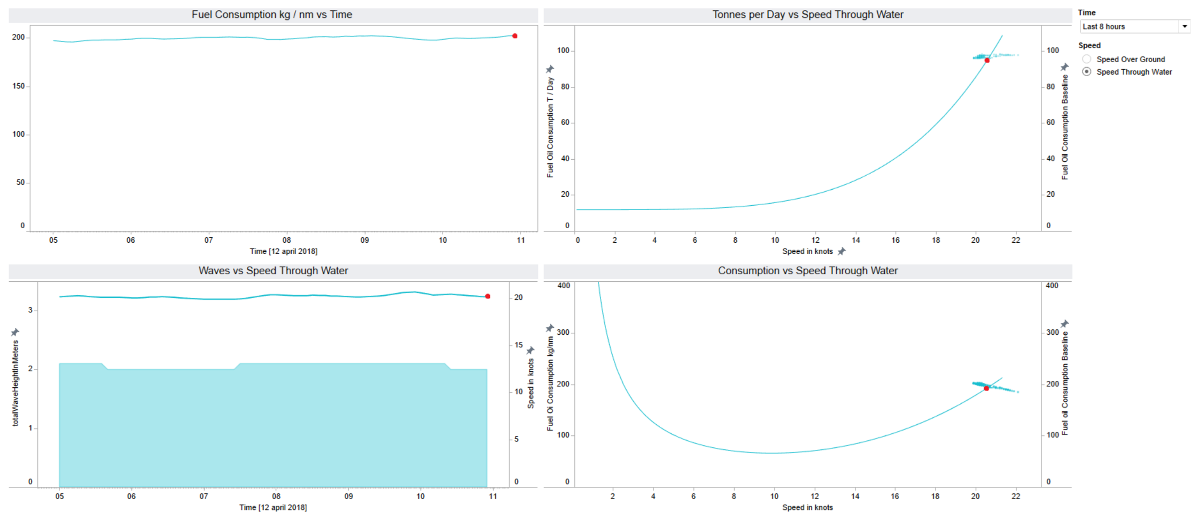

Figure 5.8: Dashboard Concept for on board the vessel (Red dot showing the current operational point)

Lastly, the dashboard for the technical department is to aid in planning maintenance. The dashboard will give a trend off the required power to sail at a certain speed at fair weather conditions. This can then be used to determine if the hull and propeller are fouled. It will also give an overview of the specific fuel consumption of main engine of the vessel compared to a formulated baseline. This can give an indication about the condition of the engine. Lastly, data from oil diagnostics reports and other conditions monitoring sources is to be visualised in such a way that trends can be formulated. Before this can be implemented more research needs to be done into condition monitoring.

To manage and realise the implementation, manpower is needed. Therefor a performance team is to be set up. The team will be responsible for the implementation of the performance management plan and the tasks named in the plan. The performance team is also tasked with analysing the data and the further development of the system. One full time performance manager/data analyst and one part time IT specialist are proposed to carry the workload. Further part time input is required throughout the company. Every department should appoint a representative to support the performance management.

Performance Monitoring

The performance monitoring system will be used to verify if the performance management plan is effective and thus adding value for Spliethoff. The analysis of the performance is to be carried out by the designated performance management team. This will consist of a daily quick-scan and more elaborate performance audits. The performance audits will consist of detailed data analysis of the vessels but also visits to the vessels to raise awareness and implement performance optimising strategies. Also, the on board audits will inspect if machinery is performing optimally.

From the performance monitoring a slight drop in the average fuel consumption per nautical mile should be seen as well as improved weather routing. Performance optimising cases are to be documented and their total value creation is to be calculated. The checking step of the management plan is thus done easily because of the performance monitoring system.

Management Review

A yearly management review is to be carried out. In this review, the created value is to be tested against the costs made by the performance management system. Performance optimising cases are to be discussed and performance data to be reviewed. This will then determine whether changes have to be made or if the performance management has to be continued or discontinued. The management review should also indicate the direction of the development of the performance management system and redefine the scope and policy.

5.3. The role of the Performance Monitoring System

During this research it has become clear that without a performance monitoring system effective performance management is impossible. Every part of the performance management plan is related to the performance monitoring system. It is nearly impossible to optimise the performance without measuring the performance itself.
It is possible to implement performance optimising tools that do not require performance data as an input. Examples of this are the weather routing tool and the voyage management system. This being said, without physical proof that these tools help optimise performance the implementation of these tools is hard. Having the performance monitoring system showing the actual benefits in using these tools will greatly motivate the use of these tools. Without this proof the use of these tools is seen as added workload without giving them a visible reward. The reward is so important when it comes to motivating people for specific tasks.
This means that without proper performance monitoring these tools are often ineffective. This also means that all created value within performance management is to be contributed to the performance monitoring system as well. Without performance monitoring there is no performance management. This means that throughout the rest of this report no differentiation is to be made with regards to value creation for performance management or performance monitoring.

III

Part 3: Added Value

6 Determining the Added Value

The goal of this chapter is to determine the added value of the new performance management plan and the performance monitoring system within this. To accomplish this the costs and the value creation are specified in detail. Their origin and dependency on certain parameters are thus also defined. The answer to the question: How and how much value can be created with performance management and the performance monitoring system at Spliethoff?, is given by this chapter.
To answer this, firstly, the definition for "added value" in this research is given. Secondly, the costs of performance management and the performance monitoring system are given. Thirdly, the value created by the performance management system is defined. After this the added value is determined in the form of the "Net Present Value (NPV)" for several different scenarios. The sensitivity to certain parameters is then analysed and lastly, the results are discussed.

6.1. The definition of added value in this research project

It is important to firstly specify the definition for the added value as it is used in this research because the definition of added value is not set in stone. De Chernatony et al. [2000] addresses the difficulties with defining added value as his research shows that it is used in many different ways. Getting more than is paid for stands out as a definition but here the definition of "more" is again varying from person to person and is dependent of their vision of value. Added value also cannot be confused with "value added" which does have a well defined definition. Value added is defined as the resources invested in a product plus the profit made with the product. In other words all the value that has been added to a product. Value added is thus not the same as added value. Kay [1995] defines the added value as the economic rent. Economic rent being the difference between the price needed to break even or the minimum price needed to proceed and the price at which something is sold. A second example definition is the difference between the selling price and the costs of making a product. This definition comes close to profit but is different in the numbers that are included in the calculation.
To give a better view on how the added value is defined in this research we look at the two words separately, similarly to how De Chernatony et al. [2000] approaches defining added value. In this research "Value" defines the benefits that are realised with the performance management system. These benefits can be monetary but they can also be non monetary. "Added" reflects the fact that costs are required to create these benefits. These have to thus be subtracted to find the net value increase or decrease. This net value increase or decrease is what defines the added value. It should also be noted that in this case cost reduction is also seen as value for Spliethoff because this will in most cases lead to better results.

It is also important to define the scope that covers the costs and values used to determine the added value for Spliethoff. This is important because there are different stakeholders connected to a project such as this and what is value for one stakeholder could be a cost for another stakeholder. Also there are monetary and non-monetary values. While non-monetary values can be very important for one stakeholder, they might not be as important to the other stakeholders. It should also be considered that Spliethoff has taken a certain direction and certain decisions when setting up the performance management. Other directions or decisions might have given different costs or values. It is also important to consider these. All in all there is a lot of

differentiation to be made when performing such an analysis. The scope chosen is defined below.
With regards to the stakeholders it is decided to focus on the value which is created for Spliethoff internally. Meaning that for the calculation of the NPV only value for Spliethoff directly is considered. This means that for instance potential subsidising derived from third party value creation is not considered. This is done because for a project as this the main focus for Spliethoff is on a direct return on investment in monetary value. Value created for third parties are still important but are seen as some sort of a bonus. This being said, an analysis of potential value created for other shareholders is done at the end of section 6.3. Externalities are also addressed there.
Monetary and non-monetary value are both considered in this analysis but the non-monetary value potentials will not be monetised and used in the determination of the NPV. This is again done to show the direct tangible result of this project. The non-monetary values are thus again seen as a bonus on top of the added value.
The decisions made during this project lead to a certain value creation and costs. Other decisions would have led to different costs and created value. These differences or missed values are often described by opportunity costs. The opportunity costs are not defined in this research specifically. To compensate for the unique approach that was taken for this project the costs will be split into the minimum, maximum and actual value whenever possible to describe alternative approaches[1]. This allows us to see the effect of certain decisions on the costs. On the value side this is compensated for with the use of scenarios and the sensitivity analysis.

6.2. Costs of Performance Management

The are several different cost types associated with the performance management. There are investment costs which consist of the development of the system and the investment costs of the hardware needed for for instance the monitoring system. There are investment costs per vessel but also investment cost that are independent of the number of vessels in the system. There are also operational costs associated with the system. These costs vary from data transfer costs, to maintenance costs and dedicated personnel costs. Due to the fact that Spliethoff has developed the entire system in house the cost structure is more complicated than if an "off-the-shelf" application was purchased. In this section a breakdown of the costs associated with performance management system is given.

6.2.1. Development Costs

The development costs are specified separately from other CapEx since Spliethoff has been developing the performance monitoring system from the ground up in house and with minimal help of third party companies. Due to this hands on approach the development costs were kept low. There are three main sources for the development cost of the performance management system.
The first source is specified as general R&D and project management. This source consists of the time put in by the project manager and the researchers that have researched the theory behind performance management. The general R&D has largely been done by two graduate interns (this research and Grutterink [2017]). The project management has fallen under the task of business development and amounted to on average half a work day per week for three years. These costs sum up to a total of around 50000 euro. This is very low due to the use of graduate interns.
The second source is the data-logger software development. This software runs on all the data-loggers on board of the vessels. This software has been designed in such a way that it can deal with almost all signals, making it not reliant on the differences between sensor and other systems suppliers. The software has been developed by a third party IT solutions provider. The development costs include the latest changes to the sampling method as was recommended after researching the data quality. The total costs of the third party data-logger software development is around 33500 euros. It should be noted that future expected development costs of this software are not included in this number.
The third source of development costs is the database development. The development of the database has been going on throughout the project and is also partly done as part of the general R&D. For this reason only the time invested in the development of the latest database is included here. The total cost comes from a month of work by an internal IT specialist which is around 4000 euros.
Lastly, the future development costs should be discussed. As specified in the new performance management plan a live dashboard for on board the vessels has to be developed. The software behind this system is to be developed by the same third party developer as the data-logger software. Also a test version of the data-logger

[1] The minimum and maximum costs are based on estimations but serve as a rough estimation for other alternatives.

itself has been purchased for further development. The height of these costs is around 5000 euros. These future development costs are already specified but there will also be development costs in the future which are not yet specified. These unspecified future development costs will be accounted for in the OpEx.
In table 6.1 an overview of the total development costs is given. Where the above named costs are found under actual. These development costs are a one time investment costs (CapEx).

Table 6.1: Development Costs overview (year:2016/2018)

Development Costs			
Name	*Min*	*Max*	*Actual*
R&D and Project Management	€0	€120000	€50000
Data-logger Software	€0	€50000	€33500
Database Development	€0	€10000	€4000
Future Software Development	€0	€7000	€5000
Total	€0	€187000	€92500

Spliethoff has managed to keep the development costs low due to the use of graduate interns and a small data-logger development company. This decision came with a risk in the form of using inexperienced people but has paid off in the end. The minimum costs are set to zero because it can also be decided to not develop your own performance monitoring/management system but buy an off the shelve system. These costs will then be transferred to capital expenditure and operational expenditure and will most likely not result in a lower total cost. The maximum cost is based on in house development but with the use of in house personnel and the use of a more high end data-logger developer. This decision would have lowered the risk of unsuccessful development but obviously comes at a price.

6.2.2. Capital Expenditure (CapEx)

The capital expenditure or capital costs come from the hardware needed for the performance management system and the hours needed for installation. All hardware has been paid from cash so there are no interest costs. Normally this cash would be used to potentially pay of loans but this is not the case for Spliethoff. There are no significant hardware investments needed on shore. The server space that is required for the system will be billed as rented and will thus fall under operational costs. The rest of the hardware investment is dependent on the ships. The costs include the required sensors, data logging/storage equipment and installation costs. The costs that are the same for every ship is the data-logger and storage hardware. These costs are independent of ship configuration. The data-logger is provided by the same third party as the data-logger software. The cost of the data-logger is €3660 excluding installation and €4000 with installation. The data storage on board is done on a server on board. This server is already present for other systems apart from additional cables and switches no extra costs are introduced. The costs for the cables and switches is about €2000.
The costs of the sensors is dependent on the vessel type. It is also dependent on what data is required. The costs of the separate components of the sensor system are given in table 6.2.

Table 6.2: Sensor System Component Costs (year:2018)

Sensor System Component Costs	
Signal Processing Unit	€3860
Flow meter	€1550
Density/Viscometer	€3333
Shaft Torque Sensor	€9885
Bridge Dashboard/Control unit	€1480

The are many machinery configurations throughout the Spliethoff Group fleet but these can be grouped into two main configurations with regards to the sensors needed for these systems. There is the single screw, single main engine with a shaft generator, auxiliary generators and a boiler configuration and there is the twin screw twin main engine with shaft generators, auxiliary generators and boiler configuration. For these two configurations a minimal required sensor specification is given in table 6.3. The minimal specification is the cheapest specification at which the performance management could be performed. Shaft power is not measured in this specification. The minimal specification is the same for both propulsion configurations. The sensor specification only consists of the equipment and sensors that would not be on board of the ships without the performance monitoring system. Other sensors like for example the GPS that is already needed on board for other applications are not included in the costs.

Table 6.3: Minimum Specification Sensor System (year:2018)

Minimum Additional Sensor Specification			
Device name	**Unit price**	**Quantity**	**Total**
Signal Processing Uni	€3860	1	€3860
Flow meter	€1550	3	€4650
Density/Viscometer	€3333	1	€3333
Shaft Torque Sensor	€9885	0	-
Bridge Dashboard/Control unit	€1480	0	-
Total			€11843

The downside to this minimum specification is that not all useful KPI's can be determined. The specific fuel consumption can not be determined and the propeller shaft power is also not measured. Fuel consumption per consumer group can be determined with this specification. The specification can be expanded by adding torque sensors on the propeller shafts and by having a flow sensor for every separate consumer instead of per consumer group. This will enable the analysis of performance for every single consumer more accurately. The torque sensor enables the determination of the main engine(s) efficiency (SFC) and gives a better picture of the hull and propeller fouling. If needed, the torque sensor can always be added later.
A medium sensor specification cost overview is given in table 6.4. The medium specification does include torque sensors on the propeller shafts but it does not include a separate flow meter on every consumer.

Table 6.4: Medium Additional Sensor Specification (year:2018)

Medium Additional Sensor Specification					
		Single Screw Type		**Twin Screw Type**	
Device Name	**Unit Price**	**Quantity**	**Total**	**Quantity**	**Total**
Signal Processing Unit	€3860	1	€3860	1	€3860
Flow meter	€1550	3	€4650	3	€4650
Density/Viscometer	€3333	1	€3333	1	€3333
Shaft Torque Sensor	€9885	1	€9885	2	€19770
Bridge Dashboard/Control Unit	€1480	0	-	0	-
		Total	21728	**Total**	31613

It is clear that the investment is already significantly higher due to the torque sensor which comes at a high cost. This specification enables to monitor the specific fuel consumption and to have a more accurate indication of the hull and propeller fouling.

What also can be seen is that the bridge dashboard/control unit has been left out in both specifications. This is due to the fact that it has been seen that this dashboard screen on the bridge provided by the sensor supplier is not used properly (see section 4.1). Since making the performance information visible and usable on the bridge is so important the dashboard will be developed in house. The software development costs for this system are already specified in the development costs but the hardware that is needed on board of the vessels has not. The hardware costs for this dashboard are estimated at €2500.

