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Fuel Consumption Monitoring: A management perspective to Efficiency

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ABSTRACT

With increasing environmental concerns, reducing emissions by improving fuel efficiency is imperative for shipowners around the world. The purpose of this study is to explore how fuel consumption monitoring can be utilized from a management perspective to improve fuel efficiency of ship operations.

This research has a qualitative design, where six persons in management positions working directly with fuel efficiency are interviewed. Interview subjects were sampled from "Norges Rederiforbund" (Norwegian Shipowners Association) using both convenience and snowball sampling. Semi-structured interviews of around 1h each were carried out.

Results evidently showed three ways fuel consumption monitoring can improve fuel efficiency; 1) A fuel monitoring system that provides a dashboard that communicates with all sensors, collects all data, and clearly indicates fuel efficiency status to assist personnel in making timely and strategic decisions to improve fuel efficiency. 2) The importance of accurate data, with high quality, digital flow meters to improve decision-making. 3) Continue to improve fuel efficiency awareness and understanding amongst crew.

Keywords: Fuel consumption, fuel monitoring, energy efficiency, shipowners, management, maritime industry, human factors, awareness

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The writing of this thesis has been a highly fulfilling, interesting, and challenging experience. I have learned equally much about research as myself during this process. Immersing myself in research and the qualitative approach, has only led to more curiosity and interest for the subject.

I would like to thank my supervisor Tor Erik Jensen and co-supervisor Nils-Olav Skeie for their excellent assistance along the way. I would also like to thank all interview subjects for their time and contribution to this research project.

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1 Introduction

The maritime industry is one of the largest consumers of fuel in the world. The shipping industry alone was responsible for about 1076 million tons of CO_2 emissions in 2019 (European Commission, 2023). IMOs goal is to reduce the carbon intensity on all ships by 40% within 2030. As concerns about environmental sustainability and rising fuel costs continue to grow, there is increasing pressure on companies to improve their fuel efficiency. Several technologies can be implemented to achieve this, like hull improvements, ship machinery and energy management (Guangrong et al., 2017). To identify these areas for improvement fuel consumption monitoring can be used (Wijaya et al., 2020). However, simply installing a fuel consumption monitoring system is not enough - it is also important to use the data generated by the system to make strategic decisions in a way that can improve efficiency (Wijaya et al., 2020).

To investigate the management perspective, the researcher has connected with several shipowners with a variety of larger ship types. Most of the shipowners have dedicated personnel working with fuel efficiency, these will be the interview subjects.

There are several types of systems to monitor the fuel onboard a vessel. A fuel consumption monitoring system can be delivered as a completed package, including software installation and sensors. The following selection of companies delivers this solution,

- Ascenz https://www.ascenz.com/
- KROHNE Marine https://krohne.com/en/industries/marine-industry
- Breezermarine Group https://breezemarine.eu/home/
- Emerson https://www.emerson.com/no-no
- Endress+Hauser https://www.no.endress.com/no

Other companies delivered only the fuel consumption monitoring software itself with availability to connect to existing sensors,

- Yara Marine https://yaramarine.com/
- Scan React https://www.scanreach.com/
- Service Marine https://en.service-marine.com/

Whilst companies like InsaTech (https://www.insatech.com/) delivers sensors only.

1.1 Presentation of research questions

"How can fuel consumption monitoring be utilized from a management perspective to improve fuel efficiency of ship operations?"

This question encompasses a range of potential topics, such as the development of management strategies for using fuel consumption data, the analysis of case studies of companies that have successfully implemented fuel consumption monitoring, and the exploration of potential challenges and barriers to the adoption of fuel consumption monitoring systems.

To answer this question, the research will answer following sub questions,

"What are the current fuel consumption monitoring practices in the maritime industry?"

"What are the most significant challenges in terms of fuel consumption and efficiency?"

1.2 Research approach

The researcher approached this project by contacting and interviewing as many ship owners as both time and resources allowed, aiming to gain their knowledge and experience on fuel monitoring and fuel efficiency by exploring a multitude of themes related to the research questions.

1.3 Contribution

This paper contributes to the studies within the maritime sector with the management perspective in combination with fuel monitoring. There are a lot of studies in relations to fuel efficiency and how vessels can operate and implement new technology to improve the efficiency, but limited research on fuel monitoring and how this can contribute to improve efficiency from a management perspective (Yin et al., 2017) (Mak et al., 2014) (Oikonomou et al., 2021) (Wang et al., 2017) (Wijaya et al., 2020).

Furthermore, using IEEE and Scopus, research who provide insight on fuel efficiency from a management perspective is limited. This project will include perspectives from personnel in charge of managing fuel efficiency on their fleet and explore the managements impact on fuel efficiency. By this additional element the researcher hopes to provide new insight to fuel efficiency in the maritime industry.

1.4 Contents

Literature review will include a literature review of the most relevant studies related to this topic to give context for the reader. Next chapter, System Description, will cover the current types of fuel consumption monitoring systems available at the marked today and go more in detail with one fuel consumption monitoring system. The Methods chapter explains the different approaches in the study, research design, sampling methods and content analysis in addition to bias and research quality and limitations. Next, the results will be presented, and topics related to the findings will follow in the Discussion chapter. Lastly, the paper will be finalised with a conclusion on how fuel consumption monitoring can be utilized from a management perspective.

2 Literature review

When locating articles for the literature review, the researcher primarily utilized database IEEE and Scopus. Both databases are essential for technology, natural sciences, and maritime subjects. The researcher chose these two databases based on recommendations from the University Library. Some relevant literature from other sources have also been reviewed.

Keywords used in both databases, fuel, consumption, monitor*, ship, vessel, emiss*, efficienc* and awareness. These have been used together and I combination.

