# Greening Smaller Ferries by Optimizing Operations

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**Abstract**

*A significant reduction in fuel can be achieved through operational changes, but to establish better practices, it is necessary to have equipment for evaluating the energy consumption under given circumstances and to be able to identify and evaluate energy-saving and cost-effective initiatives.*
*Many smaller ferry companies have no tradition for documenting operations or digital performance monitoring and analyse of their energy and fuel consumption. Therefore, the ferry crew, rely mainly on their assumptions about parameters influencing the operation, and how this impact the fuel consumption. The present study shows the results of an analyses of more than one year of logged data from operations of an older small island ferry. The preliminary results indicate that via digital decision support and effective decision support the ship can reduce the fuel consumption and the emissions with 10-20%.*

## 1. Introduction

There have for many years been an increasing attention to sustainable maritime transport. The increasing focus on climate change problems have brought environmental questions and pollution prevention high on the international agenda and the International Maritime Organization (IMO), has put forward a series of measures aimed at reducing the total amount of greenhouse gas (GHG) emissions from ships. In April 2018 the International Maritime Organization, IMO, adopted an initial strategy aimed at reducing total annual GHG emissions by at least 50% by 2050 compared to the 2008 level (IMO, 2018).

The present study deals with green and energy efficient ferry operation. Ferry operators are as all other shipping companies interested in saving energy, not only to comply with regulation but also to reduce cost and to comply with the increasing demand for green transportation and sustainable transport from the costumers. The global ferry industry is very large and the ferries play an essential role in transporting people, cargo and vehicles. Interferry, an organisation representing the Ferry Industry World-Wide (Interferry, 2020), estimates that there are approximately 1,300 ferries over 1,000 GT (gross tons) and thousands of smaller ferries globally. These vessels transport yearly 2.1 billion passengers, 250 million vehicles and 32 million trailers. Many of these vessels are older and are therefore to be renewed and substituted by more carbon friendly vessels in the coming years. A large part of this reduction can be achieved by new and updated ship design and the introduction of new fuels or low carbon fuels, but the transition will not be fulfilled tomorrow, retrofitting and replacing older vessels with newer will take years. While this replacement process is ongoing there need to be a focus at the practical operation of the old vessels. Operating the vessels in an energy efficient way is very important for reaching the goal.

The paper presents results develop in the EU funded projects ECOPRODIGI (2020) and EXOPRODIGI (2021), where eco-efficiency of shipping has been improved by introducing digitalization solutions on board island ferries in Denmark. In accordance with IMO, The Danish Government has set the course for a more climate friendly future, with a target of reducing GHG emissions by 70% by 2030 and the aim of making shipping carbon neutral. The smaller island ferries are also part of this goal. In Denmark there are 42 inland ferry routes operated by 52 vessels. The Island Ferries connect the Danish mainland to small islands of strategic importance, and their operations are supported financially by municipalities and government. The EU project involves four out of the 25 ferries.

The aim of the present study is to present the great potential for energy savings to be achieved using digital performance data and monitoring tools to optimize the operational practices on board smaller ferries. To illustrate and highlight the potential a case study of a small Danish ferry has been chosen. The crew has a lot of knowledge about the ship, route, and the operation, but need visual and accurate information about energy consumption and good energy practices. To establish a successful system for energy efficient operation, it is necessary to have equipment for evaluating the energy consumption and to be able to identify and evaluate energy-saving and cost-effective initiatives, monitoring systems are therefore a must. Even though that the importance of monitoring and analysing the performance of the ship is well known, only a few ferries systematically collect, store, and analyse data from the operation. Furthermore, research has also demonstrated that small shipping companies, as local ferry companies often will be, lack the resources to analyse, make decisions and implement energy efficient solutions (Johnson et al.; 2014), (Poulsen and Johnson; 2016).

The paper is organized as follows: Section 2 introduces ferry operation, digitalisation, and energy efficiency of ferries in general. Section 3 outlines data for the illustrative case “Exploring the energy efficiency of a small ferry”, section 4 contains the performance analysis of the case. Section 5 contains a short discussion and Section 6 presents the conclusions.