Lastly, the installation costs for the different specifications has to be determined. Spliethoff does all the installation itself so it does not use external service engineers to install the systems. This keeps the cost for installation to a minimum. The amount of hours needed for installation will vary for the different specifications and added costs for transport and accommodation will also vary depending on the location. Since the location can not be determined before hand this will be set as a fixed cost of €1000 for all specifications since the installation is often done in Europe. Man-hours will range between two days with two engineers for the minimum specification, to two and a half days for the medium single screw specification, to three days for the twin screw specification. Miscellaneous material costs are set to €500. Table 6.5 gives the total installation costs for the three specifications. Third party or sensor supplier installation costs are estimated to be around 30% higher.

Table 6.5: Installation Costs (year:2018)

Installation Costs		
Minimum	€3900	€5070 3rd party install
Medium Single Screw	€4500	€5850 3rd party install
Medium Twin Screw	€5100	€6630 3rd party install

The total CapEx per vessel are thus dependent on the amount of sensors and ship type and are given in table 6.6. It is recommended to apply the minimum specification to older vessels and smaller vessels and the medium specification to the younger and larger consumers in the fleet. Older vessels and smaller vessels have less potential for large returns so reducing the investment is recommended.

Table 6.6: Total CapEx for three specifications (year:2018)

Total CapEx	
Minimum	€20243
Medium Single Screw	€30728
Medium Twin Screw	€41213

Differentiation in the sensor prices is not made because there is no data available about different sensor suppliers. Differentiation can be made in the data-logger price. The Spliethoff solution comes at minimal costs. Other third party data-logger/performance monitoring systems can go up to prices of €100000 for fully integrated systems. These systems are more extensive than the one used at Spliethoff and also contain power management systems for large auxiliary power consumers and are often found on for instance cruise vessels.

6.2.3. Operational Expenditure (OpEx)

The operational expenses are partly related to the amount of vessels that are included in the system and are dependent on how many users are using the performance management dashboards. Others are not or less related to the scale of the performance management system. The main groups of operational costs are personnel costs, software costs, maintenance costs and data costs. All operational costs will be defined in yearly costs.

Firstly, the personnel costs are specified. As proposed in section 5.2, a small team is required to make the project successful. The team will consist of one full time performance manager/data analyst and one part time IT specialist. The total yearly cost for this will be €70000/year. This team will be responsible for analysing the performance, developing dashboards and systems and doing maintenance and installation of these systems. This is considered as the minimum requirement for the performance management system to be successful at Spliethoff.
A larger team will increase costs but will speed up the implementation and further development of the performance management system. A smaller team is possible if the performance monitoring system is provided by a third party and thus no further IT expertise would be needed internally, this would save €20000 per year.

Secondly, the software subscriptions costs will vary on the amount of users and the choice of the BI solution. Depending on how the information is desired to be transferred to the users the costs will vary. The costs per user of the BI tool (Tableau) currently in use is 480USD/year. An expected 12 accounts will be needed to serve all the users bringing the total yearly BI tool costs to 5760USD/year.
These costs can be reduced in two ways. The first way is to use a different BI tool which is cheaper but has a far lower usability (PowerBI). This will thus require extra time from the dashboard developers. The costs of this alternative tool is €120/year per user. This is cheaper but it might cause extra costs down the line due to the lower usability. The second option is to develop the tools in house which would eliminate the need for a third party BI tool but this option might bring high development costs and will take time before it can be applied. Benchmarking these options against the current solution should be continued during the project

but are not chosen now because the downsides do not way up against the ease of use of the current solution used (Tableau).
If opted for a third party performance monitoring system the costs of the software provided by this third party will be very high. Costs of a third party performance monitoring system could rise up to €2000 per month per ship.

The maintenance costs are defined by experience and estimations. The experience with the sensor systems at Spliethoff shows that the systems are reliable with the exception of the density/viscometer. For the reliable parts the cost of maintenance is estimated in the same way as in the work of Grutterink [2017]. Two percent of the total investment costs yearly for the sensor system and one percent yearly for the data-logger. For the viscometer it is assumed to be at 30% of the unit price per year. Depending on the specification of the sensor system the maintenance costs are calculated based on the above named assumptions (See table 6.7). Since the viscometer greatly increases the maintenance costs, replacing this sensor to reduce these costs should be considered[2]. It should also be noted that the total expected lifetime of the sensor and data-logger hardware is on average 10 years. After this a full replacement is needed. This will be accounted for in the NPV calculations in section 6.4 and is thus not included in the maintenance costs.

Table 6.7: Yearly Maintenance Costs per Ship

Maintenance Cost per Ship	
Minimum	€1400/year
Medium Single Screw	€1600/year
Medium Twin Screw	€1800/year

Fourthly, the data costs are specified. The data costs are comprised of the costs of the storage of the data on shore, the costs of transferring the data from the ship to the shore and the costs the weather data provider.
The data storage costs are estimated at around €600 per terabyte (TB) of storage per year for Spliethoff's in house solution. The size of the performance management data is 60 gigabyte (GB) at the start of the project and is estimated to grow with 4GB per year per ship. This means that the data storage cost will grow from €36 per year to several €100 euros per year depending on the fleet size and is thus a insignificant cost compared to others. Non the less €200 per year will be accounted for so that unexpected database management costs are covered. If opted for external storage (e.g. Azure) the costs could easily rise to €1000/year.
The weather data is provided by a third party. Currently this data is provided free of charge since Spliethoff helped develop this service. This is expected to change in the near future so there are costs that have to be accounted for. The expected weather data costs are estimated at around €334 per month. This brings the total weather data costs to around €4000 per year. Other third party weather providers offer similar services against around €6000 per year.
The data transfer costs are dependent on which connection is used to transfer the data to shore. There are two systems available at Spliethoff. There is the VSAT which is a low cost means but does not have a 100% coverage and there is Fleet Broadband which is significantly more costly but does have 100% coverage. Fleet broadband thus serves as a back-up whenever VSAT is not available. The cost for VSAT are $0.016 per MB (megabyte) and Fleet Broadband comes at $22 per MB. 2566 MB are transferred per ship per year. In the best case scenario where the Fleet Broadband is not needed the entire year the data transfer costs are $50 USD per year per ship. In the worst case where the Fleet Broadband is used 10% of the time the data transfer costs are $5000 per year per ship. In practice Fleet Broadband is used around 3% of the time bringing the costs of data transfer to around $1700 per year per ship
An overview of the data costs is given in table 6.8. It can be seen that the costs can get substantial of the data transfer via fleet broadband occurs frequently. Means should be explored to reduce the frequency of this happening in order to reduce the costs.

[2]Replacements are already being considered but the currently installed viscometer is still used in the calculations

Table 6.8: Data Costs Overview (Year:2018)

Data Costs			
Name	*Min*	*Max*	*Actual*
Data Storage Costs	€36/year	€1000/year	€200/year
Weather Data	€0/year	€6000/year	€4000/year
Data Transfer Costs	€40/year per ship	€4065/year per ship	€1382/year per ship
Total per year	€36 + €40 per ship	€7000 + €4065 per shp	€4200 + €1382 per ship

Lastly, the future development costs are accounted for since it is expected that the performance management system will add different data sources and expand the functionality in the future. These future development costs are estimated at €3000 per year. These costs will mostly be produced by software development. These costs are low for the same reason as the low development costs in section 6.2.1. Costs are zero if an external performance monitoring provider is used and can be close to double for different developers.

An overview of the total OpEX is given in table 6.9. Depending on the amount of ships that are included the total costs per year will vary.

Table 6.9: Operational Expenditure overview in costs per year (Year:2018)

OpEx Overview (per year)			
Name	*Min*	*Max*	*Actual*
Personnel Costs	€50000	€150000	€70000
Software Costs	€1440	€2000 per ship	$5760
Maintenance Costs	€1400 per ship	€1600 or €1800 per ship	€1400 per ship
Data Costs	€36 + €40 per ship	€7000 + €4065 per ship	€4200 + €1382 per ship
Future Development Costs	€0	€6000	€3000

For the calculation of the net present value only the actual value will be used. The minimum and maximum value are there to indicate how costs might vary depending on the chosen strategy for the performance management.

6.3. Value Created by the Performance Management System

Determining the value that is created by the performance management system is not as straight forward as it is to determine the costs of the system. As said earlier the created value can be either monetary or non monetary. Another obstacle is that since the performance management system has not been implemented fully the determination of the value it can create will thus be largely based on the potential to create value. This potential will also partly come from assumptions since it is hard to say how much value a certain action might create. In section 6.4 scenarios will be formulated to account for the uncertainty in the effectiveness of certain tools and changes to operations. In this section a realistic overview of the potential value that can be created with the performance management is given.

Spliethoff Group is a shipping company which does everything in house. Meaning that they have their own fleet, do their own fleet management, maintenance and freighting. This means that are many areas where value can be created. Other owners which do not do everything internally has to create value in a different way. A simple example of this is when a different shipowner which time charters out most of its fleet installs a performance monitoring system. They can then simply raise the time charter rate and in this way, easily create added value for themselves. The charterer that charters the vessel from this company then has to find ways to create the added value that this system offers. In the case of Spliethoff both of these steps are done in house meaning that it as a higher potential to create more added value.

An argument can also be made that the performance monitoring system can cause an increase in the freight rate but this will require definite proof that the performance management also realises added value for the freight owner. The performance management system could create value for the freight owner by reducing the risk and uncertainty. It can provide better estimations of the ETA and about the fuel consumption when the freight owner is paying the fuel. The increased freight rates will not be further specified since it is hard to proof this value as of yet.

The largest part of the created value will come from operational cost reduction and planning optimisation.

This being said value is also created in the form of knowledge creation and potentially a better reputation. The activities, plans and tools described in the performance management plan will guide as a framework in which the value created by these activities, tools and plans are discussed one by one. Some of the parts will be grouped together to avoid double counting of certain values.

Performance Data Analysis

The performance monitoring system enables Spliethoff to analyse the performance of the vessels through the data as shown in chapter 3. Detailed analysis is to be carried out by the performance management team. Value can be created for Spliethoff with this data analysis. The answer to how and how much is very situational. Determining how much value can be realised is not as easy as saying that performance monitoring can reduce fuel consumption with several percent like some suppliers of performance monitoring systems do. During this project a lot of data analysis has been performed and the conclusion from this is that there are different levels at which value can be created and these levels belong to different types of value. There is value to be created by reducing the fuel costs and there is value to be realised with creating knowledge from the data analysis.

The value created from fuel cost reduction is addressed first. Within the fuel reduction potential there is the potential which does not require further financial investments and there are the measures which can be taken but need another investment. The fuel reduction that can be realised with another extra investment is not specified here but it should be said that the performance management system greatly reduces the risk of these type of investments since they are based on actual data and thus the potential savings can be specified far better. Specifying how much the fuel costs can be reduced is challenging. The fuel costs saving potential is often derived from sub-optimal operation, meaning that the vessel is not operated as fuel efficient as it can be in a certain operational condition. An example of this is given in figure 6.1. In this figure all the recorded consumption data for 2017 of two of Spliethoff's ConRo vessels is shown. The data of the Plyca (in Brown) is plotted together with the data of the Timca (in Yellow) in the same graph. What can be seen is that at speed below 11 knots the Timca shows a large cloud of data where the Plyca does not (indicated with the red box). This difference in the fuel consumption is caused by the use of combinator mode in the Kiel Canal, on the Westerschelde and under pilotage at St. Petersburg (Indicated by blue boxes on the map). This means that the Timca does use combinator mode in these areas and the Plyca does not.

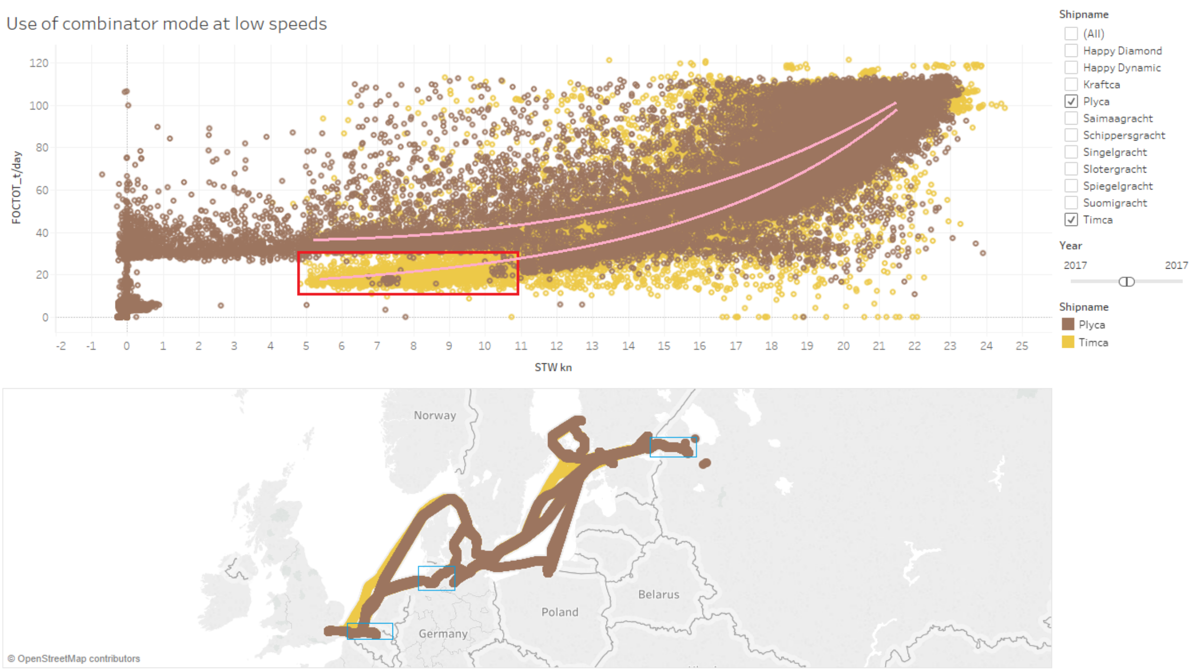

Figure 6.1: Low hanging fruit: Use of combinator mode at very low speeds

The total fuel cost savings that can be achieved if the Plyca uses combinator mode in a similar fashion as the Timca is around 52000 USD/year at a fuel price of 350 USD/tonne. A more detailed description of this case

can be found in appendix B. Out of the three vessels currently in the performance monitoring system two do not use combinator mode below speeds of 11 knots. This means that for this case already 104000 USD/year can be saved on fuel costs for these three vessels.
Without the data from the performance monitoring system it would have been far less easy to find the above defined savings. It would have also been nearly impossible to show the impact of changing the operation. Being able to show the impact is very important since simply telling a captain to change the way he/she operates the vessel is not the way to inspire change. Showing the actual benefits of the change in operation and letting the captain firstly decide himself if the change is worth it keeps their professional integrity intact. Educating the personnel about the effects of certain operational decisions is where the true value lies.
Another fuel cost reduction potential is sailing at the correct ECO-speed. If we look at the operational speed profile between 5 and 21 knots of three of Spliethoff's S-Type vessels in figure 6.2 we see that by far the most time is spent sailing at speeds between 14 and 18 knots. The orange line overlaying the operational profile is the fit curve of the fuel consumption per nautical mile which was made in chapter 3. It can be seen that barely any time is spent sailing at the most fuel efficient speed which lies around 11.5 knots. Without the performance monitoring system the most fuel efficient speed would already be hard to determine and the operational profile would have been just as hard to establish. The fact that the ships do not often sail the correct ECO-speed also became clear when visiting the ships (see section 4.1). The vessel did not have a clear picture about the ECO-speed, the vessel captain stated the ECO-speed laid around 14 knots. Calculating the potential fuel costs saving by sailing at the correct ECO-speed is hard to determine since it is unknown how often the vessels sail at ECO-speed. Also, when it is assumed to sail at a lower speed and that waiting times are not reduced, the total distance that will be sailed in that year will decrease. This also means that less cargo is transported over distance and thus the revenue will go down as well.