There are several studies exploring how fuel consumption monitoring systems can result in improved fuel efficiency (Oikonomou et al., 2021) (Mak et al., 2014) (Yin et al., 2017) (Wijaya et al., 2020). Yin et al, (2017) writes about a self-checking functionality system that exceeds the checking functionality of the existing fuel monitoring systems. Together with real-time monitoring this self-checking system helps the operators to better manage ships fuel efficiency performance. This design uniquely identifies the fuel consumption abnormality with the correlation between the different relevant data for main engine and for auxiliary engine. By implementing this design, management performance of fuel consumption will improve (Yin et al., 2017).

Mak et al. (2014) explains how a baseline could be developed according to key performance indicators for performance of fuel consumption on a vessel. To establish this baseline a three-week period of data collection with automatic measurements were conducted. By this baseline it was possible to detect that constant speed and using the same routes impacts the fuel efficiency significantly.

Some systems that measure fuel consumption monitoring are developed to measure additional data. “SmartShip” is an example of this. It is designed to create a complete framework of vessels, to reduce emissions and improve fuel efficiency (Oikonomou et al., 2021). Algorithms can also be developed to monitor fuel consumption (Wijaya et al., 2020). According to Wang et al. (2017) it is possible to improve ship energy efficiency by optimizing ship navigation based on big data analysis algorithms (Wang et al., 2017).

Most studies elaborate on different ways fuel consumption monitoring and general fuel efficiency can be affected technologically. There are also studies that focuses on human factors related to energy efficiency, though these studies are limited compared to technical studies.

Rasmussen et al. (2018) elaborate on the impact of human factors by interviewing 49 seafarers and onshore employees about their understanding of fuel efficiency. These interviews resulted in situation awareness playing an important role for fuel efficiency, and that solely improving situation awareness is not sufficient. Factors like hierarchy and communication also impacts the fuel efficiency. The human factors in relation to fuel efficiency is of great complexity and it is important to understand this issue to improve fuel efficiency performance (Rasmussen et al., 2018).

Rasmussen et al. (2018) have a very wide approach focusing on a general way to improve fuel efficiency by studying the impact of human factors. The results have limited practical and direct value for shipowners.

To better understand the challenges related to fuel efficiency, it is important to interview key personnel who are in a management position with decision-making authority related to fuel efficiency. It is reasonable, by relating fuel efficiency with fuel monitoring systems and interviewing key personnel, this research would lead to more tangible findings and solutions that are easier to implement.

This research project aims to shed light on fuel efficiency from a management perspective, understanding the experienced challenges related to optimizing fuel consumption and hopefully provide suggestions that are functional, and viable to implement for shipowners today.

3 System Description

The most common ship types in the industry are bulk carriers, tankers, container ships, ro-ro ships and passenger ships. Both bulk carriers and container ships transports long distance, eg., over the Pacific Ocean, while tankers and ro-ro ships travel shorter distance. Passenger ships can vairy as they are dependent on the type. For example, passenger ferries or cruise ship have major difference in transporting distance (Raunek, 2021).

During all these major transport distances, ships consume significant amount of fuel. Fuel consumption can be influenced by a variety of severe various factors related to the condition and design of the vessel, and how the vessel is operated. The most relevant data for fuel monitoring is position of speed, average speed, average RPM, wind force, sea and swell condition (Anish, 2021).

3.1 IMO regulations

IMO Emission Plan 2050 will take the carbon intensity measure into account with the collection of carbon intensity data (CII) starting 1st of January 2023. By 2025 Energy Efficiency Design (EEDI) phase 3 will be in effect. This means 30% reduction of carbon intensity is required for all newbuilt ships. In 2030 amendment for 40% reduction in CO_2 emission per transport work compared to 2008 is coming into effect. In 2050 this will be increased to 70% (IMO, 2022).

3.2 Fuel consumption monitoring

Fuel consumption monitoring systems measure fuel consumed over a period of time or distance, and allow the user to have an overview of the amount of fuel consumed by different consumers onboard their vessel or fleet. To achieve this overview, the system can work in different ways depending on which functionality is most important for the operator and/or customer. This is often a cost versus benefit matter, higher accuracy on the measurements requires more expensive sensors. Tank sounding is one of the most common methods, and its used to preform “sounding corrections”. This indicates the tank fuel level, done by inserting a sounding pipe in fuel tanks. It is a cost beneficial method that has a low accuracy. Continuous monitoring with sensors is another common method that has a higher accuracy depending on type and quality of sensors (European Commission, 2017) (Hunsucker et al., 2018). Digital fuel consumption measurements with flowmeters can be 0.5% below tank soundings (Mak et al., 2014). Flowmeters are a type of sensor.

Volumetric flowmeters can have accuracy ranging from 0.5-1% or more, while mass flowmeter ranging from 0.1-0.2% or less (Hunsucker et al., 2018). If the regulations from IMO stated above are to be achieved, these decimals will be of great importance when monitoring fuel consumption data.

When monitoring fuel consumption, both sensor type and quality is important to consider. However, how the data is collected can also impact the results of the measurements. Figure 3-1 shows an overview of how different data collection methods can be utilized,