## 2. Ferry Operations, Digitalization and Energy Efficiency

Performance can generally be defined as the amount of useful work performed by a system compared to the time and resources used. For a ferry the performance can be defined as resources used for a given voyage. It relates to the energy consumption compared to the amount of useful work to sail and maneuver the vessel through the water and supplying electricity and heat to the operation of the ship and comfort of crew and passengers on board. When designing a ferry, the performance and the energy efficiency is taken into considerations through an energy-efficient hull design, optimized hotel load efficiency and focus at energy-efficient engines at the right engine layout – but awareness to the daily operation is very important and a significant reduction in fuel consumption can be achieved through changes in the operational practices, see e.g. , Jensen et al. (2018), DNV GL (2015), Eriksen et al. (2018) and Viktorelius and Lundh (2019).

### 2.1 Ferry Operation and voyage modes

Ferries have a unique sailing pattern that differ from the normal operational patterns of other vessel types. They usually have shorter sea passage followed by longer stay in port engaged with loading and discharging passengers, cars and trucks. The sea passage will for many ferries, especially the smaller sailing near the coast, be influenced by complex navigation in congested waters with heavy traffic. The traffic might in periods be increased by fishing or pleasure boats sailing at random crossing the route. The navigation near the coast will probably be restricted because of sailing in narrow channels or the presence of shallow water giving a low keel clearance resulting in a relatively high speed reduction. The crew is therefore busy navigating the ferry and has only limited time for voyage evaluation or optimization. Furthermore, for the crew energy efficiency is secondary to safety on board - in operations where there is limited maneuverability due to traffic congestion, complex navigation, low water depth or other environmental conditions, the focus is, and will always be, on safety first. Parameters that also will refrain the crew and the shipping operator from thinking greener and having an energy efficient operation will be the large focus at passenger comfort and keeping the pre-planned schedule.

A ferry sailing on a fixed route has good conditions for comparing operational parameters and thereby evaluate the level of energy efficiency. If a voyage having equal sailing distance and duration where the ship is exposed to comparable external conditions as e.g. similar wind and current, result in different energy consumption, a detailed analysis can identify reasons for the extra consumption. In order to compare voyages, it is important that the operational condition of the vessel is known. The fuel consumption for the situation where the vessel is alongside in port is very different from the consumption when it is sailing at full speed. Therefore, for reasons of comparability, the voyage must be separated into clear and comparable segments. The present study uses the definition of modes presented by Lützen et al. (2017) and Eriksen et al. (2018). See also figure 1, where the modes are illustrated.

- Manoeuvring where the vessel is operated under conditions restricting the vessel's movements, such as arrival and departure from port.
- Passage where the vessel is unrestricted in its manoeuvrability and able to operate at its design speed.
- Harbour where the ship is stationary in port without using its own propulsion.

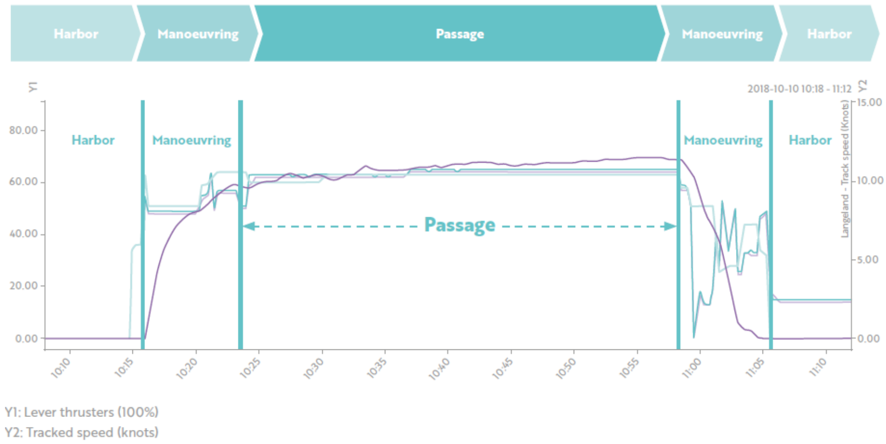


Figure 1. Modes – Harbour, Manouvrering, Passage, (Aro, 2020)

For ferries, the total voyage time is fixed due to timetables. Spending more time in one mode means that less time is available for the others. Therefore, looking at one mode in isolation will not give a true picture of the energy efficiency of the entire voyage. But the modes can be used for sub-optimisation as external conditions and operational parameters within each mode are comparable. On board ferries the separation between the modes can with advantage be geographic positions, which will give similar distances for all modes – and thereby comparable modes across more voyages.