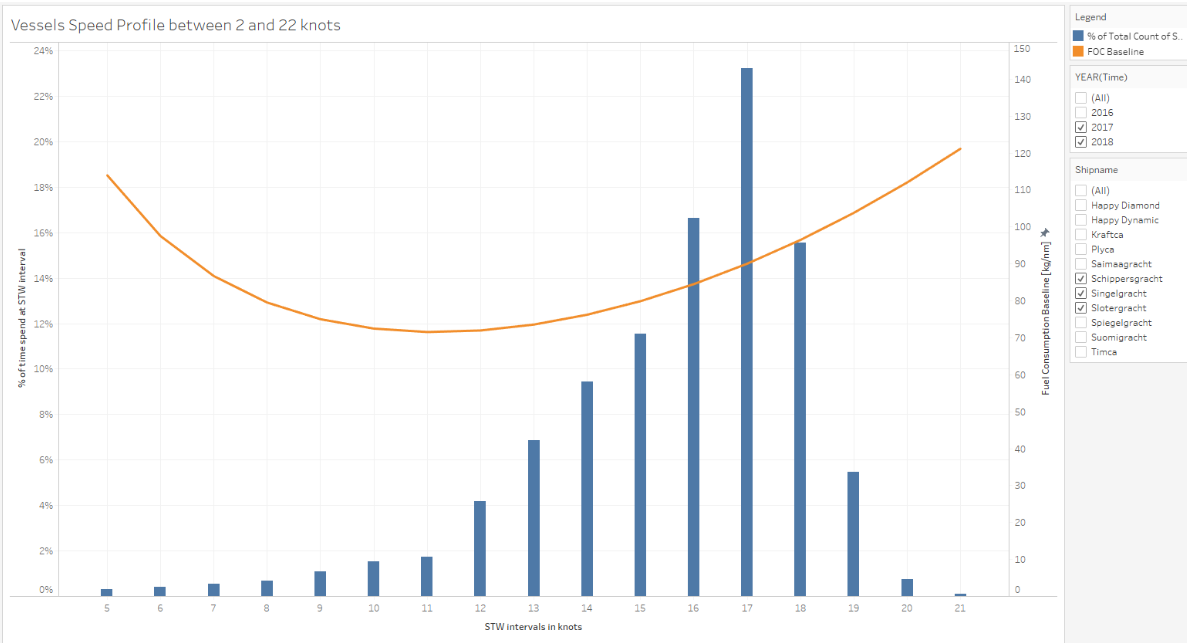

Figure 6.2: Sailed vessel speeds versus fuel consumption fit curve

A fuel cost reduction case can be made if it is assumed that the vessels only sail ECO-speed when there are long waiting times at the destination. It should be assumed that sailing a lower speed will then also reduce the waiting time so that the total distance sailed per year stays the same. The S-type vessels sail around 87600 nautical miles per year. The difference in fuel consumption per nautical mile between 11.5 knots and 14 knots is 4.75 kg per nautical mile. If we assume that 10 percent of the sailed distance is sailed at ECO-speed a total yearly fuel savings of 41.61 tonnes per year is achieved. This translates to 14560 USD/year per vessel at a fuel price of 350 USD per tonne.
These two cases give a more concrete example of how value can be created in the form of fuel cost reduction. Further analysis of the data is to be continued and this will bring forth more potential fuel savings cases. One of the cases that has not been researched in detail is speed loitering. This is where the vessels sail full speed

the first part of the journey and slack off afterwards to avoid arriving too early. Sailing at a constant speed will reduce the total fuel used on a trip but the risk of being too late has to be accounted for.

The knowledge that is created from analysing the data is also valuable. The created value from knowledge is different from the value created by fuel cost savings since the knowledge does not directly translate to monetary benefits. This does not mean that it cannot realise monetary benefits in the long term. The knowledge can create value in different ways and in different parts of the organisation.
The knowledge that is created from the data analysis gives great details about the vessel characteristics. For instance, the fit models that were produced can be used for many different applications. They can be used to make business cases more detailed and accurate. The risk in these business cases can be reduced since they can be based on detailed operational profiles in which less assumptions have to be made. Meaning that besides the direct cost saving potential the knowledge created with the performance monitoring also unlocks greater potential for further investments. It both gives an indication of where further investments can improve performance and it greatly reduces the risk of these investments.
The knowledge about the operation of the vessels can help improve designs for new build projects because far larger detail is known about operational profiles and performance influencing factors. The historic data can for instance give an overview of weather conditions along a certain trade. The vessel design for a new ship on the same trade can than be optimised for this. It can also give an indication of bad performing designs since they can be benchmarked against other vessels.
The knowledge can also be used to create tools and to test existing tools. For example, how good are the predictions and optimum speed determination of the voyage management system and are the assumptions made in the weather routing program about the influence of weather on the vessel accurate. This could increase the value of these tools.
It can thus be said that the amount of knowledge that can be created is extremely valuable. Exactly how valuable in monetary value is not specified because this might cause some double counting with the other benefits and as stated earlier all non-monetary value creation is seen as a sort of bonus. This being said, it is important to note the knowledge creation because it is such an important part of the performance management system.

Performance Dashboards in the office

Transferring performance data and information on to the personnel at Spliethoff is important to the success of performance management. Dashboards are designed to transfer this information to the users. The question that is needed to be answered here is how these dashboard can create value for Spliethoff. The dashboards as they are described in section 5.2 are different for different departments. There are two main implementations of the dashboards on shore. There is an operators dashboard and a still to be developed technical department dashboard. The dashboards are designed after consulting with the personnel of these departments to fulfil their performance information needs.
Firstly, the potential value creation from the operator dashboard is discussed. This dashboard is designed to give the operators a near live (1 hour delay) overview of the vessel position, operational performance and operational conditions and secondly to analyse the performance of the vessel over a certain voyage. The live position, operational performance and operational conditions enable the operators to make a better estimation about the ETA of the vessel and thus see if there are any expected delays. This also enables them to instruct the vessel if there is a risk of missing a certain arrival window. At such a moment the operator can call the vessel and give them a new revised arrival window and the vessel could for instance reduce speed to reduce fuel consumption. It could also work the other way around in which case it can tell the vessel to speed up to make a certain arrival window to reduce delays. The tool is expected to greatly improve the communication between shore and vessel and in its turn reduce delays and fuel consumption. This communication, knowledge and information sharing is the core of the performance management system. It is the improvement of these things that stand and the base of most of the value realisation of the performance management. An example of this is given in figure 6.3, where a vessel was approaching Baltimore at full speed but had to start drifting since the vessel could not enter due to low tide. With better communication and knowledge about the ETA this might have been avoided.

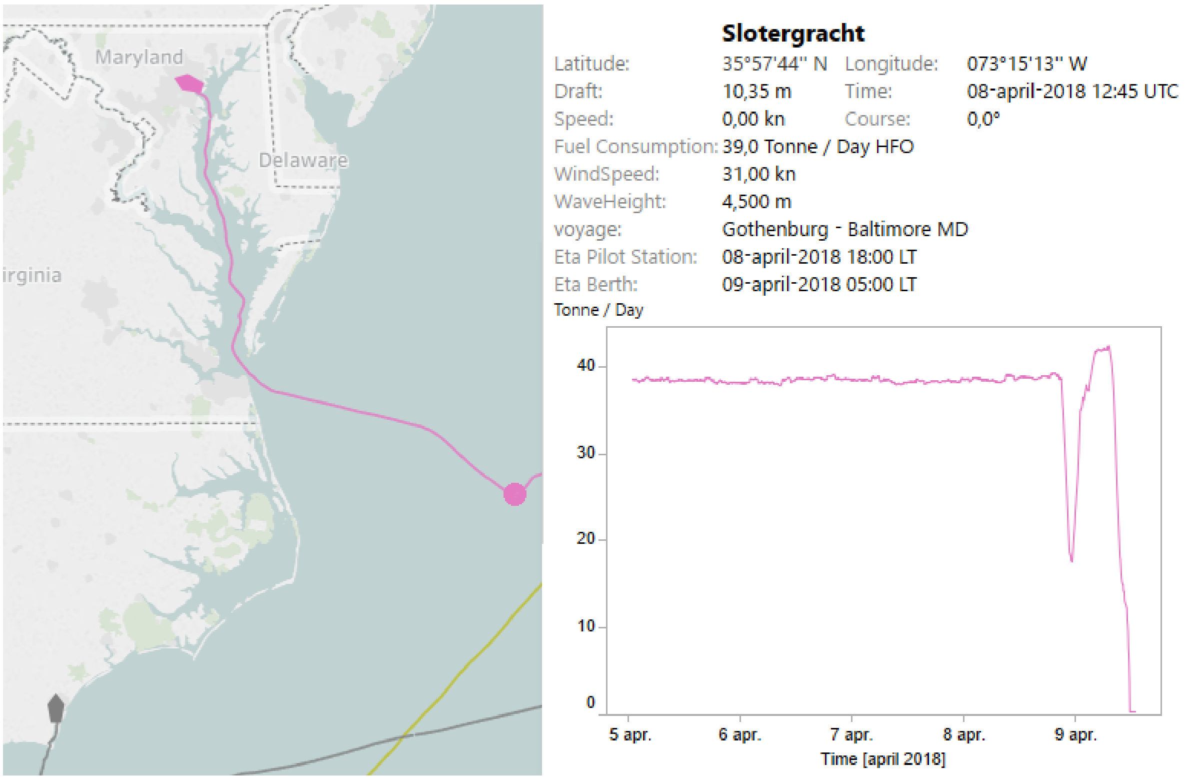

Figure 6.3: Drifting as result of arriving too early

In this case the waiting time was only short but larger gains are to be made when a vessel arrives in port at the weekend instead of arriving early on friday or thursday. In these cases large extra stevedore costs have to be made due to the higher fees in the weekend. Instead of arriving in the weekend the vessel could have slacked off to have an ETA after the weekend and thus avoiding high costs. This important communication can only occur when the operator of the vessel knows the exact location and conditions the vessel is in and having this information in a clear overview makes it more interesting to optimise.
As stated earlier it also enables the operators to analyse the voyage performance. In figure 6.4 an example is given of the performance data which the operators get to see in the dashboard. On the right side the fuel consumption data versus a calm weather baseline is given and on the left the sailed speeds, fuel consumption and wave height over time is shown. It can be seen that on this voyage the vessel performance was far above the baseline. The vessel experienced heavy weather while loaded with steel making the roll period very low and thus forcing the vessel to reduce speed several times to reduce the motions of the vessel and avoiding damage to the ship and cargo. The vessel also suffered engine damage and had to drift for some time to do repairs. The knowledge the operators gain from the analysis of these trips will help them in planning future trips where they can then account for delays due to weather in combination with a certain type of cargo and increased fuel consumption. From the analysis it can also be learned what to do in the future to prevent this. In the case of this voyage two routing decisions were made which caused most of the difficulties which was most probably due to incorrect use of the weather routing tool. A different route could have greatly reduced the delay and increased fuel consumption in this case.

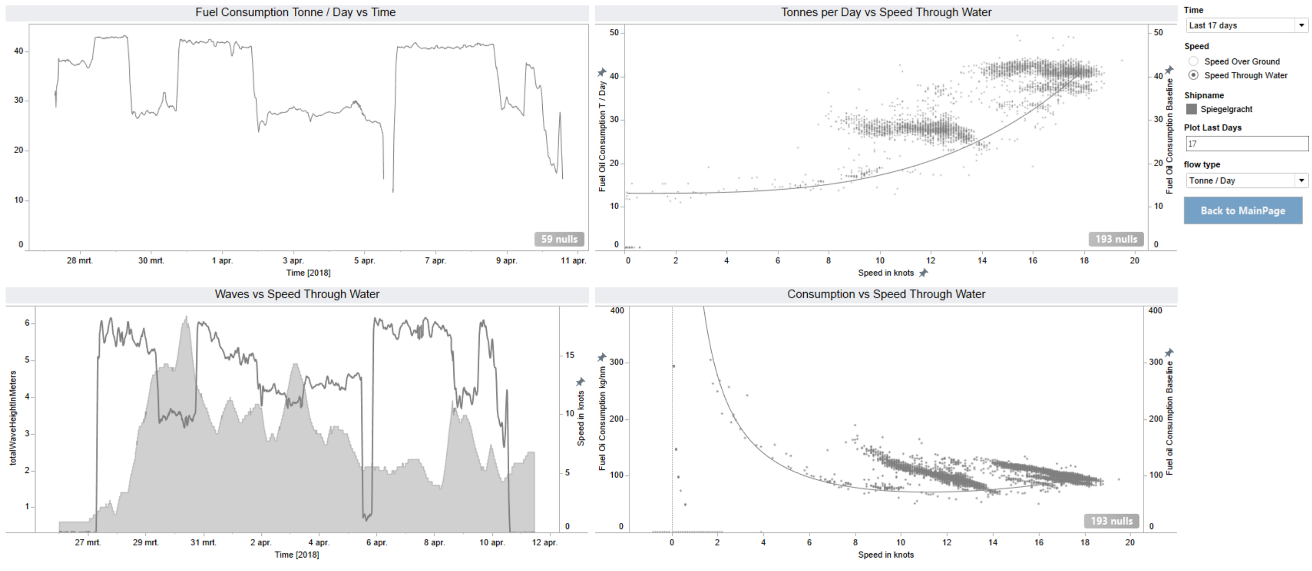

Figure 6.4: Operator Dashboard: Voyage analysis

Value can also be created by the operator dashboard because the weather routing decisions of the captain and his officers can get a second opinion. Besides the example given in section 4.1 in figure 4.6 another example of poor weather routing is given in figure 6.5. In this case the vessel sailed full speed into a depression which is indicated with the blue oval. The vessel then encountered 7 meter significant wave height waves which forced it to sail at only 4 knots in order to not lose the containers on deck. If the vessel would have used his weather routing tool correctly and had it chosen to sail great circle across the Atlantic (which is also a shorter distance) it would have avoided the storm and the day of delay and extra fuel costs with it. This proposed route is indicated with the green line.