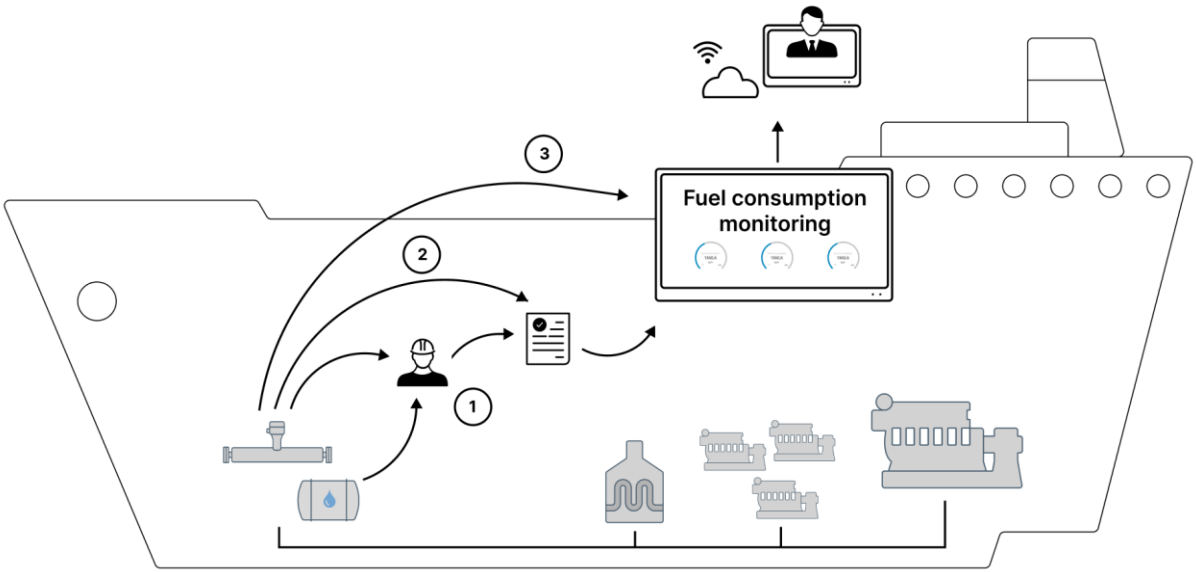

Figure 3-1: Methods of data collection

The main consumers onboard a vessel is often main engine, generators and boilers. The report icon represents the noon-report, which Is a report collected once a day by the crew to gather data about the performance of the vessel (Anish, 2021).

Consumption is measured by either sensors or sounding corrections as mentioned above. Method 1 shows how manual readings of analog flowmeters and sounding corrections is used to report consumption data to the noon-report, and then the fuel monitoring system received this data directly from the report. Method 2 shows consumption data collected from digital sensors. This can be received by the fuel monitoring system either from noon-report or directly from the sensor, like method 3. Often it is done a combination of these methods as noon-reports are reported regardless.

The collected data can be presented in a monitor onboard the vessel, supporting the crew to track their fuel consumption. This data can also be visible for the onshore employees, who works closely with tasks related to fuel efficiency, by a cloud solution sketched in figure 3-1.

The EcoMATE™ system is chosen to give a more detailed description of the functionalities of a fuel monitoring system and provides sensors that allows the client to use method 3 explained above. This system is chosen because the researcher has personal experience with this system. EcoMATE™ measures fuel consumption momentarily with digital Coriolis mass flowmeters, a high accuracy sensor. Accuracy can be 0.1-0.2%, depending on flowmeter type and operational condition. Coriolis meters measures mass flow directly, so the uncertainty in a potential calculation is reduced. The system also has automatically real-time measuring from the flow computer sensors, so it is possible to see the fuel consumption developing at all time. A reporting module is also included, which allows the operator to automatically report noon-reports, voyage reports, consumption reports and bunker reports (KROHNE Group, 2023).

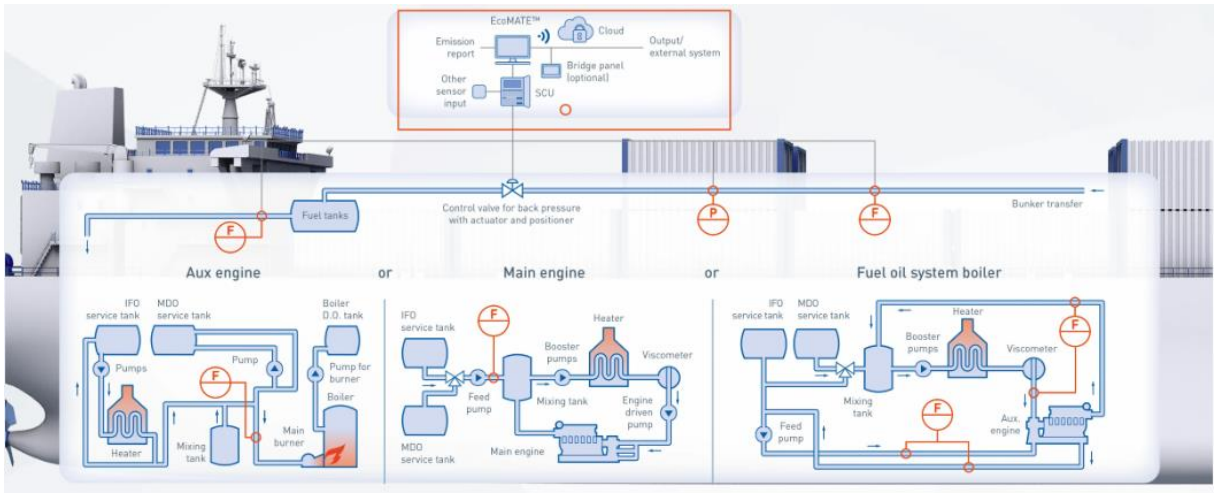

Figure 3-2: EcoMATE™ System

Figure 3-2 shows overview of an example of an EcoMATE™ system (KROHNE Group, 2023). The software receives data from the flowmeters, no need for manual reading or sounding corrections. This contributes in improving the accuracy, as the human factor is reduced to zero. Additionally, it reduces the workload to the crew, as the fuel consumption data is automatically imported to the report, compared to manual readings and sounding corrections.

EcoMATE™ can also be delivered with a Cloud functionality. The cloud is a shore-based web reporting tool and allow the shipowner to have an overview of the entire fleet with all

vessels running EcoMATE™ (KROHNE Group, 2023). Without Cloud, EcoMATE™ is only presenting locally at the vessel. The system can receive input from other external systems and can expand the output accordingly. For example, when it receives input from a navigation system onboard, EcoMATE™ can calculate and present the performance speed of the vessel, given the displacement of the ship and the amount of fuel consumed.

4 Methods

This research aims to explore how fuel monitoring can be used to improve fuel efficiency from a management perspective. As qualitative research methods are used when understanding the practices and experiences of individuals and groups. Qualitative method approach is preferable and appropriate to gather data for this research (Frankfort-Nachmias et al., 2015, p. 242). Six semi-structured interviews with key personnel related to fuel efficiency at shipowners were interviewed to gather data on this topic.