As seen the whole operation is strongly controlled and regulated by the timetables, examining these are therefore of great importance. Rethinking schedules and timetables will open up for energy savings, an issue also mentioned by Jensen et al. (2019) and Johnson and Styhre (2015). Changing the timetables might seem a simple solution but can in practices be very difficult as many stakeholders are involved. Keeping the time intervals but making room for a more dynamic planning can be considered as e.g. allowing shorter harbour stays in period with less passenger and cargo, to allocate more time for sea passage.

## 2.2 Operational data sources and monitoring

Modern ferries generate a large amount of data for a wide variety of operational parameters - navigational and engine parameters are monitored and displayed on the bridge. Even thought that data is stored in the vessel's integrated control system, it is difficult to access, and it is often not possible to export data for analysis. On board older ferries operational data is only sparsely available. Minimum information for estimating the energy efficiency will typical be:

- Navigational information as position and speed over ground available from the GPS and ECDIS
- Relative wind direction and speed from an anemometer
- Main engine RPMs and/or Power output from digital or analogue readings
- Water depth will in some vessel be measured by an echosounder, but some vessels have only access to depth information from the chart or ECDIS
- Fuel consumption measured by a flow meter though many vessels only monitor the fuel

consumption by manual tank readings or by summing up bills from the weekly bunker purchases.

Other operational parameters necessary for evaluating the energy efficiency can be available on board in varying number.

To improve the performance or the energy efficiency of the ferry requires that the current energy consumption is mapped and known – then energy-saving initiatives and best practices must be identified. Therefore, various operations of the ship and the use of equipment must be carefully examined. Monitoring systems are therefore a must. A range of commercial energy performance systems are available at the marked, e.g. Vessel Performance Solutions (VPS, 2021), Kongsberg Vessel Performance (Kongsberg, 2021), Marorka Marine Energy Management (Marorka, 2021) and the performance monitoring system SeaTrend (Force, 2020). The problem is that these systems are mostly develop for long-distance sailing and cannot directly be used onboard working vessels or ferries. Only very few systems can handle these vessels, one of these is developed by Insatech (Insatech, 2021). The company's focus is on visualising data about fuel management and operation – they deliver a full package ranging from instrument installation, data collection and visualisation. The company BlueFlow (BlueFlow, 2021) has also developed an energy management package special for smaller ferries.

The biggest problem is however, for both newer and older ferries, that, even when data is monitored, it is not stored, and very few ferry companies have resources to invest, and monitoring systems are therefore seldom installed in these vessels. Many of the ferry companies having installed performance systems struggle to find time for analysis and lack more in-depth training of crew on how to convert data into systematic evaluations of energy use and optimized daily operational practices.

## 2.3 Parameters influencing Energy efficiency

This section considers energy savings or energy efficiency initiatives that can be considered during all modes when the ship is in operation. The description will include parameters that will influence the performance of ferries and only parameters that are easy to measure and evaluate. It is therefore not a fully thorough list of parameters to be evaluated for a detailed analysis of parameters affecting the resistance of the vessel. The external environment conditions as wind, sea and current are unchangeable and the crew must adapt to the conditions at the present time. As the route normally is short and the time relatively fixed, it will in most cases not be possible to change the navigational conditions great, but it is of most importance that the crew know the influence. The course and speed must be adjusted by increasing or decreasing the speed to the suitable level. Fouling at the hull will have a great influence at the energy consumption. The smoother the hull is the lesser the resistance will be, and thereby it will sail faster for the same power output. The draught and trim will affect the resistance. Most vessels are designed for a specific amount of cargo giving a specific draught and for a given draught there also exists a trim, that minimises the propulsion power. For a ferry with frequent arrivals and short passages the trim issue will be considered during loading, but it will normally not be a parameter for optimization due to time limitation.

During all modes a general instruction is to use the equipment most efficient. Reduce idling mode, start when needed and be aware of running equipment in most optimal load configuration. Be aware of the hotel load, turn off light, heat, and other electrical equipment when not in use.