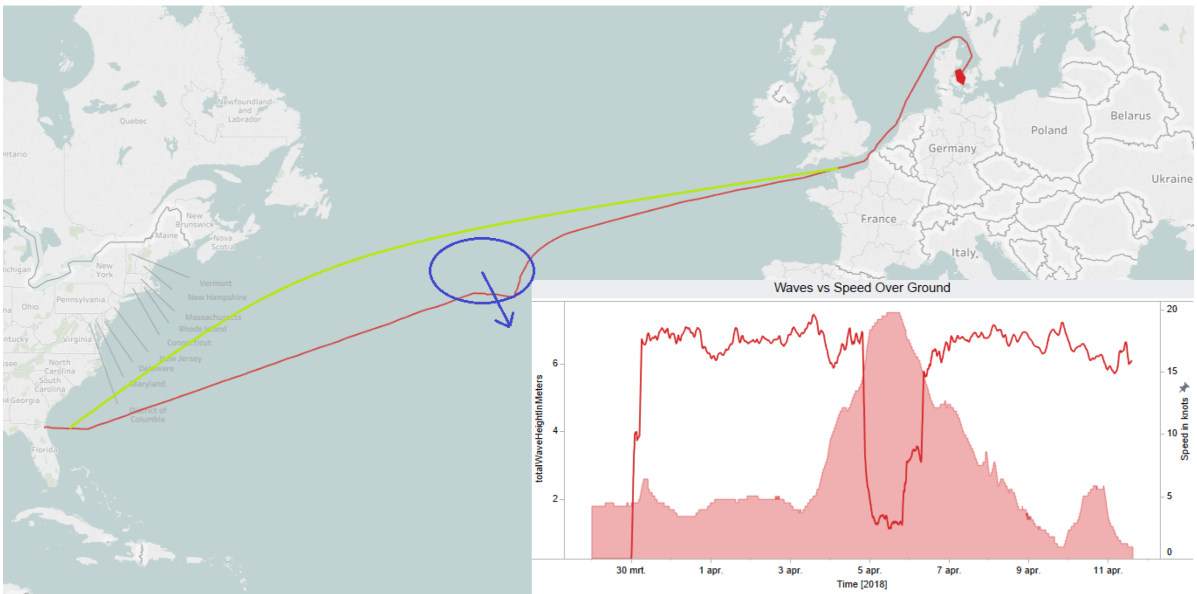

Figure 6.5: Incorrect Weather Routing (Blue:Depression, Red:Sailed route, Green:Proposed Route)

These two cases were not avoided for several reasons. The first reason is that the vessels do not yet use the weather routing tool in the correct way. Showing the captains the results with the help of the performance monitoring system will raise awareness and encourage better use of the tool. The second reason is that the planned route of the vessel is not yet available in the dashboard so it can not be predicted yet where the vessel will sail. This being said the planned route is scheduled to be implemented in the dashboards in the near

future which means this issue will be solved. The last reason is that the Spliethoff culture sees shore staff advise on sailing inferior to the skill of the ship crew when it comes to weather routing. While this might be true having multiple minds working together to optimise the performance has great potential as shown in the demonstrated cases. If we factor in the costs of a day of delay which lies around €15000 included missed revenue it can be seen that large optimisation is to be gained here. This means that for the routing to be optimised some company culture changes within Spliethoff are necessary.
How much value does this actually create for Spliethoff? To answer this question we look at the cases demonstrated above. There is a lot of value to be gained if the delays from these cases can be reduced or even eliminated when considering that a day of delay costs around €15000. If only one of these cases is prevented per ship per year the value created for a fleet of 60 vessels would already be €900,000 per year. This number can be achieved because since the implementation of the dashboard (period of one month) already four of these cases have presented itself for a performance monitoring fleet of 8 vessels. This is just counting the weather routing optimisation possibilities. The value created with more accurate planning, speed instruction optimisation and knowledge creation can be added on top of this. A conservative estimation for the potential value creation of €20000 per year per vessel can be realised, provided that Spliethoff is willing to change company culture slightly. Meaning that they are willing to follow up on the performance deficits by giving feedback to the crew on how to operate the vessel and to accept data driven decision making into their operations. This number is thus very sensitive to the effectiveness of the implementation[3]. The sensitivity will be further discussed in section 6.4.

The dashboard for the technical department at Spliethoff will convey different information than the one for the operators. The dashboard has not been implemented yet at the moment of this research project but an outline can be given of what the goal is of this dashboard and what is expected to be achieved with it.
The focus of this dashboard is on maintenance. The goal of the dashboard is to assist in the planning of maintenance and in doing so, reduce fuel consumption and costs caused by breakdowns. To achieve this, data from different systems will be blended so that they increase the knowledge contained within this data. The data from the performance monitoring system is to be blended with the condition monitoring data collected by the technical department. The weekly machinery condition reports or operational data records (ODR) are to be collected in a database after which trends can be created and visualised in the dashboard. This data can then also be enriched with the data from the performance monitoring system to reduce the uncertainty.
Firstly, there will be a visual indication of the hull and propeller fouling of the vessel. This visualisation will show the trend of the required fuel consumption or shaft power (dependent on the sensor configuration) to sail a certain speed at a small operational circumstances window. This will enable the users to see the effect of hull fouling on the fuel consumption or vessel speed and will help optimise the interval of hull and propeller cleaning.
Secondly, an indication of the main engine efficiency over time will be given in the form of the specific fuel consumption at certain operational conditions (e.g. at part load and at full load). This metric will only be available for vessels which are equipped with a torque sensor. This will give an indication of the main engine condition, for instance compression loss or scavenge air system problems.
Lastly, the trends from the condition monitoring data (ODR) will be visualised. This will give an indication of the condition of the machinery systems on board of the vessels. This could serve as diagnostics after a breakdown or to assist in planning preventive maintenance.
The amount of value that can be created with this dashboard is yet to be determined. To determine this, further research is firstly needed on the current state of Spliethoff's maintenance management and how condition monitoring will influence the maintenance. It can be said that the performance monitoring system offers the possibility to implement condition monitoring or a more data driven maintenance strategy like Reliability Centered Maintenance.
The value that can be gained with an optimised hull cleaning strategy is also yet to be determined since only one vessel with the performance monitoring system has docked. After the docking the vessel showed a fuel performance improvement of 8 percent but the longevity of this effect has not yet been determined since the docking was performed too recently. The fact that the performance monitoring system enables Spliethoff to do such an analysis means that it is possible to create value here. This value will come in the form of improved planning of hull cleaning which will lead to fuel cost savings.

[3] Since the implementation of the dashboard a large increase in awareness about routing has been seen. This has greatly improved the communication between vessel and shore and has started the dialogue between them in optimising routing.

Performance Dashboards on board the vessels

The most expertise about the operation of the vessels is found with the crew on board of the vessels. This is one of the reasons why it is so important to have tools on board of the vessel that provide performance information and thus enable the crew to optimise performance. In section 4.1 it is indicated that the current solution for the performance dashboard (also named performance indicating device) is ineffective in doing so. An improved dashboard is still under development but a concept is shown in figure 6.6. The dashboard will be displayed on a large screen suspended from the sealing on the bridge so it is clearly visible.

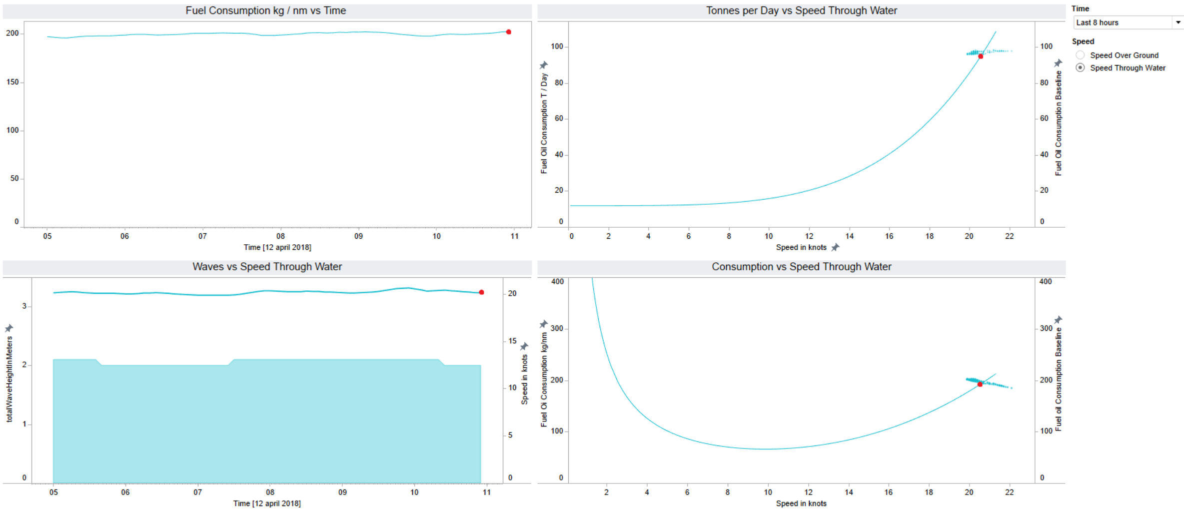

Figure 6.6: Dashboard Concept for on board the vessel (Red dot showing the current operational point)

The dashboard displays similar information as on the operators dashboard but on this dashboard the data will be live and the time series data will be displayed over a far shorter period. The dashboard enables the crew to see their performance compared to a specified baseline and to see the development of the performance over the past 8 hours. This means that they can see the effects of their inputs to the vessel on the performance of the vessels and to optimise the performance in a certain situation. It also enables them to sail at the correct ECO-speed since this speed is clearly indicated by the lowest point of the baseline in the bottom-right graph. It also introduces a competition element between the different different watches on board the vessel since it shows the performance of the previous 8 hours.

What this dashboard will mainly do is create awareness about performance on board of the vessel and give the information needed to optimise their performance. Since the added value of sailing at the correct ECO-speed has already been determined it is hard to judge the rest of the value that is created by this dashboard. If we assume that by providing the information needed to optimise performance and by the creation of awareness, only reduces the fuel consumption by half a percent, the value created by this fuel cost reduction will already range between €10000 and €30000 per year per vessel at a fuel price of $350 per tonne, depending on the vessel type.

Regulation, Reputation and External Value

Having accurate operational data on the vessels can also create value for Spliethoff when it comes to regulations. The European Union has the EU MRV where vessels are obligated to report on their emissions for voyages made to and from European ports. A similar regulation set up by the International Maritime Organisation (IMO), comes into force January 1st 2019. This emissions monitoring and reporting regulation is called the IMO DCS (Data Collection System). This regulation applies to the whole world and not just EU ports. The performance monitoring system could greatly reduce the administration work needed to comply with these regulations. The fuel consumption data that is required to be reported is automatically stored in a database from which the required data can easily or even automatically be published in reports. A note should be made that this is most effective when the entire fleet is included into the performance monitoring system. It would not be effective if only part of the fleet is included because then two different methods of reporting have to be set up and approved by the regulatory body. This being said, if it is decided to comply to this regulation with the use of the performance monitoring system the administrative man-hours can be reduced to practically zero. Depending on the amount of man-hours needed for the other reporting method the created value can be specified. The amount of man-hours cannot be specified yet since the regulations are not yet in effect. Having accurate operational data can also assist in claims against received fines or be used in preventing fines by showing how they occur. An example of this are fines that are given when a vessel is allegedly sailing in the wrong part of the traffic separation zones. Fines are often given out in the Baltic area but the captains often claim that they were sailing in the correct lane. The performance monitoring system could actually provide proof of this. The fine can then be fought or the captain can be addressed about the fact that he was actually sailing in the wrong lane and hopefully learn from the mistake. Other examples of this are the speed sailed in whale zones and fuel switchover or scrubber mode in emission control areas. How much value is to be created here can be quantified if the height of the fines, frequency of the fines and the frequency of false accusation is known. It is also unknown if authorities will accept the operational data as legitimate proof of not committing the offence. The quantitative value is thus not defined in this research but it should be noted that value is to be created here.

On the 13th of April 2018 the IMO publicly announced its target to reduce CO2 emissions from shipping by 50 percent in 2050 compared to 2008. Even though no regulations have been established as of yet to realise this target, it can be expected that this will follow as the target closes in. Spliethoff has on the same day set this target as well for their own company. Besides the fact that the performance management system can reduce the fuel consumption of the vessels and thus reduce CO2 emissions, performance monitoring is needed to accurately measure and quantify the CO2 emissions. Similar to the performance management system which will only be effective with the performance monitoring system, the reduction of CO2 emissions from operations will also only be effective with the performance monitoring system. How much value the performance monitoring system thus creates with respect to the CO2 reduction target is dependent on how much value is created for Spliethoff by realising this emission reduction target.
To determine this value, the scope of this analysis has to be widened to also analyse the value that is created for external stakeholders. What is the created value for external parties when Spliethoff reduces its emissions by 50 percent in 2050 or better yet, what is the value created for these external stakeholders for every tonne of fuel saved? Similar to how the reduction of fuel costs creates value for Spliethoff, the reduction of the external costs which are related to the consumption of fossil fuel creates value for society. The external costs are defined as the costs to a third party which are not covered by the price of the product that is consumed. In the case of fossil fuel consumption this is the costs or damages that the emissions of burning fossil fuels cause to for example the environment and health of the third party. Many of these damages and costs are non monetary and methods of monetising these costs have been the subject of many research projects. Commonly used methods are the "willingness to pay" or "willingness to receive" methods. In short, these methods try and determine what people are willing to pay to prevent for instance the emission of a tonne of CO2 or what they want to receive as compensation for the emission of a tonne of CO2 by another party.
Research into monetising the external costs or social costs of the emission of CO2 has led to the creation of the "carbon price". The carbon price is thus the monetary value which covers the external costs of a unit of CO2 emission. Nordhaus [2007] and Gerlagh and Liski [2018] both give similar estimations of this carbon price. They value the price of emitting one tonne of CO2 at around €14.50/tonneCO2 in 2018. Meaning that by every tonne of CO2 not emitted €14.50 in value is created. This number can be translated to Heavy Fuel Oil (HFO) by multiplying it with the carbon emission factor. This results in a value created per tonne of unburned HFO of around €46. A part of this value could then also be specified as value for Spliethoff in the shape of for example potential subsidising or when this target in emission reduction is made public, in the shape of improved reputation and increased demand for transport. Other externalities include all the other harmful constituents in exhaust gas that are not emitted by reducing fuel consumption. These include SOx, NOx and particulate matter. The value created by these can be determined with the same method as the CO2.

The improved reputation by reducing emissions has become more and more important in shipping. An example of this is the company Rightship. This company rates vessels in respects to several parameters like for example emissions, management, flag and state of the vessel. Poor ratings can lead to a lower demand for transport by that vessel. The problem with this is that Rightship bases there ratings on poor data. This causes vessels to be rated incorrectly. Accurate operational data can be used to fight bad ratings. Also showing that the company is actively working on improving performance already boosts the rating and thus the reputation. This could lead to higher demand for the vessels.
This value also extends to the freight owners. They might base their decisions on reputations and ratings.

Having owners like Spliethoff actively working on their reputation and ratings with accurate data will also decrease the risk for the freight owners of being wrongly informed. It also improves the reputation of the freight owner if he transports his goods environmentally friendly.
This value creation for the freight owner can be extended even further if information sharing is introduced. Knowledge about where the freight is located and the conditions the freight are in, can offer the freight owner a sense of security and allows him to make better plannings as well. A test has already been done with the measurements of accelerations on the cargo. Data and information sharing is becoming more and more important and enabling this with performance management thus also creates value for other stakeholders.

To further specify the created value for other stakeholders a full cost/benefit analysis is recommended. This is not done in this research because the goal was to determine the added value for Spliethoff directly. The above mentioned value is thus seen as an added bonus of which the scale will not be determined. This being said, it is clear that there is more value to be created than just direct monetary value with the use of performance management.

Total Created Value Potential

The created value determined in this section is a realistic estimation of how much value can be created with the performance management system. Table 6.10 gives an overview of the determined value creation potential. Not all of the value potentials in table 6.10 have been quantified. These will thus not be considered in the calculation of the total added value (NPV) but it should be noted that these might create even more value in the future. Also, even though the value created by emissions reductions is specified in the table, it will not be used in the added value calculations since it is value for a third party and the goal is to determine the internal added value for Spliethoff. It should also be noted that this value is only derived from cases where no further investment is needed. The value that can be realised with further knowledge creation should also not be forgotten even though this is not specified in table 6.10.