4.1 Research design

This research is a qualitative study, and it allows the researcher to gather data on experienced challenges of key personnel in the industry related to fuel efficiency. The research has a management perspective, so quantitative research methods would not be appropriate. Quantitative research methods related to emission data could have played a supportive role in this research, however, due to the limited time and resources, qualitative approach is the sole method used.

The shipping companies name and system name will be anonymized, as there was a large amount of confidential information shared during the interviews.

4.2 Population and sample

Interviewing personnel that work closely on fuel efficiency and have the decision-making authority to purchase systems and new technology will be a great contribution to this project and ensure a management perspective. Criteria for all interview subjects are to have main responsibilities for their company's fuel efficiency and its improvement. Historically fuel prices fluctuate considerably, but both VLSFO (very low sulfur fuel oil) and HFO (heavy fuel oil), have increased dramatically the last 2-3 years (Isnee, 2023) (Statista, 2023). It is now profitable for major companies to have personnel working targeted on fuel efficiency only.

All interview subjects were the deciding factor weather or not the shipowner should implement fuel monitoring systems. What they see as fundamental, essential, and functional will be the basis of this data collection.

Nonprobability, convenience sampling was used to collect the interview subjects, as a certain knowledge and experience is required to collect meaningful data (Frankfort-Nachmias et al., 2015, p. 148-149). The accessibility of this knowledge is all over the world, but to increase

the information exchange conducting them physically, convenience sampling was used to find key personnel within travel distance. Eleven people where contacted using "Norges Rederiforbund" (Norwegian Shipowners' Association) membership list, were the researcher chose to contact shipowners by the size of the company and variety of ship types, assuming this would result in more valuable data. Four replied positive and agreed to be participate in the project. Two replied, but where not able to participate. Five did not reply. Additionally, snowball sampling was used during the pilot interview; the interview subject suggestion an additional shipowner and one ship management company (Frankfort-Nachmias et al., 2015). Both replied positive to join the project. A total of 6 semi structured interviews were conducted.

4.3 Interview subjects

Table 4-1 shows an overview of the interview subjects participating in this research project. The interviews had a duration of about 60 minutes each. All interview subjects received the framework for the interview in advance, no exact questions where shared to increase the reliability and validity of the answers.

Table 4-1 Interview Subjects

Name	**Position**	**Type of vessels**	**Number of vessels**
Shipowner A *(Pilot interview)*	Two participants; one responsible for bunker purchasing and one vessel operator manager	Deep-sea vessels	10+
Shipowner B	Performance Manager responsible for all projects related to fuel efficiency, also been responsible for the performance of the fleet	Deep-sea vessels	10+
Shipowner C	Project Manager responsible for all projects related to maintenance and energy efficient	Seismic vessels	10+

	technology implementations on the fleet		
Shipowner D	Performance Analyst mainly responsible for data collection from the fleet	Chemical tankers and FPSO's	5+
Shipowner E	Energy Conservation Specialist responsible of implementing energy efficient technology	Chemical tankers	100+
Ship Management	Fleet Performance Manager responsible for energy efficiency and performance on the vessels	Management and crewing	500+

4.4 Interview guide

The interview guide was developed by the researcher based on the experience from the industry. Prior to the pilot interview a guide was developed with a list of questions divided into two sections, one for each of the research questions, see appendix 1. The guide was then adjusted with additional questions, and some questions where reformulated to encourage more precise answers.

The same adjusted guide was used for the remaining shipowners, see appendix 2. As the interviews were conducted as semi-structured, follow up questions were asked during the interviews. A special guide, similar to the shipowners guide, were developed for the ship management company, see appendix 3.

4.5 Data collection method

All semi-structured interviews, except one, where conducted in Norwegian as this was the mother language for all participants and the researcher. The reliability in qualitative research is challenging (Davey et al., 2010). To increase reliability, transcription tools are preferred, but due to the poor quality of these tools for the Norwegian language all interviews where transcribed manually by the researcher. The last interview was conducted in English, as this was the only common language for the researcher and interview subject. This interview was transcribed with Word transcription feature.

4.6 Data analysis method

Thematic content analysis (TCA) is used to analyze the data from the interviews. In qualitative analysis, TCA is the most foundational analytical procedure. It allows the researcher to identify and structure themes, while the analysis in not influenced by the researchers' own thoughts and feelings related to the themes (Anderson, 2007). All transcriptions are coded with different colors according to themes. The themes were decided based on the data from the interviews. After transcribing the interview manually, the researcher gained a sense of which topics that where most relevant for the interview subjects. During the color coding, the researcher experienced that one additional theme, "Collect and Unite Data" should be extracted from "Data Collection and Analysis" to cover this relevant topic more specifically for the research question. A total of six themes where established.

Table 4-2 shows the different themes found in the transcriptions.

Table 4-2 Themes for content analysis

Themes	**Subthemes**
Data Acquisition and Analysis	- How the shipowner is monitoring their fuel - How they analyze the fuel monitoring data
Collect and Unite Data	- The challenges with several systems onboard the vessels - The importance of analyzing all data in once place
Data Quality	- Inaccurate data from flowmeters - Importance of high-quality data to make good decisions
Awareness	- Communication between people working onshore and the crew onboard - Knowledge of performance systems - Strategies for increasing the awareness
Data directly related to Fuel Efficiency	- Hull cleaning - Machinery optimization - Optimal trim - Constant speed
Reporting	- Reporting tools - Types of reports

During the analysis it was also discovered that the theme “Reporting” did not answer any of the research questions. Data related to this theme will not be presented any further in this study.

4.7 Research quality and limitations

Microsoft Teams were used to conduct two out of six interviews. Using an online platform for communication limits the researcher’s ability to read body language. Communication flow was occasionally interrupted and/or delayed due to poor connection.