The energy consumption in harbour is relatively low compared to the consumption in other modes, but the length of the port stay may have a big impact on the subsequent passage, where most of the energy is consumed. Minimising the time in harbour and instead using the saved time for an increase in passage time allows for a decrease in speed and thereby a lower fuel consumption and less emissions. Therefore, when analysing energy-efficiency initiative in the harbour mode, it is important not just considering directly energy saving issues but also to consider time reduction proposals.

Manoeuvring in the harbour is normally done manually and the length of the docking operation can vary greatly. The vessel is operated under conditions restricting the vessel's movements and maybe also traffic congestion. The use of engines and thrusters must be carefully considered. The on/off switching must be considered such that idling is avoided. At the same time, it is also very important that the navigator is fully confident with the situation – safety is the most important factor. Manoeuvring the vessel is both time and energy consuming and more attention to the mode can probably increase the time for passage and thereby reducing the speed and energy consumption. It is important to evaluate this in more detail for the individual vessel and route. Will a short manoeuvre running the equipment in high load be better than a longer manoeuvre with low equipment intensity? In the first case the vessel will have more time for the passage, but will this compensate for the extra energy used for the "aggressive" manoeuvre?

During sea passage the parameters can be separated into two main topics. One regarding the engine – running the engine with optimal settings and adjust the speed to allow for "just in time" arrivals. Navigational considerations are also important for obtaining an energy efficient operation. In most ferries the voyage is pre-defined, and the same procedures have been followed for years. But is this the optimal route under all circumstances - the crew should maybe re-consider the navigation. If the vessel is passing areas with shallow water, it must also be evaluated if it is advisable to slow down the vessel in this specific area and thereby reduce the resistance. If avoiding passing these low water areas is possible a route change might be a good solution, but this must be analysed in more detail.

### 2.4 Importance of Crew skills and training

Monitoring systems are essential, but as it is the crew on board that operate the ship, their daily work practices play a significant role. It is important that the crew understand the basics of energy efficient operation and achieve the necessary training, which is emphasized in studies by Banks et al. (2014), Jensen et al. (2017) and Hansen et al. (2020). Installation of monitoring equipment on board must be followed by training (Viktorelius and Lundh; 2019) and (Jensen, 2018), if the system is not intuitive to use or if the output is not meaningful for the crew, the system will not be used as expected. On board smaller ferries it will primarily be the crew themselves that will evaluate the output, and upon this plan for operational changes.

## 3. Case study - Exploring the energy efficiency of a small ferry - Data collection

A case study of a small Danish ferry is conducted to illustrate the great potential for energy savings to be achieved using digital performance data and operational optimization.

This section describes the process of collecting data for the analysis. The section starts with a description of the ferry and the route. Then follows sections on the collected performance data and voyage information from one year of data. The section ends with an overview of challenges identified during data logging, analysis and evaluation combined with interview and observations on board.

### 3.1 The ship and the route

The ferry is sailing in the area south of the island Funen in Denmark. The trade is in between the city of Svendborg and the two smaller islands Skaroe and Drejoe. The ferry has on a normal day 8 voyages from Svendborg to Drejoe and return – which is expanded with an evening voyage Friday, Sunday and holidays. The sailing time is fixed to 75 minutes.

The area is heavily trafficked by smaller leisure boats in the peak period in the summer and outside this period there is very little traffic in the area. The ferry is staying overnight at Drejoe. The Skaroe stay may in the winter season be skipped in case of no passengers to and from the island. This information is conveyed to the vessel by a telephone call.

The waters are confined with very little sea state even with high winds. The water depths are changing with very low water depths in some areas on the route. The current conditions change along the route and is difficult to predict, due to the high dependence on the wind conditions. The magnitude of the current can vary up to 5 knots in peak periods. Between the two islands the ferry passes through a channel “Hojestene”, which is very narrow, and it is difficult for two vessels to pass at the same time. The water depth is very low in this area, and the vessel experience a great influence from the shallow water effect. The current is not pronounced in this area.


| | |
|---|---|
| Name | m/f Hoejestene |
| IMO | 9169794 |
| Built / Yard | 1997 / Tórshavnar Skipasmiðja |
| LOA | 31 m |
| B | 10 m |
| Draught | 2.10 m |
| Service speed | 11.6 knots |
| Engines | 2 x 750 kW Volvo Penta |