Table 6.10: Overview of Value Creation Potential (year:20018)

Value Creation Potential		
Value from Data Analysis		
Combinator Mode	52000USD/year per ship	Two out of Three ConRo vessels
Correct ECO-speed	14560USD/year per ship	Will vary per ship type
Performance Dashboards in the office		
Operators Voyage planning/routing	€20000/year per ship	
Tech. Dept. Fouling/Maintenance Planning	TBD	
Performance Dashboard on board		
Fuel Consumption Reduction due to Awareness	10000-30000USD/year per ship	Based on 0.5 percent savings
Regulations, Reputation, External		
EU MRV, IMO DSC	TBD	
Fines/Penalty Reduction	TBD	
Emissions Reduction	€46 per tonne fuel saved	Value for third party

It can be said that a large amount of potential value is to be realised with the performance management system. Especially considering that values derive from conservative estimates. As mentioned earlier it has to be noted that in order to realise this value potential, some changes are needed to the culture within Spliethoff. The culture has to shift to a more information sharing culture where the communication between the different parts of the organisation is improved. The performance management system also helps this drive towards better communication or even enables it by providing clear information which is easily available and easy to interpret. Making data driven decisions is also part of this shift in culture. When this is achieved the value creation shown above is realised and possibly even succeeded.

6.4. The added value

The added value can be determined now that both the costs and the value have been specified. This will be done by calculating the net present value (NPV) of the performance management system for different scenarios. The scenarios will also serve as a sensitivity analysis for created value. It will be assumed that the maximum running time of the performance management system is 10 years starting from the installation of the sensor and data-logger system. This is done because the expected lifetime of the sensor and data-logging system is 10 years. After these 10 years a full reinstallment is needed, but this will not be done in these scenarios. This means that the calculations will run until 10 years after the last sensor systems installation. All ships calculated with have a remaining life time of more than 10 years. Calculations will be done in Euro so all USD values are converted to Euro with an exchange rate of 1.23 Dollar per Euro (19-04-2018). In this section, firstly, the scenarios are defined, then the calculations are done and lastly, a discussion of the results is done.

Scenarios

Since the project is to last for 10 years and since there is still a lot of uncertainty in the implementation and effectiveness of the system, some scenarios should be determined. Most of the value creation is derived from fuel cost savings and the fuel price is very volatile. This should also be accounted for in the scenarios. The following parameters are to be varied in the scenarios: the fuel price, the size of the implemented fleet and the effectiveness of the performance management system. Also a low, middle and high discount rate is to be applied to these scenarios (3%, 6%, 9%).
Six scenarios are defined. There are three different scenarios which are done with both a large fleet and a small fleet implementation. This brings the total to six scenarios. There is the "base scenario" which keeps the fuel price fixed at $350 per tonne and assumes that all the specified value potential is utilised. The second scenarios will be the "pessimistic scenarios" where the fuel prices go down by 5 percent per year from their starting point of $350 per tonne and only 60 percent of the value potential is utilised. The last scenarios will be the "optimistic scenarios" where the fuel price will increase by 5 percent per year from its starting point of $350 per tonne and a 110 percent of the value potential will be utilised. The pessimistic and optimistic scenarios are to define the outside boundaries of what the expected result will be. Reality should lay somewhere in between this two boundaries. These three scenarios will thus be done for two fleet sizes. The large variant where 60 vessels will be in use after three years. 15 vessels in the first year, 35 in the second year. The small variant will assume 15 in the first year and 22 in the second year. These 22 vessels will consists of the Spliethoff S-types (14), the ConRo's (6) and HappyD-series(2). An overview of the scenarios is given in table 6.11.

Table 6.11: Scenarios for Net Present Value calculations

Scenarios			
Name	*Fleet size*	*Fuel Price*	*Effectiveness*
Base Scenario Large	60 after 3 years	350USD/tonne	100%
Base Scenario Small	22 after 2 years	350USD/tonne	100%
Pessimistic Case Large	60 after 3 years	Down 5% per year	60%
Pessimistic Case Small	22 after 2 years	Down 5% per year	60%
Optimistic Case Large	60 after 3 years	Up 5% per year	110%
Optimistic Case Small	22 after 2 years	Up 5% per year	110%

It is decided to equip all of the vessels with the minimum specification of the sensor system. This is done because the value the torque sensor can create has not yet been specified. The torque sensors can also installed at a later point in time when it is clear what value can be created with the torque sensor.

Added Value: Base Scenario Small

The determination of the added value is started with the small base scenario. This calculation will give an estimation of the added value when it is decided to only implement the largest consumers of the fleet into the performance management system. The calculations of the Net Present Value for this scenario are shown in figure 6.7. For these first calculations a discount rate of 6% is used. Bare in mind that this also includes the inflation.

Added Value (NPV): Base Scenario Small

	Created Value				Costs				Total		Discount Rate 6%			
Year	ConRO Combinator	ECO-Speed	Planning/Routing	Awareness	Development	CapEx	OpEx fixed	OpEx Variable	Yearly total	Cumulatively	DCF	DPV	NPV	R.O.I
0					€ 92.500,00	€ 303.645,00			€ -396.145,00	€ -396.145,00	€ -	€ -	€ -396.145,00	-74%
1	€ 84.552,00	€ 94.696,00	€ 200.000,00	€ 270.000,00		€ 141.701,00	€ 81.883,00	€ 41.730,00	€ 383.934,00	€ -12.211,00	€ 362.201,89	€ 362.201,89	€ -33.943,11	-2%
2	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 903.198,00	€ 1.176.912,64	€ 814.710,75	€ 780.767,64	168%
3	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 1.818.607,00	€ 1.945.507,69	€ 768.595,05	€ 1.549.362,69	338%
4	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 2.734.016,00	€ 2.670.597,35	€ 725.089,67	€ 2.274.452,35	508%
5	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 3.649.425,00	€ 3.354.644,21	€ 684.046,86	€ 2.958.499,21	679%
6	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 4.564.834,00	€ 3.999.971,43	€ 645.327,22	€ 3.603.826,43	849%
7	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 5.480.243,00	€ 4.608.770,70	€ 608.799,27	€ 4.212.625,70	1019%
8	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 6.395.652,00	€ 5.183.109,63	€ 574.338,93	€ 4.786.964,63	1189%
9	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 7.311.061,00	€ 5.724.938,81	€ 541.829,18	€ 5.328.793,81	1359%
10	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 8.226.470,00	€ 6.236.098,42	€ 511.159,60	€ 5.839.953,42	1530%
11	€ 84.552,00	€ 94.696,00	€ 80.000,00	€ 150.000,00			€ 81.883,00	€ 19.474,00	€ 307.891,00	€ 8.534.361,00	€ 6.398.291,56	€ 162.193,14	€ 6.002.146,56	1587%
12									€ -	€ 8.534.361,00	€ 6.398.291,56	€ -	€ 6.002.146,56	1587%
13									€ -	€ 8.534.361,00	€ 6.398.291,56	€ -	€ 6.002.146,56	1587%
14									€ -	€ 8.534.361,00	€ 6.398.291,56	€ -	€ 6.002.146,56	1587%
15									€ -	€ 8.534.361,00	€ 6.398.291,56	€ -	€ 6.002.146,56	1587%
Total	€ 1.691.040,00	€ 1.893.920,00	€ 2.800.000,00	€ 4.200.000,00	€ 92.500,00	€ 445.346,00	€ 900.713,00	€ 612.040,00	€ 8.534.361,00					

Figure 6.7: Net Present Value Calculation for a small fleet base scenario

It can be seen that already early in year two the NPV is zero. Meaning that the project has almost paid itself off after a bit more than one year. The total NPV after 11 years is €6,000,193. Meaning that the performance management system is a great investment in this scenario, especially considering the small investment of almost €550,000

It should be said that in this scenario it is assumed that the performance management system is fully effective right from the implementation of the sensors on the vessels. This might not be a realistic assumption. Time is needed to create baselines, do the data analysis and for the crew to get used to the system. For this reason we assume that in the first two years the performance management system is only 50 percent effective. The implemented start up effects give the following results as shown in figure 6.8. Even though the results are less high than without the start up effects the performance management still shows a positive NPV in the second year. The final NPV after 11 years is €5,220,172 which is a great result for such a small investment.

Added Value (NPV): Base Scenario Small with Start up Effects

	Created Value				Costs				Total		Discount Rate 6%			
Year	ConRO Combinator	ECO-Speed	Planning/Routing	Awareness	Development	CapEx	OpEx fixed	OpEx Variable	Yearly total	Cumulatively	DCF	DPV	NPV	R.O.I
0					€ 92.500,00	€ 303.645,00			€ -396.145,00	€ -396.145,00	€ -	€ -	€ -396.145,00	-74%
1	€ 42.250,00	€ 47.300,00	€ 100.000,00	€ 135.000,00		€ 141.701,00	€ 81.883,00	€ 41.730,00	€ 59.236,00	€ -336.909,00	€ 55.883,02	€ 55.883,02	€ -340.261,98	-63%
2	€ 84.550,00	€ 89.500,00	€ 140.000,00	€ 210.000,00			€ 81.883,00	€ 61.204,00	€ 380.963,00	€ 44.054,00	€ 394.938,73	€ 339.055,71	€ -1.206,27	8%
3	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 959.463,00	€ 1.163.533,78	€ 768.595,05	€ 767.388,78	178%
4	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 1.874.872,00	€ 1.888.623,45	€ 725.089,67	€ 1.492.478,45	349%
5	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 2.790.281,00	€ 2.572.670,31	€ 684.046,86	€ 2.176.525,31	519%
6	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 3.705.690,00	€ 3.217.997,53	€ 645.327,22	€ 2.821.852,53	689%
7	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 4.621.099,00	€ 3.826.796,80	€ 608.799,27	€ 3.430.651,80	859%
8	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 5.536.508,00	€ 4.401.135,73	€ 574.338,93	€ 4.004.990,73	1029%
9	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 6.451.917,00	€ 4.942.964,91	€ 541.829,18	€ 4.546.819,91	1200%
10	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 81.883,00	€ 61.204,00	€ 915.409,00	€ 7.367.326,00	€ 5.454.124,51	€ 511.159,60	€ 5.057.979,51	1370%
11	€ 84.552,00	€ 94.696,00	€ 80.000,00	€ 150.000,00			€ 81.883,00	€ 19.474,00	€ 307.891,00	€ 7.675.217,00	€ 5.616.317,65	€ 162.193,14	€ 5.220.172,65	1427%
12									€ -	€ 7.675.217,00	€ 5.616.317,65	€ -	€ 5.220.172,65	1427%
13									€ -	€ 7.675.217,00	€ 5.616.317,65	€ -	€ 5.220.172,65	1427%
14									€ -	€ 7.675.217,00	€ 5.616.317,65	€ -	€ 5.220.172,65	1427%
15									€ -	€ 7.675.217,00	€ 5.616.317,65	€ -	€ 5.220.172,65	1427%
Total	€ 1.564.184,00	€ 1.746.632,00	€ 2.560.000,00	€ 3.855.000,00	€ 92.500,00	€ 445.346,00	€ 900.713,00	€ 612.040,00	€ 7.675.217,00					

Figure 6.8: Net Present Value Calculation for a small fleet base scenario with start up effects

Added Value: Base Scenario Large

The same base scenario is repeated but in this case with a larger fleet. This will require a larger investment but should also yield larger returns. The results are shown in figure 6.9.

Added Value (NPV): Base Scenario Large

	Created Value				Costs				Total		Discount Rate 6%			
Year	ConRO Combinator	ECO-Speed	Planning/Routing	Awareness	Development	CapEx	OpEx fixed	OpEx Variable	Yearly total	Cumulatively	DCF	DPV	NPV	R.O.I
0					€ 92.500,00	€ 303.645,00			€ -396.145,00	€ -396.145,00	€ -	€ -	€ -396.145,00	-30%
1	€ 84.552,00	€ 118.374,00	€ 200.000,00	€ 270.000,00		€ 404.860,00	€ 81.883,00	€ 41.730,00	€ 144.453,00	€ -251.692,00	€ 136.276,42	€ 136.276,42	€ -259.868,58	-19%
2	€ 169.104,00	€ 295.935,00	€ 500.000,00	€ 470.000,00		€ 506.075,00	€ 81.883,00	€ 97.370,00	€ 749.711,00	€ 498.019,00	€ 803.516,54	€ 667.240,12	€ 407.371,54	38%
3	€ 169.104,00	€ 532.683,00	€ 900.000,00	€ 720.000,00			€ 81.883,00	€ 166.920,00	€ 2.072.984,00	€ 2.571.003,00	€ 2.544.033,88	€ 1.740.517,34	€ 2.147.888,88	197%
4	€ 169.104,00	€ 532.683,00	€ 900.000,00	€ 720.000,00			€ 81.883,00	€ 166.920,00	€ 2.072.984,00	€ 4.643.987,00	€ 4.186.031,37	€ 1.641.997,49	€ 3.789.886,37	355%
5	€ 169.104,00	€ 532.683,00	€ 900.000,00	€ 720.000,00			€ 81.883,00	€ 166.920,00	€ 2.072.984,00	€ 6.716.971,00	€ 5.735.085,60	€ 1.549.054,24	€ 5.338.940,60	514%
6	€ 169.104,00	€ 532.683,00	€ 900.000,00	€ 720.000,00			€ 81.883,00	€ 166.920,00	€ 2.072.984,00	€ 8.789.955,00	€ 7.196.457,52	€ 1.461.371,92	€ 6.800.312,52	672%
7	€ 169.104,00	€ 532.683,00	€ 900.000,00	€ 720.000,00			€ 81.883,00	€ 166.920,00	€ 2.072.984,00	€ 10.862.939,00	€ 8.575.110,28	€ 1.378.652,76	€ 8.178.965,28	831%
8	€ 169.104,00	€ 532.683,00	€ 900.000,00	€ 720.000,00			€ 81.883,00	€ 166.920,00	€ 2.072.984,00	€ 12.935.923,00	€ 9.875.726,09	€ 1.300.615,81	€ 9.479.581,09	990%
9	€ 169.104,00	€ 532.683,00	€ 900.000,00	€ 720.000,00			€ 81.883,00	€ 166.920,00	€ 2.072.984,00	€ 15.008.907,00	€ 11.102.722,13	€ 1.226.996,04	€ 10.706.577,13	1148%
10	€ 169.104,00	€ 532.683,00	€ 900.000,00	€ 720.000,00			€ 81.883,00	€ 166.920,00	€ 2.072.984,00	€ 17.081.891,00	€ 12.260.265,57	€ 1.157.543,44	€ 11.864.120,57	1307%
11	€ 84.552,00	€ 414.309,00	€ 700.000,00	€ 450.000,00			€ 81.883,00	€ 125.190,00	€ 1.441.788,00	€ 18.523.679,00	€ 13.019.781,50	€ 759.515,93	€ 12.623.636,50	1417%
12		€ 118.374,00	€ 200.000,00	€ 200.000,00			€ 81.883,00	€ 69.550,00	€ 366.941,00	€ 18.890.620,00	€ 13.202.139,94	€ 182.358,44	€ 12.805.994,94	1445%
13									€ -	€ 18.890.620,00	€ 13.202.139,94	€ -	€ 12.805.994,94	1445%
14									€ -	€ 18.890.620,00	€ 13.202.139,94	€ -	€ 12.805.994,94	1445%
15									€ -	€ 18.890.620,00	€ 13.202.139,94	€ -	€ 12.805.994,94	1445%
Total	€ 1.691.040,00	€ 5.208.456,00	€ 8.800.000,00	€ 7.150.000,00	€ 92.500,00	€ 1.214.580,00	€ 982.596,00	€ 1.669.200,00	€ 18.890.620,00					

Figure 6.9: Net Present Value Calculation for a large fleet base scenario

What can be seen is that the "ConRo Combinator" does not scale with the increasing fleet size. This is because there are not more of these type of vessels in the fleet. This being said the returns are still very large with a total NPV after 12 years of €12,805,994 against a total investment of €1,300,000. This shows that the return on investment is slightly lower than with the small fleet. The reason for this is that the rest of the fleet are smaller consumers and the value created by the ConRo vessels does not scale any further.