The researcher used convenience sampling, interviewing subjects from “Norges Rederiforbund”, due to location and the likeliness of positive response. A larger sample size with worldwide sampling and greater variety in ship types would have been beneficial for this project and is suggested for future research projects.

Data triangulation in qualitative methods is used to increase the validity of the results (Frankfort-Nachmias et al., 2015, p. 170-171). This research only used one type of data, semi structured interviews, consequently triangulation is not possible.

All interviews performed in Norwegian, were transcribed and then translated to English. The quality of these translations are limited to the translation expertise of the researcher.

The researcher had time and resource limitations for this project, hence the low sample size and amount of data collected. Literature review only contains research from two different databases, Scopus and IEEE. Two additional databases would have been ideal, but researcher experienced time restriction.

4.8 Bias

Both participant- and researcher bias presented itself during the process. The researcher previously worked for one of the interview subjects. A former relationship with the interview subject could influence the openness and honesty of the interviewee in the interview process, depending on the existing relationship. The participant may have bias due to their opinion about the interviewer, which could lead them to agree or oppose (Shah, 2019).

Efforts were made to limit participant bias. An interview subject is likely to respond what they believe the researcher or interviewer want to hear. By asking open-ended questions, participants are less able to anticipate an expected answer and by asking non-threatening questions, participants are more likely to share (Frankfort-Nachmias et al., 2015, p. 225-227).

Furthermore, the researcher is currently employed by a company delivering maritime industry solutions. Interview subjects could be influenced by this fact and participant bias could occur. Efforts were made to limit participant bias by clearly informing participants that the researcher were not representing the employer when performing this research.

Researcher bias could transpire where the researcher attempts to skew results in favor of existing employer. Efforts were made to limit researcher bias by maintaining awareness on this subject throughout the process and discussing the issue with University supervisors.

Additionally, the researcher conducted all interviews. As the interviewer and researcher is the same person, a peer perspective is not available, and the same potential bias will be reflected throughout the interviews and throughout the report.

5 Results

This chapter will present the findings retrieved from analyzing the six semi-structured interviews. This research project aims to explore how fuel monitoring can be used to increase the fuel efficiency onboard several types of vessels. The main research question is divided into two sub-questions:

> *What are the current fuel consumption monitoring practices in the maritime industry?*
> *What are the most significant challenges in terms of fuel consumption and efficiency?*

Using thematic content analysis, the researcher will present the results found most relevant for these two questions, categorized by themes.

5.1 Research question 1

> *What are the current fuel consumption monitoring practices in the maritime industry?*

Themes related to this question is "Data Acquisition and Analysis" and "Data Directly Related to Fuel Efficiency" as both of these themes are describing shipowners current fuel monitoring situation.

5.1.1 Data acquisition and analysis

During the interview with Ship Management, it was stated that all shipowners use noon-reports to collect data, as seen below;

"Many assume you can receive autologged data, but all ships already have that core of data no matter who you speak to. Those stating differently are either a part of a per mille, or they don´t know what they are talking about. All ships have their core received from a noon-reporting system. Now, you can solve this in several different ways, but basically, it's all related to reporting. That´s because they do not have reliable sensordata to replace it, it's a floating factory that moves, and you need trim and draught sensors, these must be cleaned somehow. For fuel monitoring you need a lot of reported numbers anyway. A lot of elements are involved and several of them are impossible to automatically detect. This must be reported at some level."

Almost all other interview subjects confirmed the same data collection method when they were asked to elaborate how they monitor their fuel consumption.

Shipowner A,*"Our ships send noon-reports to a platform where they issue reports and have noon-reports and arrival/departure reports. Noon reports are typically once a day, at*

12:00pm, describing what has transpired the last 24 hours; consumption, average speed, and all that. We use about 30 minutes to collect data, and then 10-15 minutes to finish the report. Next, the report will pass through some automatic assessments to ensure the data is correct and no major deviation can be found. Subsequently it will be returned to the operator, who corrects potential mistakes before it is sent out to the system. Next, it proceeds to us, to our platform, so we can monitor it, and then it goes on to our weather routing provider, and finally it goes to our performance system."

Shipowner B,*"It means that the newest fleet has more updated sensors and systems on board installed when delivered. We have flowmeters that automatically sends signals into our performance system. Nevertheless, the way we collect data for our reporting today is through our noon-reporting system. This is the easiest because this way we have one system and one way to collect data."*

Shipowner D,*"We can´t properly detach from manual reporting, so we run parallel tracks. What is officially reported to the client regarding fuel consumption is based on what is aggregated and printed in the reports on board."*

Shipowner E,*"Now this is an ordinary system that we have on board of our vessels, same as many other shipowners. We have flow meters installed on most of the vessels in our organization. Then of course the data is collected manually by crew. They report it as noon-reports and then the data automatically records in our system. We use noon-reports to submit the data to different parties."*

5.1.2 Data directly related to fuel efficiency

Several of the factors emerging in this theme, like constant speed, optimized number of generators and hull cleaning optimization are already well established in the industry.

Shipowner A explains how the crew has improved fuel efficiency by using constant speed,

"Earlier the crew was driving with a high speed in the beginning of the voyage to make sure they reached the destination within the target date they were given. They wanted to secure themselves, so they moved at low speeds, perhaps the last 2-3 days at 10 knots. Optimally, they should stay at 15 knots the whole time. There has been a development, and it´s better now. We see clear improvements that they drive with more constant speed throughout their voyage."

Ship Management explains how driving on an optimized number of generators is a transient problem,

"For a large ship we see that the boiler and the generator is responsible for ¼ of the total consumption in one year. At sea it is naturally not that high, but a ship is often anchored or in port so obviously, if we can optimize here, we have a lot to gain. We have made efforts to ensure consumption stays low. You mentioned running an optimal number of generators, often it´s not more than one. That´s one of our measures that I hope we are past, frequently discussed 6-7 years ago."