Figure 2: Ferry characteristics

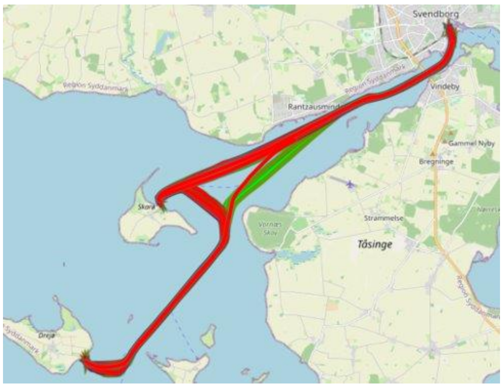


Figure 3: The Route. Svendborg – Skaroe - Drejoe

### 3.2 Performance data collection and visualization

The fuel consumption was not measured on board when the project was initiated. As this parameter is essential a flowmeter was installed. All other measures were identified, and an automated data logging solution was installed. Data is logged and transmitted to a cloud server where it is accessible for researchers, crew, and route leaders via a software application developed by the University of Southern Denmark, se figure 4. As the vessel is relatively old, only few parameters are possible to measure and log.

The following data were found accessible and measurable on board:

- Position (from ECDIS)
- Heading - over ground (from ECDIS)
- Speed - over ground (from ECDIS)
- Dept (echo sounder)
- Wind – direction and speed (anemometer)
- RPM from starboard and port engine (ME tachometer)
- Fuel consumption starboard and port engine (flowmeter)

All data are logged with intervals of 30 seconds.

The current – direction and magnitude – is not measured in the area. It is possible to receive prognosis current information from meteorological institutes, but as the current is very wind dependent in the area these data must be used with caution. Current direction and magnitude can be estimated if speed through the water is measured. Unfortunately, a log is not installed onboard, only speed over ground is registered.

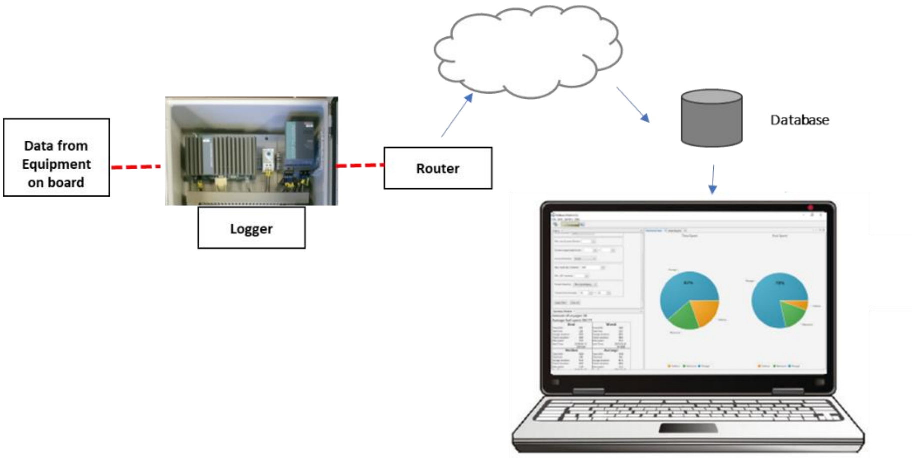


Figure 4: Dataflow – from equipment to computer

A software module has been developed to create transparency and insights into vessel operations and performance. This enables the user to select and filter imported data sets with respect to a given period, sailing conditions and operational modes with the purpose of viewing, or plotting operational performance for one or more variables. The system enables the officers on board or shore staff to identify the most environmentally friendly way of operating the ship. The system is not a real-time decision support system, but a system for evaluating and reflecting on voyages in order to determine best operational practices.

The presented study shows the results of analyses of more than one year of logged data from operations of the ferry.

### 3.3 Voyage information

The current analysis is based on data collected onboard during the whole year of 2020, from a total number of 2945 voyages. The distribution of time and fuel spent in the different modes can be seen in Figure 5 visualized by way of pie charts. The distribution of the three modes passage, manoeuvre and harbour is respectively 56%, 11% and 34 % for the time and 79%, 13% and 9% for the fuel consumption.

The number of individual voyages including voyages where the island Skaroe has been skipped can be seen in table 1. The average, minimum and maximum fuel consumption and time used are also shown in the table. The large variation in fuel consumption – difference between minimum and maximum - can be due to parameters that cannot be changed such as different external conditions as wind or current, and traffic congestion, but it may also be due to the way of operating the ferry, this will be analysed further in section 4.