Added Value: Pessimistic Scenario, Small Fleet

The next scenario describes a scenario where only 60% of the potential value is realised and where the fuel prices drop with 5% every year. The 5% drop in fuel price is plausible due to the upcoming sulphur emission regulations and Spliethoff has its fleet equipped with scrubbers allowing them to keep using high sulphur fuels. The results of this scenario are shown in figure 6.10.
The results are lower but the project still breaks even after less than 2 years. The NPV after 11 years is €2,165,970 which is still high considering the small investment required.

Added Value (NPV): Pessimistic Scenario Small

	Created Value				Costs				Total		Discount Rate 6%			
Year	ConRO Combinator	ECO-Speed	Planning/Routing	Awareness	Development	CapEx	OpEx fixed	OpEx Variable	Yearly total	Cumulatively	DCF	DPV	NPV	R.O.I
0					€ 92.500,00	€ 303.645,00			€ -396.145,00	€ -396.145,00	€ -	€ -	€ -396.145,00	-74%
1	€ 48.194,00	€ 53.976,00	€ 120.000,00	€ 153.900,00		€ 141.701,00	€ 81.883,00	€ 41.730,00	€ 110.756,00	€ -285.389,00	€ 104.486,79	€ 104.486,79	€ -291.658,21	-53%
2	€ 91.569,00	€ 102.555,00	€ 168.000,00	€ 227.430,00			€ 81.883,00	€ 61.204,00	€ 446.467,00	€ 161.078,00	€ 501.840,83	€ 397.354,04	€ 105.695,83	30%
3	€ 86.991,00	€ 97.427,00	€ 168.000,00	€ 216.058,00			€ 81.883,00	€ 61.204,00	€ 425.389,00	€ 586.467,00	€ 859.005,64	€ 357.164,81	€ 462.860,64	109%
4	€ 82.641,00	€ 92.556,00	€ 168.000,00	€ 205.255,00			€ 81.883,00	€ 61.204,00	€ 405.365,00	€ 991.832,00	€ 1.180.092,69	€ 321.087,05	€ 783.947,69	184%
5	€ 78.509,00	€ 87.928,00	€ 168.000,00	€ 194.992,00			€ 81.883,00	€ 61.204,00	€ 386.342,00	€ 1.378.174,00	€ 1.468.789,91	€ 288.697,22	€ 1.072.644,91	256%
6	€ 74.584,00	€ 83.532,00	€ 168.000,00	€ 185.243,00			€ 81.883,00	€ 61.204,00	€ 368.272,00	€ 1.746.446,00	€ 1.728.407,13	€ 259.617,23	€ 1.332.262,13	325%
7	€ 70.854,00	€ 79.355,00	€ 168.000,00	€ 175.980,00			€ 81.883,00	€ 61.204,00	€ 351.102,00	€ 2.097.548,00	€ 1.961.910,02	€ 233.502,88	€ 1.565.765,02	390%
8	€ 67.312,00	€ 75.387,00	€ 168.000,00	€ 167.181,00			€ 81.883,00	€ 61.204,00	€ 334.793,00	€ 2.432.341,00	€ 2.171.963,29	€ 210.053,27	€ 1.775.818,29	452%
9	€ 63.946,00	€ 71.618,00	€ 168.000,00	€ 158.822,00			€ 81.883,00	€ 61.204,00	€ 319.299,00	€ 2.751.640,00	€ 2.360.955,87	€ 188.992,59	€ 1.964.810,87	512%
10	€ 60.749,00	€ 68.037,00	€ 168.000,00	€ 150.881,00			€ 81.883,00	€ 61.204,00	€ 304.580,00	€ 3.056.220,00	€ 2.531.031,75	€ 170.075,88	€ 2.134.886,75	568%
11	€ 28.855,00	€ 32.317,00	€ 48.000,00	€ 51.192,00			€ 81.883,00	€ 19.474,00	€ 59.007,00	€ 3.115.227,00	€ 2.562.115,91	€ 31.084,15	€ 2.165.970,91	579%
12									€ -	€ 3.115.227,00	€ 2.562.115,91	€ -	€ 2.165.970,91	579%
13									€ -	€ 3.115.227,00	€ 2.562.115,91	€ -	€ 2.165.970,91	579%
14									€ -	€ 3.115.227,00	€ 2.562.115,91	€ -	€ 2.165.970,91	579%
15									€ -	€ 3.115.227,00	€ 2.562.115,91	€ -	€ 2.165.970,91	579%
Total	€ 754.204,00	€ 844.688,00	€ 1.680.000,00	€ 1.886.934,00	€ 92.500,00	€ 445.346,00	€ 900.713,00	€ 612.040,00	€ 3.115.227,00					

Figure 6.10: Net Present Value Calculation for a small fleet pessimistic scenario

This means that even in a bad scenario a lot of added value is to be created with this project. This reduces the risk connected to this investment considerably.

Added Value: Pessimistic Scenario, Large Fleet

This pessimistic scenario is also performed for the large fleet. Will the reduced value creation be enough to way up against the higher costs required for the total fleet? The answer is shown in figure 6.11 and the short answer is yes.

Added Value (NPV): Pessimistic Scenario Large

	Created Value				Costs				Total		Discount Rate 6%			
Year	ConRO Combinator	ECO-Speed	Planning/Routing	Awareness	Development	CapEx	OpEx fixed	OpEx Variable	Yearly total	Cumulatively	DCF	DPV	NPV	R.O.I
0					€ 92.500,00	€ 303.645,00			€ -396.145,00	€ -396.145,00	€ -	€ -	€ -396.145,00	-30%
1	€ 48.194,00	€ 67.473,00	€ 120.000,00	€ 153.900,00		€ 404.860,00	€ 81.883,00	€ 41.730,00	€ -138.906,00	€ -535.051,00	€ -131.043,40	€ -131.043,40	€ -527.188,40	-41%
2	€ 91.569,00	€ 160.248,00	€ 300.000,00	€ 254.505,00		€ 506.075,00	€ 81.883,00	€ 97.370,00	€ 120.994,00	€ -414.057,00	€ -23.359,17	€ 107.684,23	€ -419.504,17	-32%
3	€ 86.991,00	€ 274.025,00	€ 540.000,00	€ 370.386,00			€ 81.883,00	€ 166.920,00	€ 1.022.599,00	€ 608.542,00	€ 835.234,67	€ 858.593,84	€ 439.089,67	47%
4	€ 82.641,00	€ 260.324,00	€ 540.000,00	€ 351.866,00			€ 81.883,00	€ 166.920,00	€ 986.028,00	€ 1.594.570,00	€ 1.616.261,20	€ 781.026,53	€ 1.220.116,20	122%
5	€ 78.509,00	€ 247.307,00	€ 540.000,00	€ 334.273,00			€ 81.883,00	€ 166.920,00	€ 951.286,00	€ 2.545.856,00	€ 2.327.117,44	€ 710.856,24	€ 1.930.972,44	195%
6	€ 74.584,00	€ 234.942,00	€ 540.000,00	€ 317.559,00			€ 81.883,00	€ 166.920,00	€ 918.282,00	€ 3.464.138,00	€ 2.974.470,02	€ 647.352,57	€ 2.578.325,02	265%
7	€ 70.854,00	€ 223.195,00	€ 540.000,00	€ 301.681,00			€ 81.883,00	€ 166.920,00	€ 886.927,00	€ 4.351.065,00	€ 3.564.327,13	€ 589.857,11	€ 3.168.182,13	333%
8	€ 67.312,00	€ 212.035,00	€ 540.000,00	€ 286.597,00			€ 81.883,00	€ 166.920,00	€ 857.141,00	€ 5.208.206,00	€ 4.102.107,99	€ 537.780,87	€ 3.705.962,99	398%
9	€ 63.946,00	€ 201.433,00	€ 540.000,00	€ 272.267,00			€ 81.883,00	€ 166.920,00	€ 828.843,00	€ 6.037.049,00	€ 4.592.698,89	€ 490.590,90	€ 4.196.553,89	462%
10	€ 60.749,00	€ 191.362,00	€ 540.000,00	€ 258.654,00			€ 81.883,00	€ 166.920,00	€ 801.962,00	€ 6.839.011,00	€ 5.040.510,28	€ 447.811,39	€ 4.644.365,28	523%
11	€ 28.855,00	€ 148.837,00	€ 420.000,00	€ 153.576,00			€ 81.883,00	€ 125.190,00	€ 544.195,00	€ 7.383.206,00	€ 5.327.185,42	€ 286.675,14	€ 4.931.040,42	565%
12		€ 38.378,00	€ 120.000,00	€ 64.843,00			€ 81.883,00	€ 69.550,00	€ 71.788,00	€ 7.454.994,00	€ 5.362.861,86	€ 35.676,44	€ 4.966.716,86	570%
13									€ -	€ 7.454.994,00	€ 5.362.861,86	€ -	€ 4.966.716,86	570%
14									€ -	€ 7.454.994,00	€ 5.362.861,86	€ -	€ 4.966.716,86	570%
15									€ -	€ 7.454.994,00	€ 5.362.861,86	€ -	€ 4.966.716,86	570%
Total	€ 754.204,00	€ 2.259.559,00	€ 5.280.000,00	€ 3.120.107,00	€ 92.500,00	€ 1.214.580,00	€ 982.596,00	€ 1.669.200,00	€ 7.454.994,00					

Figure 6.11: Net Present Value Calculation for a large fleet pessimistic scenario

Even though the project does not break even until half way into year three, the total added value (NPV) still sums up to €4,966,716. What can be seen in the pessimistic and large scenarios is that the planning and routing creates the highest total value. This is because the value created with the reduction of delays is not dependent on the fuel price but on the lost income and vessel costs.

Added Value: Optimistic Scenario, Small Fleet

In the optimistic scenario 10% more value is realised than in the base scenario and the fuel prices will rise with 5% every year. The results are shown in figure 6.12. In this scenario the break even point is already within the first year of the project. The total NPV after 11 years is €8,711,272, which is around €3,500,000 more than the base scenario. The optimistic scenarios are done to give an indication of how quick the added value can increase due to the low costs of the performance management.

Added Value (NPV): Optimistic Scenario, Small Fleet

	Created Value				Costs				Total		Discount Rate 6%			
Year	ConRO Combinator	ECO-Speed	Planning/Routing	Awareness	Development	CapEx	OpEx fixed	OpEx Variable	Yearly total	Cumulatively	DCF	DPV	NPV	R.O.I
0					€ 92.500,00	€ 303.645,00			€ -396.145,00	€ -396.145,00	€ -	€ -	€ -396.145,00	-74%
1	€ 97.657,00	€ 109.373,00	€ 220.000,00	€ 311.850,00		€ 141.701,00	€ 81.883,00	€ 41.730,00	€ 473.566,00	€ 77.421,00	€ 446.760,38	€ 446.760,38	€ 50.615,38	14%
2	€ 205.080,00	€ 229.685,00	€ 308.000,00	€ 509.355,00			€ 81.883,00	€ 61.204,00	€ 1.109.033,00	€ 1.186.454,00	€ 1.433.795,80	€ 987.035,42	€ 1.037.650,80	221%
3	€ 215.334,00	€ 241.169,00	€ 308.000,00	€ 534.822,00			€ 81.883,00	€ 61.204,00	€ 1.156.238,00	€ 2.342.692,00	€ 2.404.595,52	€ 970.799,72	€ 2.008.450,52	436%
4	€ 226.101,00	€ 253.227,00	€ 308.000,00	€ 561.563,00			€ 81.883,00	€ 61.204,00	€ 1.205.804,00	€ 3.548.496,00	€ 3.359.705,23	€ 955.109,71	€ 2.963.560,23	660%
5	€ 237.406,00	€ 265.889,00	€ 308.000,00	€ 589.642,00			€ 81.883,00	€ 61.204,00	€ 1.257.850,00	€ 4.806.346,00	€ 4.299.643,92	€ 939.938,69	€ 3.903.498,92	894%
6	€ 249.272,00	€ 279.183,00	€ 308.000,00	€ 619.124,00			€ 81.883,00	€ 61.204,00	€ 1.312.492,00	€ 6.118.838,00	€ 5.224.898,99	€ 925.255,07	€ 4.828.753,99	1138%
7	€ 261.740,00	€ 293.142,00	€ 308.000,00	€ 650.080,00			€ 81.883,00	€ 61.204,00	€ 1.369.875,00	€ 7.488.713,00	€ 6.135.944,10	€ 911.045,11	€ 5.739.799,10	1392%
8	€ 274.827,00	€ 307.800,00	€ 308.000,00	€ 682.584,00			€ 81.883,00	€ 61.204,00	€ 1.430.124,00	€ 8.918.837,00	€ 7.033.221,59	€ 897.277,49	€ 6.637.076,59	1658%
9	€ 288.569,00	€ 323.190,00	€ 308.000,00	€ 716.713,00			€ 81.883,00	€ 61.204,00	€ 1.493.385,00	€ 10.412.222,00	€ 7.917.153,88	€ 883.932,29	€ 7.521.008,88	1936%
10	€ 302.997,00	€ 339.349,00	€ 308.000,00	€ 752.549,00			€ 81.883,00	€ 61.204,00	€ 1.559.808,00	€ 11.972.030,00	€ 8.788.142,52	€ 870.988,64	€ 8.391.997,52	2226%
11	€ 159.073,00	€ 178.158,00	€ 88.000,00	€ 282.205,00			€ 81.883,00	€ 19.474,00	€ 606.079,00	€ 12.578.109,00	€ 9.107.417,38	€ 319.274,86	€ 8.711.272,38	2339%
12									€ -	€ 12.578.109,00	€ 9.107.417,38	€ -	€ 8.711.272,38	2339%
13									€ -	€ 12.578.109,00	€ 9.107.417,38	€ -	€ 8.711.272,38	2339%
14									€ -	€ 12.578.109,00	€ 9.107.417,38	€ -	€ 8.711.272,38	2339%
15									€ -	€ 12.578.109,00	€ 9.107.417,38	€ -	€ 8.711.272,38	2339%
Total	€ 2.518.056,00	€ 2.820.165,00	€ 3.080.000,00	€ 6.210.487,00	€ 92.500,00	€ 445.346,00	€ 900.713,00	€ 612.040,00	€ 12.578.109,00					

Figure 6.12: Net Present Value Calculation for a small fleet optimistic scenario

Added Value: Optimistic Scenario, Large Fleet

Lastly, the same optimistic scenario is performed for the large fleet implementation. The results are shown in figure 6.13.