Shipowner D supports this statement by expressing the following,

"In the beginning, we focused on it more frequently. Nowadays, we see operators being good at making it work with what they have."

There are several statements from the interview subjects that actions related to speed and machinery optimization are already well established. All subjects also provided a well-established strategy for optimizing the hull cleaning on their vessels.

5.1.3 Summary

As stated above all interview subjects acquire their majority of fuel monitoring data from noon-reports. Most of the shipowners interviewed use a combination of the methods described in figure 3-1. Only shipowner D use mainly method 3, as they have flowmeters on all consumers who sends data directly to their integrated automation system, while shipowner E only use method 1. The remaining shipowners use a combination of method 1 and 3, as they have vessels built in different years, the newest ones are equipped with high quality sensors and flowmeters.

The reason why none of them can properly detach from manual reporting is that noon-reports collects other relevant data, like position of ship, propeller slip and external forces from other systems (Anish, 2021). Noon-reports provides an easy way to monitor fuel consumption, and the data needs to be collected regardless.

Noon-reports offers both pros and cons; it is a time-consuming task for the crew, a total of 45-60 minutes each day is required to conduct the data collection and reporting. However, it does increase crew awareness of the fuel consumption on their vessel.

Additionally, data confirmed the most substantial actions to reduce fuel efficiency (constant speed, running low number of generators and hull cleaning optimization) are already established and by these actions we can see a decrease in fuel consumption. All subjects stated that these actions were on the table several years ago and require no further investigation at this time.

5.2 Research question 2

What are the most significant challenges in terms of fuel consumption and efficiency?

Themes related to this research question will be “Collect and Unite Data”, “Data Quality” and “Awareness”.

5.2.1 Collect and unite data

Gathering and unite all data in one place were expressed as the main challenge by shipowner D,

“One thing we continue to notice challenges with is that there are many systems. On our ships, the integrated automation system collects data from a variety of places. Several suppliers want to offer their own systems, many do not function very well with the other systems. It´s crucial that all data is collected in one place, so we don´t have to login in to 10 different supplier portals to collect data. It makes it cumbersome and hard to see the full picture. All we want is a simple overview indicating how well we are doing that day. Currently, we must dig deep before we can achieve a full picture on how the fleet is doing. In an ideal world, we would´ve had a dashboard who collected data from all systems and gave us a red or green light. But we are not there yet, that´s the challenge. We spend a lot of time collecting data from all the different systems that could be used at analyzing data and provide feedback to the fleet.”

Ship Management supports this statement,

“A lot of smaller systems with different solutions for monitoring different systems will never be ideal. I believe that if you can share the data in a good way and large companies can implement it in their overall system, with key performance indicators (KPI’s) or an analysis or whatever, you will obtain an easier way to implement.”

Both shipowner B and C have developed their own powerBI dashboard to present all the data received for the vessels,

"Data collected from the ship, from all systems are inserted into a data lake. Based on this, we can assemble whatever dashboard we want. Now they communicate like we´ve customized it."

"We want everything to be gathered, all data will be visualized here. The data is collected from several different sources, both API´s and live data witch continuously updates, but we also have dead excel sheets we have to manually update. We don´t want the ship managers to have 5 different websites to log into. We want all the data to be collected here, and then do whatever we want with it."

While shipowner B express a challenge with receiving data directly in their own dashboard from software systems delivered by external suppliers,

"We see a trend, that suppliers of these software systems wish to retain the data, but we feel we own the data. We need to fight hard to get our data."

5.2.2 Data quality

Both shipowner A, B and C were not pleased with the data accuracy of their flowmeters, and expressed challenges when analyzing data,

Shipowner A,*"The flowmeters often report mistakes, we can see the trends in our performance system, it looks like faulty measurements. It can look like it's fouling, but it's just defective flowmeters."*

Shipowner C,*"Another issue is that we know the sweet spot for efficiency is here (pointing). Something tells us we are not running the engines optimally. However, if we can´t trust the data 100% we don´t get very far."*

Shipowner B,*"It´s expensive, but we want both decarbonization and to be data smart, we want high quality data. That means we need high quality equipment."*

Shipowner B mentioned that in the beginning of every year feedback from the classification society is received describing errors related to their fuel consumption data, even though they have verifications features in their systems,

"We have a deviation in the data, and it should not exceed 5%. If it is small errors it can slip through, like it has done today. But if we install digital coriolis flowmeters on all ships this will minimize the errors. I spend a lot of time troubleshooting this once every year."

Shipowner E did not express any challenge with the analysis, but mentioned the following,

"Data is the key, plus the quality of data. This is critical for your final recommendations. Otherwise, if you receive inaccurate data, you must investigate and you need to find the source or a way to improve the quality."

While the Ship Management expressed following,

"We´ve been doing this for a long time and performed our own analysis and spend a lot of effort on this. We want accurate data just of pure interest. To achieve lower fuel consumption, we can extract a lot of the potential with the reliability in the conventional flowmeters, tank level indicators and such. That might contribute to not having to deal with the insecurities. When performing a tank survey, it´s not unusual to have 10 tons too much or too little, and that is a lot. Obviously, if we knew the flowmeters provided accurate numbers, it would be valuable."

5.2.3 Awareness

When asked the main challenging experience regarding fuel consumption monitoring, shipowner E replied,

"I think the main challenge is our nature, our human nature, because it's very hard to change mentality. This is the largest challenge that I face in my position. To implement something new, you must convince the people that it will work…You can feel the resistance coming from the people without any reason… Green future is important for sure, but again, it's about mentality. Everything is about psychological change."

Shipowner E continue to focus on increasing crew awareness,

"This is a part of our responsibilities, to raise awareness among the crew about the energy conservation activities that we are leading within our fleet. We are doing campaigns every month or every two months, depending on our working schedule. In these campaigns, we are trying to explain to the crew about how they can calculate, for instance, power of main engine auxiliary, then how they can convert the daily soundings and readings of fuel oil tanks into the fuel oil consumption and how they can calculate specific fuel consumption."