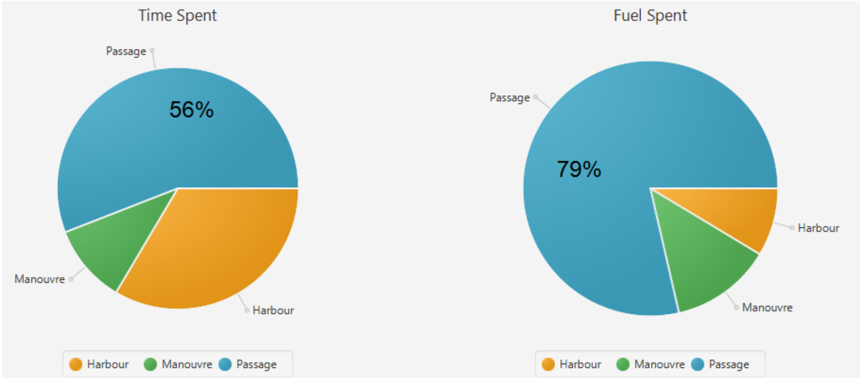


Figure 5. Time and fuel spent in different modes

Table 1. Voyage information for 2020

| | Voyages | Average | Minimum | Maximum |
|---|---|---|---|---|
| Drejoe-Skaroe-Svendborg | 1313 | | | |
| Fuel [litre] | | 90 | 64 | 129 |
| Time [minutes] | | 66.5 | 69 | 67.5 |
| Svendborg-Skaroe-Drejoe | 1334 | | | |
| Fuel [litre] | | 96 | 62 | 136 |
| Time [minutes] | | 68.5 | 72.5 | 84.5 |
| Drejoe-Svendborg | 160 | | | |
| Fuel [litre] | | 65 | 35 | 85 |
| Time [minutes] | | 57.5 | 61 | 60 |
| Svendborg-Drejoe | 138 | | | |
| Fuel [litre] | | 64 | 35 | 104 |
| Time [minutes] | | 58 | 63.5 | 59 |

### 3.4 Challenges identified

Based on interviews and observations, onboard, the researchers identified a set of challenges with respect to operations and energy efficiency. It was seen that the ferry crew rely on their training, experience and assumptions about parameters influencing the operation, and how this impact the fuel consumption. There has been no tradition for documenting operations or monitor the effect of actions taken. The effect of wind, water depth and currents have been based on assumptions and more related to safety, passenger comfort and schedule adherence than to performance. No documentations or baselines for e.g. speed or RPM versus fuel consumption are available, and therefore there has been no link in between engine settings and consumption. The apparent difference in fuel consumption on different voyages, see section 3.3, calls for a deeper analysis of root causes. Unfortunately, factors that may influence the performance as e.g. navigational difficulties or late departures due to a large number of cars or passengers are not registered today, therefore the analyses must be based on logged data only.

## 4. Case Study - Exploring the energy efficiency of a small ferry - Performance Analysis

Four different analyses have been chosen for illustration. Analyses that will provide the crew with useful information and knowledge, which can help them to evaluate and improve the performance of the ferry in the future.

The four analyses:

- Baselines - creation
- Shallow water effect on speed and fuel consumption
- Wind effect – added resistance and fuel consumption
- Time schedule analysis

All analyses are based on data logged on board the vessel during the year 2020 – a total of 2945 voyages. The visualization software described in section 3.2 has been used to extract data for further analyses.

### 4.1 Baselines - Creation

Baselines for speed and engine relationship did not exist for the vessel, therefore a new set of curves for were created based on measured and logged data.

- Speed (over ground) versus fuel consumption
- RPM versus speed (over ground)
- RPM versus fuel consumption

Data filtering have been applied to eliminate influencing factors from wind and water depth (heavy sea is normally not present in the area). The resulting deep water, calm sea baseline curves can be seen in the figures 6 and 7. Here data from one year of logging has been fitted by polynomials to the best curve. Speed/fuel polynomial of degree 3, RPM/speed degree 2 and finally RPM/fuel degree 3.