Added Value (NPV): Optimistic Scenario, Large Fleet

	Created Value				Costs				Total		Discount Rate 6%			
Year	ConRO Combinator	ECO-Speed	Planning/Routing	Awareness	Development	CapEx	OpEx fixed	OpEx Variable	Yearly total	Cumulatively	DCF	DPV	NPV	R.O.I
0					€ 92.500,00	€ 303.645,00			€ -396.145,00	€ -396.145,00	€ -	€ -	€ -396.145,00	-30%
1	€ 97.657,00	€ 136.721,00	€ 220.000,00	€ 311.850,00		€ 404.860,00	€ 81.883,00	€ 41.730,00	€ 237.755,00	€ -158.390,00	€ 224.297,17	€ 224.297,17	€ -171.847,83	-12%
2	€ 205.080,00	€ 358.895,00	€ 550.000,00	€ 569.992,00		€ 506.075,00	€ 81.883,00	€ 97.370,00	€ 998.639,00	€ 840.249,00	€ 1.113.082,32	€ 888.785,15	€ 716.937,32	64%
3	€ 215.334,00	€ 678.311,00	€ 990.000,00	€ 916.839,00			€ 81.883,00	€ 166.920,00	€ 2.551.681,00	€ 3.391.930,00	€ 3.255.522,90	€ 2.142.440,57	€ 2.859.377,90	260%
4	€ 226.101,00	€ 712.227,00	€ 990.000,00	€ 962.680,00			€ 81.883,00	€ 166.920,00	€ 2.642.205,00	€ 6.034.135,00	€ 5.348.396,73	€ 2.092.873,84	€ 4.952.251,73	462%
5	€ 237.406,00	€ 747.838,00	€ 990.000,00	€ 1.010.814,00			€ 81.883,00	€ 166.920,00	€ 2.737.255,00	€ 8.771.390,00	€ 7.393.832,90	€ 2.045.436,17	€ 6.997.687,90	671%
6	€ 249.272,00	€ 785.230,00	€ 990.000,00	€ 1.061.355,00			€ 81.883,00	€ 166.920,00	€ 2.837.054,00	€ 11.608.444,00	€ 9.393.844,02	€ 2.000.011,12	€ 8.997.699,02	888%
7	€ 261.740,00	€ 824.492,00	€ 990.000,00	€ 1.114.423,00			€ 81.883,00	€ 166.920,00	€ 2.941.852,00	€ 14.550.296,00	€ 11.350.343,62	€ 1.956.499,60	€ 10.954.198,62	1113%
8	€ 274.827,00	€ 865.716,00	€ 990.000,00	€ 1.170.144,00			€ 81.883,00	€ 166.920,00	€ 3.051.884,00	€ 17.602.180,00	€ 13.265.133,40	€ 1.914.789,78	€ 12.868.988,40	1347%
9	€ 288.569,00	€ 909.002,00	€ 990.000,00	€ 1.228.651,00			€ 81.883,00	€ 166.920,00	€ 3.167.419,00	€ 20.769.599,00	€ 15.139.923,84	€ 1.874.790,44	€ 14.743.778,84	1589%
10	€ 302.997,00	€ 954.452,00	€ 990.000,00	€ 1.290.084,00			€ 81.883,00	€ 166.920,00	€ 3.288.730,00	€ 24.058.329,00	€ 16.976.333,50	€ 1.836.409,65	€ 16.580.188,50	1841%
11	€ 159.073,00	€ 779.469,00	€ 770.000,00	€ 846.617,00			€ 81.883,00	€ 125.190,00	€ 2.348.086,00	€ 26.406.415,00	€ 18.213.275,91	€ 1.236.942,41	€ 17.817.130,91	2020%
12		€ 233.840,00	€ 220.000,00	€ 395.088,00			€ 81.883,00	€ 69.550,00	€ 697.495,00	€ 27.103.910,00	€ 18.559.909,56	€ 346.633,65	€ 18.163.764,56	2074%
13									€ -	€ 27.103.910,00	€ 18.559.909,56	€ -	€ 18.163.764,56	2074%
14									€ -	€ 27.103.910,00	€ 18.559.909,56	€ -	€ 18.163.764,56	2074%
15									€ -	€ 27.103.910,00	€ 18.559.909,56	€ -	€ 18.163.764,56	2074%
Total	€ 2.518.056,00	€ 7.986.193,00	€ 9.680.000,00	€ 10.878.537,00	€ 92.500,00	€ 1.214.580,00	€ 982.596,00	€ 1.669.200,00	€ 27.103.910,00					

Figure 6.13: Net Present Value Calculation for a large fleet optimistic scenario

The results in this case indicate the extreme example of the potential value realisation of performance management. The NPV after 12 years is €18,163,764 with a break even point early in the second year.

6.5. Sensitivity Analysis

In order to give more depth to the results of section 6.4 a sensitivity analysis is done. This will give a deeper view of the influence of certain parameters on the results. Even though the scenarios already give an indication of this since it also varies the parameters, analysing the parameters separately will give increased insight. Only the small base scenario will be used for the sensitivity analysis since this is closest to the reality of implementation at Spliethoff for the coming years. The NPV of this case was €6,000,193 after 11 years. This sensitivity analysis is performed in a more qualitative way. Meaning that more attention is given to the meaning behind the variation than taking a large scope of variations.

First of all, the influence of the discount rate is analysed. At a discount rate of 3% the NPV is €7,118,911 compared to €6,000,193 at 6%. At 9% the NPV is €5,110,362. Even a discount rate of 15% results in a NPV of €3,800,000. Meaning that the risk of the investment is low and that even when the company is performing extremely well with investing in other projects the investment will still create added value.

The second thing that is analysed is the influence of the OpEx. What if the OpEx are increased to the maximum value as indicated in table 6.9. This would mean that a larger performance team would be hired to manage the performance data with the help of an expensive third party performance monitoring system. The results shown in figure 6.14 show that even with around double the operational expenditure the project still creates an added value of €4,617,768. Showing that the project is not very sensitive to operational costs due to the high value creation potential. It should be noted that the NPV of the project is still almost €1,400,000 lower than the base scenario.

	Created Value				Costs				Total		6%			
Year	ConRO Combinator	ECO-Speed	Planning/Routing	Awareness	Development	CapEx	OpEx fixed	OpEx Variable	Yearly total	Cumulatively	DCF	DPV	NPV	R.O.I
0					€ 92.500,00	€ 303.645,00			€ -396.145,00	€ -396.145,00	€ -	€ -	€ -396.145,00	-74%
1	€ 84.552,00	€ 94.696,00	€ 200.000,00	€ 270.000,00		€ 141.701,00	€ 163.000,00	€ 111.975,00	€ 232.572,00	€ -163.573,00	€ 219.407,55	€ 219.407,55	€ -176.737,45	-30%
2	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 163.000,00	€ 164.230,00	€ 731.266,00	€ 567.693,00	€ 870.231,68	€ 650.824,14	€ 474.086,68	106%
3	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 163.000,00	€ 164.230,00	€ 731.266,00	€ 1.298.959,00	€ 1.484.216,72	€ 613.985,03	€ 1.088.071,72	242%
4	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 163.000,00	€ 164.230,00	€ 731.266,00	€ 2.030.225,00	€ 2.063.447,88	€ 579.231,16	€ 1.667.302,88	377%
5	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 163.000,00	€ 164.230,00	€ 731.266,00	€ 2.761.491,00	€ 2.609.892,38	€ 546.444,50	€ 2.213.747,38	513%
6	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 163.000,00	€ 164.230,00	€ 731.266,00	€ 3.492.757,00	€ 3.125.406,05	€ 515.513,67	€ 2.729.261,05	649%
7	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 163.000,00	€ 164.230,00	€ 731.266,00	€ 4.224.023,00	€ 3.611.739,71	€ 486.333,66	€ 3.215.594,71	785%
8	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 163.000,00	€ 164.230,00	€ 731.266,00	€ 4.955.289,00	€ 4.070.545,04	€ 458.805,34	€ 3.674.400,04	921%
9	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 163.000,00	€ 164.230,00	€ 731.266,00	€ 5.686.555,00	€ 4.503.380,27	€ 432.835,22	€ 4.107.235,27	1057%
10	€ 169.104,00	€ 189.392,00	€ 280.000,00	€ 420.000,00			€ 163.000,00	€ 164.230,00	€ 731.266,00	€ 6.417.821,00	€ 4.911.715,38	€ 408.335,11	€ 4.515.570,38	1193%
11	€ 84.552,00	€ 94.696,00	€ 80.000,00	€ 150.000,00			€ 163.000,00	€ 52.255,00	€ 193.993,00	€ 6.611.814,00	€ 5.013.908,47	€ 102.193,09	€ 4.617.763,47	1229%
12									€ -	€ 6.611.814,00	€ 5.013.908,47	€ -	€ 4.617.763,47	1229%
13									€ -	€ 6.611.814,00	€ 5.013.908,47	€ -	€ 4.617.763,47	1229%
14									€ -	€ 6.611.814,00	€ 5.013.908,47	€ -	€ 4.617.763,47	1229%
15									€ -	€ 6.611.814,00	€ 5.013.908,47	€ -	€ 4.617.763,47	1229%
Total	€ 1.691.040,00	€ 1.893.920,00	€ 2.800.000,00	€ 4.200.000,00	€ 92.500,00	€ 445.346,00	€ 1.793.000,00	€ 1.642.300,00	€ 6.611.814,00					

Figure 6.14: NPV with maximum operational expenditure

Now what if awareness creation on board the vessels does not lead to half a percent of fuel cost reduction? To analyse this we simply remove the value created by awareness. In this case the NPV of the project is €2,973,401

and the project still breaks even in year two. Meaning that even though no further value is created besides the other cases the project still creates added value for Spliethoff.
This insight is important because the half percent fuel saving by awareness was the most uncertain estimate. The other value creation cases are supported by actual operational data. This being said, it is believed that this half percent fuel saving by creating awareness can be achieved.

The fuel price is an important parameters in this project since most of the value potential is derived from reducing fuel costs. The NPV and year of break even are shown in table 6.12. From the results it can be seen that a rising fuel price results in an added value price of nearly the same factor. A decrease in fuel price does not show the same behaviour because then the value creation potential that is not dependent on the fuel price becomes dominant.
Even at the lowest fuel price the project still breaks even in year three and creates a total added value of €1,209,262.

Table 6.12: Sensitivity to fuel price

Sensitivity of fuel price		
Fuel Price in $ per tonne	*NPV in €*	*Year of Break Even*
50	1,209,262	3
175	3,205,831	2
250	4,402,654	2
350	6,000,193	2
450	7,601,638	1
550	9,195,538	1

Since non of the results have shown a negative result, the last analysis will find the minimum yearly value realisation needed for the project to break even after 5 years.
To break even after 5 years for the small base scenario, €265,504 of yearly value has to be realised. For the large base scenario, €497,710 of value realisation is needed to break even after 5 years.

6.6. Conclusions on added value realisation

In this chapter it has become clear that added value can indeed be realised with the performance management system. None of the analysed scenarios returned a negative or poor result.
Spliethoff has managed to keep the costs of developing the performance management system low due to their do it yourself attitude and the use of graduate interns. Operational costs are also kept low due to the small performance team. Maintenance costs can still be optimised by finding a better replacement for the viscometer.
The value creation potential is high as indicated by the cases in section 6.3. At the base of most value creation stands the improvement of information sharing, knowledge creation and communication. These things are essential when trying to optimise the performance. It is thus also said that company culture at Spliethoff has to adapt to support this. Data driven decision making and communication throughout the entire company is of the utmost important in realising this value. The performance management system enables this by providing this information sharing platform and by clearly visualising the operational performance. This causes the information that is needed to optimise performance to be common knowledge instead of being knowledge by personal experience which is then not shared throughout the company. The ConRo's combinator mode at low speed case is the perfect example of this. The captain on one ship knew that is was far more efficient to use combinator mode when sailing in the North-East Channel and realised the consequences of not doing so. The captains on the other vessels did not since there was no clear communication about this. The performance monitoring system made this performance difference visible which caused it to become common knowledge which can then be used to increase performance. It also enabled the company to clearly see the extend of the performance deficit. Something that would not be possible if it was not monitored.
Due to the low costs and the high value potential it does not come as a surprise that a large amount of added value can indeed be created by the performance management system. From the scenarios it has become clear that implementing the system over the entire fleet has the highest potential earnings but the return on investment is similar to the small fleet implementation in these cases. The advise is for this reason to start with the small fleet implementation and closely monitor how much value is actually realised. When it has

become clear that value is indeed realised the system should be rolled out over the entire fleet. More vessels means more data, means more knowledge.
The scenarios and the sensitivity analysis have also shown that the investment is low risk and that increased fuel prices will greatly increase the added value of the performance management system. Only a small amount of value is needed to be created yearly to break even after five years. This minimum value is already created by the proven cases of the combinator mode and the improved planning, routing and communication between vessel and operator.
A note should be made on the knowledge creation potential of the performance monitoring system. Having a means to use data to create knowledge is an important value adding benefit. This knowledge has to be extracted from the data by a data analyst, but once this knowledge is spread and used throughout the company it could realise great value. As mentioned before it could greatly reduce the risk of other performance optimising investments since they can be based on actual operational data. Knowledge on the operational side like for instance what causes delays or how much effect certain weather effects have on the vessel are also of value. This knowledge creation should thus not be forgotten. The same goes for the third party value creation and the other value potentials which have not yet been quantified. It is recommended to quantify these value potentials in further research.
In conclusion in can be said that investing in the performance management system is very promising and that a substantial amount of value can be realised. This does come with a side note that Spliethoff has to be willing to become more data driven and to follow up on findings of the performance management system. A culture change where communication, information sharing and the willing to change operations based on feedback becomes a central pillar within the company. The new performance management system together with the performance monitoring system enables the company to do this by greatly improving the availability of the data and offering a platform where the information is shared.

7 Conclusion

The goal of this research is to determine how and how much added value can be realised through ship performance management at Spliethoff Group with the use of a ship performance monitoring system. The demand for this research comes from the fact that simply putting a performance monitoring system in place does not realise added value. How to analyse, interpret and use the data is important to realise added value. This research has been set up as an action research in which the theory is immediately put into practise. The following conclusions about how and how much added value can be realised with the help of a performance monitoring system within Spliethoff are drawn in this research:

In validating the performance monitoring system set up by Grutterink [2017] it became apparent that a high data quality is of the utmost importance when analysing performance data. A well structured data quality assessment identifies problem areas in the data quality which can then be addressed. A large step in data quality was needed to be made at Spliethoff group. Average sampling over a sample period instead of taking a point sample over the same period greatly reduces the scatter in the data. High speed ETL processes are also implemented to provide a near live data feed (1 hour delay). The data quality is to be continually monitored and improved upon by performing a data quality assessment.
Analysing the operational data from the performance monitoring system in such a way that it provides the required knowledge and insight on the vessel performance is an important part of realising added value. Insight into the influence of operational parameters is created by fitting simple theoretical models to the filtered operational data of the vessels using regression. This form of hybrid modelling helps reduce the uncertainty of the analysis and also gives insight of how the vessels perform compared to theory. These fit curves can serve as baselines to plot future data against or can be used in tools which estimate the performance or ETA of the vessel. Visualising the performance data along these baselines with the help of BI tools is seen as an effective means to create awareness and knowledge on ship performance.
To realise added value the performance data has to be supported by effective performance management. As mentioned before, simply putting a performance monitoring system in place does no create added value. The performance management in place before the arrival of the performance monitoring system at Spliethoff was not data driven. Knowledge on how to optimise performance is often present but the information and tools needed to do so were either missing or poorly available. The performance management is based on experience of which a lot is present within Spliethoff but this knowledge is not shared well throughout the company, meaning that internal communication or information sharing can also be improved. The use of performance optimising tools such as the weather routing program were also not encouraging since there was no feedback on how the use of such a tool improved the performance. Meaning that there was no visible reward for the users. Lacking follow up when performance deficits are found on top of this make it so that a lot of added value is still to be created here.
A new well structured performance management plan is proposed. This plan is based on ISO50001. This plan addresses the above named deficits in the performance management. The performance monitoring system is to act as the backbone of this plan. It provides the platform over which knowledge and information can be shared through performance data. It creates the awareness needed by visualising the influence on performance of certain parameters or actions. This awareness also stimulates the communication between vessel and office which is of great importance when optimising performance. Tools for in the office and on board

of the vessels are created which enables them to optimise performance. These tools consists of performance dashboards which give a clear overview of performance. Next to this a performance team is to be set up which analyses the performance of the vessels by data analysis and audits. This team will be responsible for proposing operational changes and implementing a more data driven and information sharing culture to optimise performance and realise added value.
To determine how and how much added value can be realised the costs and value potential of the performance management system are analysed. In the determination of the added value only direct monetary value is considered. This being said, a lot of value is also created for other stakeholders and in non monetary form from for instance knowledge creation or reputation. The direct monetary added value realisation for Spliethoff mostly comes forward from reducing fuel costs and optimising voyage planning with the help of the data provided by the performance monitoring system. The total added value is represented by the net present value of the performance management project for certain scenarios. The capital investment of the project is either €543,000 when only the large consumers of the fleet are included or €1,310,000 when almost the entire fleet is included. The resulting total added value (NPV) of the small fleet implementation ranges from €2,165,970 in a pessimistic scenario to €8,711,272 in an optimistic scenario after 11 years. €6,000,146 is the expected total added value realisation for the small fleet implementation after 11 years. For the large fleet the results are: €4,966,756 for the pessimistic scenario, €18,103,704 for the optimistic scenario and and expected added value of €12,805,994 after 12 years. Most scenarios have a pay back period of less than 2 years with the exception of the pessimistic scenario of the large fleet which has less than 3 years. This means that non of the scenarios give a negative result and that the added value realisation potential is high at a low risk.