All interview subjects were asked to explain their strategies to improve crew awareness. Everyone stated significant efforts and resources were made, from courses to campaigns and competitions,

Shipowner A, *"We´ve had several campaigns on board. Previously we had weekly newsletters, including who was best at turning off the lights, who was best at all these little things. Anything based on the consumption among the crew. They were awarded with good food. Before the crew board they all sit through a presentation at the crewing office, about environmental, social and governance (ESG) and what focus we currently have. We have proclaimed a strong environmental focus."*

Ship Management,*"That´s the key to make it work. I believe if the crew was told to reduce fuel consumption, regardless of what kinds of systems you have onboard, you would achieve reduction. It´s about prioritization and what you choose to focus on. Several things pinpoint a performance setting, and that´s something many can, also the crew. To establish awareness about doing what you can to reduce consumption is crucial to ensure low consumption in an operation."*

Shipowner B,*"We do that a lot. We have two meetings every week, and once a month I have a presentation about decarbonization and environment and what we do. I also present at an officer conference twice yearly about everything we do for officers, captains, and chief officers. I´ve developed a course for the crew about decarbonization for seafarers. It will become mandatory for all crew onboard. We have ample communication with the ships, our own Teams channels, where we communicate with the ships and request feedback."*

Shipowner C, *"We do a lot. Obviously, we have the Ship Energy Efficiency Management Plan (SEEMP) that´s the crew´s responsibility…Beyond that, every second month, we have phone conferences with the ships. Frequently we speak with chief and captain. The inspector has review samples with the ships every three months. We have conferences, internal conferences, had one last week, we always discuss it then. We also discuss if we should run campaigns or competitions. We do challenge them, but I would like to see more engagement from the crew. I´ve thought that I must make everything easier for the crew, to ensure all reporting is as automatic as possible, so they won´t waste time on reporting. And for me to spend as little time on reporting as possible when it does nothing for us. But obviously when I do that, the crew has no ownership or knowledge about reporting. At least, in the last few years, we have spoken a great deal about demands and requirements regarding emissions. I believe everyone understands that. Only depends on who is prepared to make the extra effort?"*

Shipowner D, *"Much of that is the basis of our procedures, we have a lot of procedures about reporting, you can call it energy efficiency and energy management. We have officers'*

conferences where this is a subject. Much through daily conversations and follow up with the crew on board. Both locally on board and here at the office."

5.2.4 Summary

One of the main challenges expressed by the interview subjects were the considerable number of systems onboard the vessels that do not communicate with each other. It's time-consuming and difficult to get an overview of the fuel consumption situation onboard. Therefore, some of the interview subjects developed a powerBI in-house, allowing customized dashboards. These dashboards can also be created for the crew and give them easier access to the fuel consumption data. One interview subject mentioned it´s difficult to receive data from external systems, as they want to retain the data themselves - data equals value. Even if shipowners create their own dashboards, it is crucial that they can import data from systems onboard from other suppliers.

The importance of data quality is pointed out as an issue multiple times during the interviews. Low accuracy and down time of sensors make it difficult to trust the data. High accuracy data is crucial for providing correct recommendations.

When reporting the last years fuel consumption, all shipowners receive a report from the classification society if their calculated fuel consumption, compared to the measured, exceeds 5%. This can be avoided if an expanded self-checking function are implemented in their system (Yin et al., 2017).

The perspective that high accuracy data is a "nice-to-have" thing, and not crucial to improve fuel efficiency, that you can achieve substantial fuel savings by conventional flowmeters, was shared by one of the interview subjects.

Additionally, different aspects of the crew's awareness were shared by all interview subjects. They all have clear strategies on this topic and continue to implement several relevant actions. Supporting citations include "*Awareness is the key to make it work*" and "*Awareness is crucial to ensure low consumption in operation*".

5.3 Schematic overview

Table 5-1 shows a summary of the main findings within the different themes,

Data acquisition and analysis	Data directly related to fuel efficiency	Collection and unite data	Data quality	Awareness
The core of the data in most vessels are from noon-reports	Improvements regarding speed optimization, driving at lowest amount of generators and hull efficiency are well established	Main challenge is to unite and collect data in one place to give a complete overview of the vessels condition	Accurate data is crucial for good decision-making	Clear strategies are implemented to increase the crew's fuel efficiency awareness

Figure 5-1 Main findings

6 Discussion

A manual reading of volumetric flow meters has at best an accuracy of 0.5-1%. By implementing digital mass flowmeters accuracy is reduced to 0.1-0.2% (Hunsucker et al., 2018). Accurate data is crucial to provide strategic recommendations. If a shipowner is to implement a fuel efficient technology that will result in a decrease of fuel consumption by 1.5-2%, like PBCF (Propeller Boss Cap Fins), it's difficult to prove any effect if the measured fuel consumption differs with over 5%. However, representing another perspective, one of the interview subjects stated that accurate data is important, but not crucial to improve efficiency. When measuring improvement in fuel consumption efficiency a deviation from baseline is used. One can assume that improvement in fuel efficiency can be identified as long as the sensors measure consistently high or consistently low data.

Shipowners expressed repeatedly the need for a dashboard connected to all sensors collecting all data to easily monitor fuel consumption and implement changes. Some shipowners developed their own systems, while some had concerns about the existing dashboards on the market being overpriced and financially unavailable. We can assume prices are high due to limited competition in the market. Sensor producers have hesitancy delivering a system to cover all data and sensors because it would jeopardize their own sensor sales. Further research is recommended to fully understand these challenges and identifying potential solutions.

According to the interview subjects, all findings regarding awareness were impossible to substantiate with numeric data. When asked how one make decisions based on the fuel consumption, onshore employees (mostly the interview subject themselves) make the decisions and perform required actions when identifying deviations from baseline in the analysis. The substantial efforts made and resources spent on crew awareness, can be debated considering the limited evidence to support these efforts. One can suspect the focus on crew awareness to possibly be motivated by the companies reputation and desire to attract reliable clients.