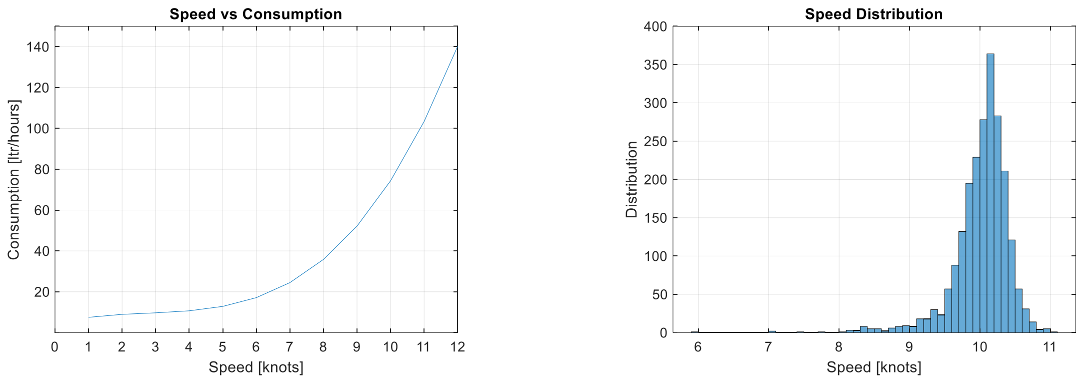

Figure 6. Left: Fuel consumption versus speed. Right: Speed distribution

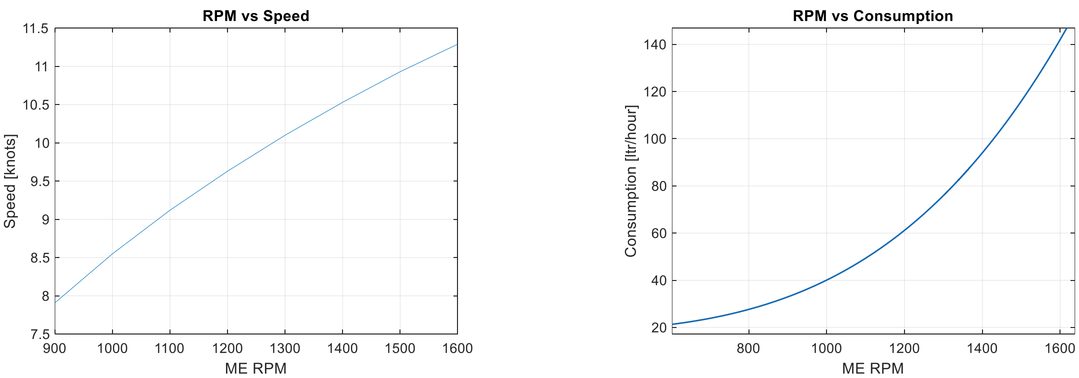

Figure 7. Baselines for the vessel. Left: RPM versus speed. Right: RPM versus fuel consumption

Figure 6, left, shows the fuel consumption as function of the speed. Right diagram in figure 6 shows the average speed distribution for all voyages. It is remarkable that the fuel consumption curve is dramatically steep in the operational area of about 10 knots. Meaning that just a small speed increase will result in a large fuel increase. For example, will a speed increase from 10 to 10.5 knots gives increased consumption of approximately 20%.

Figure 7 left and right show the RPM versus speed and fuel consumption respectively. The RPM curves will be a very useful tool for the crew on board most vessels, as it is the RPM setting that will be the input factor when they change the speed of the vessel.

### 4.2 Shallow water effect on speed and fuel consumption

The vessel is passing several areas where the water depth is low. The low water depth greatly influences the vessels speed for given RPM. Figure 8 shows the depth below keel and speed of the vessel when passing the "Hoejestene" channel. The figures show that passing areas with a depth between 3.5-4.5 meter, the shallow water effect will result in a relatively large speed reduction.