This research thus gives Spliethoff Group a means on how to create a large amount of added value with the use of the performance monitoring system and it gives some definite proof that added value is indeed to be realised within the company when proper performance management is supported by the performance monitoring system. It is recommended that firstly, the small fleet implementation of the performance management system is carried out as a verification after which the entire fleet can be implemented.
As a side note the management is to support a small company culture change towards a more data driven and information sharing company in order to make the performance management effective.

8

Discussion and Recommendations

In this chapter the research will be discussed. Was the action research method effective and what could have been improved or done in a different way? In this chapter recommendations for further research and progress on the performance management system are also given.

All in all, this research can be specified as successful as it succeeded in answering the research question and value is indeed created for Spliethoff from this research. The action research approach is seen as a good approach since in enabled the research to stay close to practise and immediately get feedback on certain results. It also allowed the performance management to be tailored to Spliethoff since the focus was on implementing it there as well. This does on the other hand mean that the same results might not apply for a different shipowner and that it might not be possible for the other owner to implement performance management in such a way.
Another set back to the action research aspect was the fact that the data analysis took much longer than expected because the data quality had to be very high in order to give a useful input to the implementation at Spliethoff. Making this large step in data quality was time consuming but worth it for Spliethoff even though it did hinder the progress of the research in a significant way.
During the analysis of the influence of draft the importance of data quality again came forwards. In hind sight it would have been better to start with the influence of draft and then use the baselines made at different drafts to do the rest of the analysis. This would have reduced the uncertainty in some of the analysis because there would be more freedom in the shape of the baseline curve.
The research mainly focuses on direct monetary value. The reason for this is that the management of Spliethoff wanted to see actual monetary returns from the performance monitoring system. This meant that the assumption had to be minimised and concrete proof of value creation potential was required. This meant that indirect value and non monetary value were set to the background. These values are still important since a large part of the strength of the performance monitoring system lies in improving internal communication, knowledge and reputation. The research thus gives a fair indication of how much direct monetary added value can be realised but this is to be extended and further researched by a more detailed cost benefit analysis where non monetary value are also monetised and indirect values are better quantified. Fortunately, enough direct monetary value is created to realise a large amount of added value. If this would not have been the case the indirect values could have been important in tipping the scales.
The scope of the performance optimisation was limited due to the availability of data. Only ship performance data with a focus on fuel consumption is available in the performance monitoring system. To apply full performance management other data sources such as commercial data are also needed. In this way the risk of optimising in one area and losing in another is minimised. It can be said that the approach of this research has not hindered the success of it. The applied method served it well, but that some changes to the order of data analysis could have improved the data analysis results.

Further recommendations are to keep expanding the scope of performance management within Spliethoff. The focus of the system currently lies on reducing fuel costs and optimising planning. This being said the platform possesses the capability to improve performance in other areas as well. Research into how maintenance can be optimised at Spliethoff with the use of the performance monitoring system is needed. Also

implementing commercial data into the performance management will allow a more complete performance management scope. Research on how to fully integrate all performance influencing operations of the company into one performance management system is the ultimate goal.
Further research into how effective the proposed changes are is also recommended. How much of the added value potential is realised and what factors influenced this? This could for instance be the human factor where personnel is not motivated to apply the performance management. What is needed to motivate this personnel?
Research into the influence of trim on the vessel could not be performed within the time frame of this project and due to the limited amount of data available. Data analysis into the influence of trim is recommended. This could be done either by gathering a large amount of data first. Another option are special sea trials. This might prove to be an effective option to determine this relation since it does not require a large amount of voyages first.
Also trend analysis with regards to hull fouling is recommended to be further researched when a longer period of data is available. The period after hull cleaning was too short for it to be analysed in this research.
Lastly, to research the full extend of the potential added value, research into the indirect values and non monetary values is recommended.

A

Appendix A: Data with original tag names

Table A.1: Available Data

Prime	**Noon**	**Norm**	**Weather**
SOG	MessageType	NormThrust	TWS
SOG1	BerthTime	NormFOCTPD	TWD
STW	DraftFore	NormFOCGps	WaveHeight
Thrust	DraftAft		CurrentSpeed
FOCGps	HFO		CurrentDir
FOCTPD	LSGO		SwellDir
Power1	Luboil		
Shaftgen1	DistBerthPilot		
PowerME	DistPilotPilot		
SFC	DistPilotBerth		
Latitude	HFO_Exp		
Longitude	LSGO_Exp		
WaterDepthKeel	CalcMeanDraft		
Torque1	CalcHFO		
Speed1			
Heading			
eto_O			
Consump1Rate			

B

Appendix B: Combinator Mode at low speeds

From analysing the consumption data of the Plyca and the Timca it became clear that below 11 knots the Timca showed a significantly lower fuel consumption than the Plyca. In figure B.2 the fuel consumption in tonnes per day versus the speed through water data is given for the Timca and Plyca. The Timca and Plyca are two ConRo vessels which are designed for high speeds (24 knots). These twin controllable pitch propeller vessels are eqquiped with combinator mode which enables them to reduce engine rpm at lower speeds and thus increase the propeller efficiency at low speeds. In combinator mode the shaft generator cannot be used. In the data in figure B.2 it can clearly be seen that below 11 knots the data splits up in two clouds for the Timca, the Plyca seems to be missing the lower cloud of data.
After consulting the captain of the Timca it became clear that this was due to the use of combinator mode at these lower speeds. The use of combinator mode thus reduces the fuel consumption considerably but the downside is that the bowthruster is non-operational while on combinator mode. The evidence shows that the Plyca does not sail on combinator mode below 11 knots which causes a significantly higher fuel consumption. This being said it is believed that when the Plyca uses combinator mode in the same way as the Timca, significant cost savings can be realised. Here under a breakdown of how high these cost savings due to reduced fuel consumption can be.

Firstly it is analysed how often the vessel sails at these lower speeds (Between 5 and 11 knots). In figure B.1 the percentage of the time sailed on a certain speed is plotted for the Plyca during 2018. The map below it shows at which locations is has sailed at this speed. It clearly shows that this mostly occurs under pilotage, in the Westerschelde and on the NOK (Kiel Canal). The total time sailed at the highlighted speeds is around 5 percent. This means that around 5 percent of the year the ship sails at a speed between 5 and 11 knots. This amounts to 18.5 days of the year. Instead of the 5 percent we take 4 percent to wash out instances where the speed was just reached shortly. 4 percent of the time leads to 14.6 days per year.

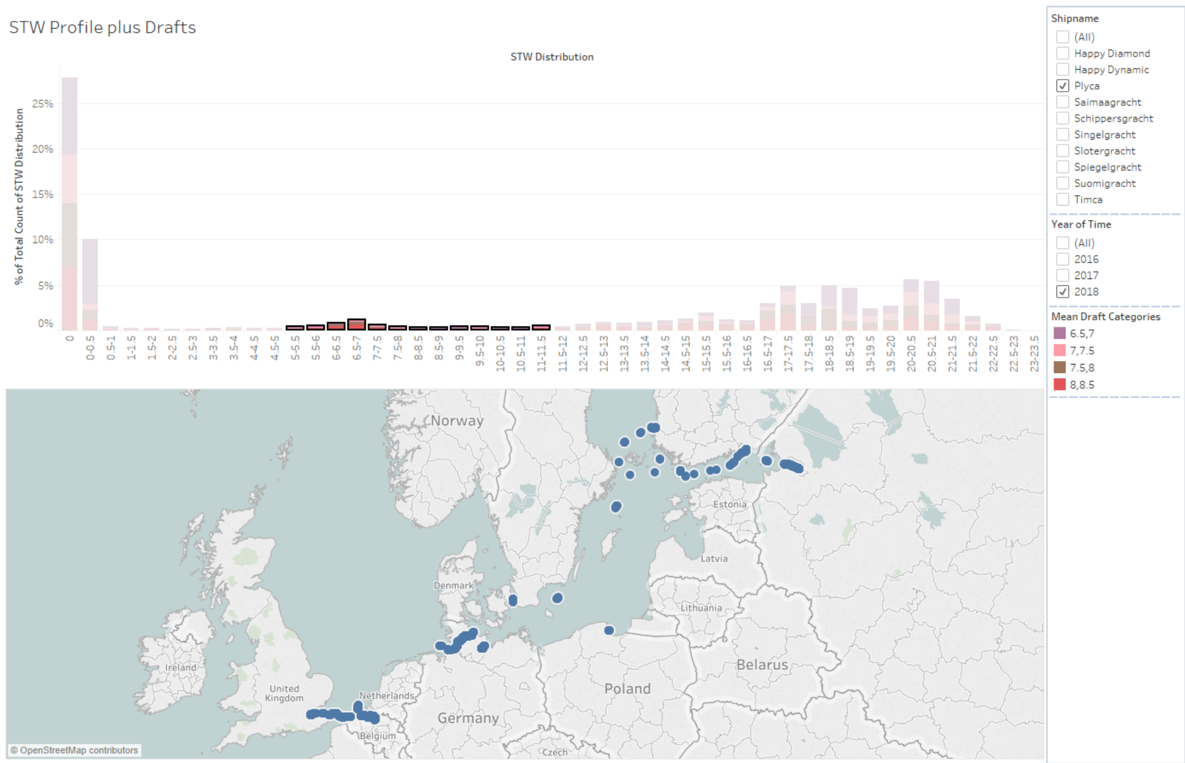

Figure B.1: Time and location sailed at low speeds

Next we analyse how much fuel is saved by using combinator mode. Figure B.2 shows the fuel consumption in tonnes per day versus the speed through water. We can see that at the highlighted point the fuel consumption is 13 knots per day at around 7.5 knots while in combinator mode. The cloud of data hovering above it is the cloud of the consumption at constant rpm mode. The fuel consumption at 7.5 knots in constant rpm mode then lies around 30 tonnes per day. Meaning that a difference of 17 tonnes of fuel per day is observed on average. Below the Timca the same consumption curve is also shown for the Plyca. It can be clearly seen that the Plyca does not use combinator mode between 5 and 11 knots.

To summarize the ships sails at these speeds 4 percent of the time so 14.6 days a year and it can save 17 tonnes of fuel per day by using combinator mode. This means we can calculate the fuel cost saving potential in the following way.

$$14.6 days * 17 tonnes/day = 248.6 tonnes/year$$

$$248.2 tonnes/year * 350 USD/tonne = 86870 USD/year$$

If we allow for a 40 percent use of the bowthruster at these speeds (similar to as seen on the Timca), the savings are 60 percent of 86870 dollars a year.

$$86870 USD/year * 0.6 = 52122 USD/year$$

So a total realistic savings of around **52,122 USD/year or 142.8 USD/day**.

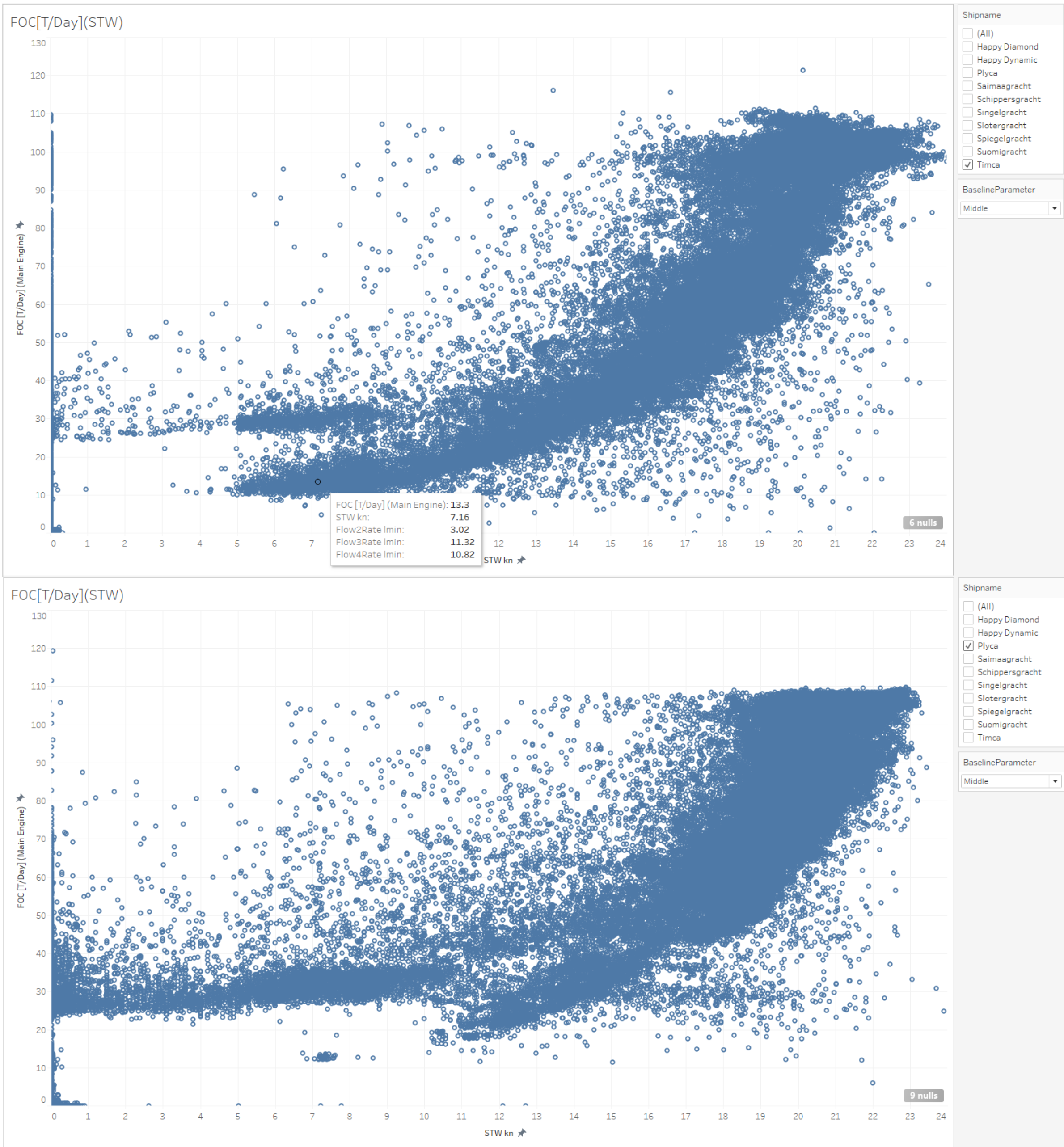

Figure B.2: Fuel Consumption vs STW data (Top:Timca, Bottom:Plyca)

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