6.1 Reliability and validity

To improve reliability the researcher interviewed six different shipowners and performed lengthy interviews with all to increase the changes of procuring accurate results that can be retested with the same conclusion.

Reliability could be improved by having a research team rather than an individual researcher. The interview guide, the interviews and the analysis are all performed by an individual researcher. With a team, these elements would have peer influence and more likely to be reproduced, furthermore the results more likely to be reproduced.

To improve the validity of the project, the researcher ensured every interview subject that their responses were to remain anonymous, one can assume anonymity encouraged a true and honest response from the shipowners. The researcher did not provide the interview guide to the interview subject ahead of time; therefore, the interview subjects were unable to prepare and fabricate responses.

Validity was somewhat limited by the shipowners concerns about their own appearance and hesitation to speak unfavourably about their own company. This could influence their honest responses and the likeliness of true findings, that could be obtained in the remaining population outside this sample.

6.2 Limitations

Despite the researcher's effort to extract data and numbers from the shipowners regarding their fuel efficiency efforts, none of them could provide that information. They all implemented a series of efforts at the same time, without measurable success. They could not answer which actions provided meaningful results.

The researcher is as stated previously in the methods chapter, currently employed by a company who delivers maritime industry solutions. This strengthens the researchers position as the researcher possess extensive knowledge and understanding of fuel efficiency.

However, as the researcher is interviewing potential clients, efforts were made to eliminate a probable conflict of interest; the researcher made it clear to all interview subjects that the sole purpose of their interaction was for the research project and the researcher was not representing the company, whilst interviewing the subjects and writing the report. The researcher attempted to balance this issue best way possible and will leave it up to the reader to assess the quality of the work.

6.3 Recommendations to future research

Investigate shipowners rating on EU MRV list, could improve the reliability on the interview data. If the vessels have high ratings, it could support the current fuel monitoring situation onboard.

To fully understand the experienced challenges related to fuel efficiency, further research is recommended with larger sample sizes including shipowners from a larger geographical area.

7 Conclusion

Fuel consumption monitoring can be utilized in several ways. Three main conclusions can be drawn from the analysis of this research:,

- To monitor the fuel efficiently it is important that the fuel monitoring system can collect and unite all relevant data for fuel efficiency. Different dashboards can be developed to present this data, allowing the operators to easily analyse the data from the fuel monitoring system in their own platform and make improved strategic decisions.
- Make sure raw, collected data is as accurate as possible to improve the decision-making progress. It can be solved by installing digital flowmeters with high accuracy, with data directly implemented into the fuel consumption monitoring system. Additionally, numerous companies are increasingly implementing more advanced monitoring systems that use sensors and data analytics to optimize fuel efficiency.
- Continue to initiate actions for increasing the fuel efficiency awareness of the crew and facilitate for the operators with knowledge and support so they can optimize efficiency of the vessels when operating.

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9 Appendix

9.1 Appendix 1 – Interview guide Pilot interview

Introduction
 	
- Thank you for your participation
- Research background
  ○ Industry needs
  ○ Breakdown (technical/operational)
- Time management
	5 min

Technical
 	
- What system do you have onboard today that measures fuel consumption?
- How are the data analyzed?
- Are decisions made based on this data?
  - If yes, what kinds of decisions?
  - If yes, who makes these decisions?
- Do you find that there are other systems on board that can give you useful information regarding fuel consumption?
- About how many reports are required for the ship to report each year?
  - What kinds of reports are these?
	25 min

Attitudes and culture - What are the attitudes and willingness of the crew to reduce fuel consumption? - What knowledge does the crew have regarding the systems measuring emissions and efficiency? - How is the communication between crew onboard the ship and personnel on shore?	**25 min**
Other - Are there other observations you have made that you believe, or know, can contribute to reduce fuel consumption?	**5 min**

9.2 Appendix 2 – Interview guide Shipowners

Introduction - Thank you for your participation - Research background ○ Industry needs ○ Breakdown (technical/operational) - Main goal of the interview, mapping your current situation • Questions?	**5 min**
Technical - How do you measure your fuel consumption? - Do you have a system that measures it directly? - How is the data from the system analyzed? - Who does it? - Do you analyze data regarding maintenance? For example, for hull efficiency and consumers? - What type of decisions are made based on this data? - Who makes these decisions? - Do you find that there are other systems on board that can give you useful information regarding fuel consumption? - Do you have reporting tools for reports other than the noon reports?	**25 min**
Operational - How do you work with crew awareness regarding fuel efficiency? - How is the system knowledge for the crew on systems that measure consumption and efficiency? - How are any deviation in the analysis reported to the crew? For example, trim/list? - How is the focus on always operating the ships with optimized SFOC? - Do you have any registered deviations about fuel consumption?	**25 min**
Other - Are there other observations you have made that you believe, or know, can contribute to reducing fuel consumption?	**5 min**

9.3 Appendix 3 – Interview guide Ship Management

Introduction - Thank you for your participation - Research background ○ Industry needs ○ Breakdown (technical/operational)	**5 min**
Technical - Can you briefly describe how your system functions (VRS)? - From where do you collect the data? - Who is analyzing the data? - Is the analysis automatic, or is it performed manually? - What functions do you experience of most value for energy efficiency? - How do you measure hull efficiency? - Do you have functions for route and speed planning? - What focus do you have on the number of generators/main engines regarding SFOC? - Do you have functions to follow up on maintenance in your performance system (VRS)? - Reporting tools, - What kinds of reports do you have available your system? - How many reports are generated annually on a ship?	**25 min**
Operational - Who makes decisions regarding data? - How do you communicate with clients? - How do you work on attitudes and cultures within the crew regarding fuel consumption? - Do you have deliveries with VRS solely? - Do you find that it is advantageous for the ships fuel consumption that you deliver one complete delivery?	**25 min**
Other - Are there other observations you have made that you believe, or know, can contribute to reducing fuel consumption?	**5 min**