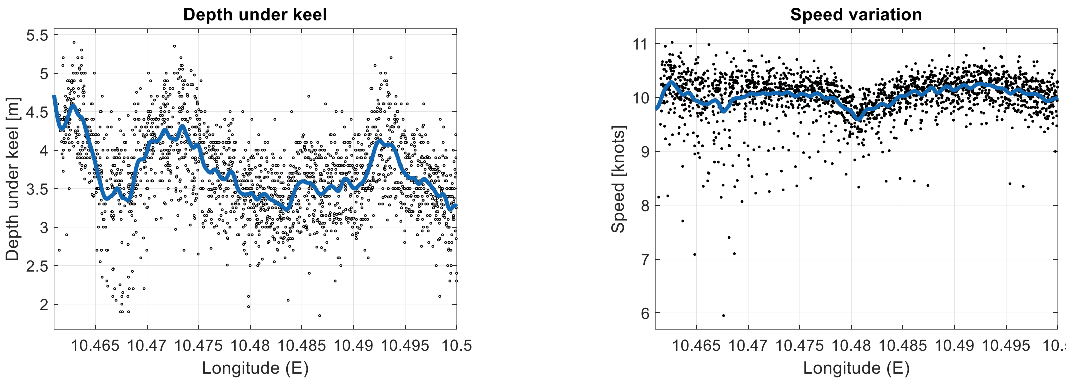

Figure 8. Left: Depth below keel, measured. Right: Vessel speed passing the channel.

Figure 9 shows the speed versus the fuel consumption for varying water depths. The deep-water baseline curve is shown for comparison. It can be seen, that if RPM (and thereby the fuel consumption) is maintained as given for 10 knots, it will result in a speed reduction of about 4%, 8% and 15% for water depths of 8m, 6m and 4m respectively. If on the other hand a speed of 10 knots is maintained when passing the channel, the increased fuel consumption will be 8%, 24%, and 70% for the same water depths.

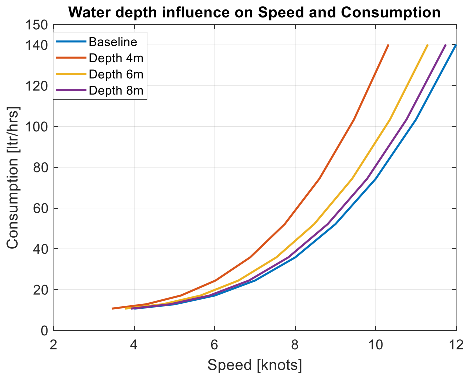

Figure 9. Fuel consumption as function of speed for various water depths.

### 4.3. Wind effect – added resistance and fuel consumption

The axial wind force acting at the ship can be determined by:

$$R_x = \frac{1}{2}\rho_A C_x A_{VT} V_R^2 \tag{1}$$

Where $\rho_A$ is the mass density of air, $C_x$ the axial wind force coefficient, $A_{VT}$ the projected area of the ship above the waterline and $V_R$ the relative wind velocity. The axial wind force coefficient $C_x$ can be determined by through model tests in wind tunnels, but in cases where these tests are not performed, the coefficient can be estimated by use of general equations. Here the empirical method suggested by

Isherwood (1973) is used. Isherwood analyzed a number of wind tunnel tests on various ship types. Data from the tests were analysed by multiple regression techniques and was fitted to an equation for the axial wind force coefficient $C_x$:

$$C_x = A_0 + A_1 \frac{2(A_L + A_{SS})}{LOA^2} + A_2 \frac{2A_T}{B^2} + A_3 \frac{LOA}{B} + A_4 \frac{S}{LOA} + A_5 \frac{C}{LOA} + A_6 M \qquad (2)$$

Where $LOA$ is the length overall, $B$ the breadth, $A_L$ the lateral projected wind area, $A_{SS}$ the lateral projected area of superstructure and deck cargo, $A_T$ the transverse projected wind area, $S$ the length of perimeter of lateral projection (excluding waterline and slender bodies), $C$ the distance from bow to the center of lateral projected area and $M$ the number of distinct groups of masts or king posts.

The constants $A_0$ to $A_6$ are derived from tests and can be found tabulated in Isherwood (1973). The specific ship related constants are determined from general arrangements drawings of the vessel.

| $LOA$ | $B$ | $A_L$ | $A_{SS}$ | $A_T$ | $S$ | $C$ | $M$ |
|---|---|---|---|---|---|---|---|
| 35 m | 10 m | 170 m$^2$ | 25 m$^2$ | 80 m$^2$ | 80 m | 17 m | 1 |

Figure 10 shows diagrams for the axial wind force coefficient and axial wind force for the ferry Hoejestene. Both values are shown as function of the relative wind direction.

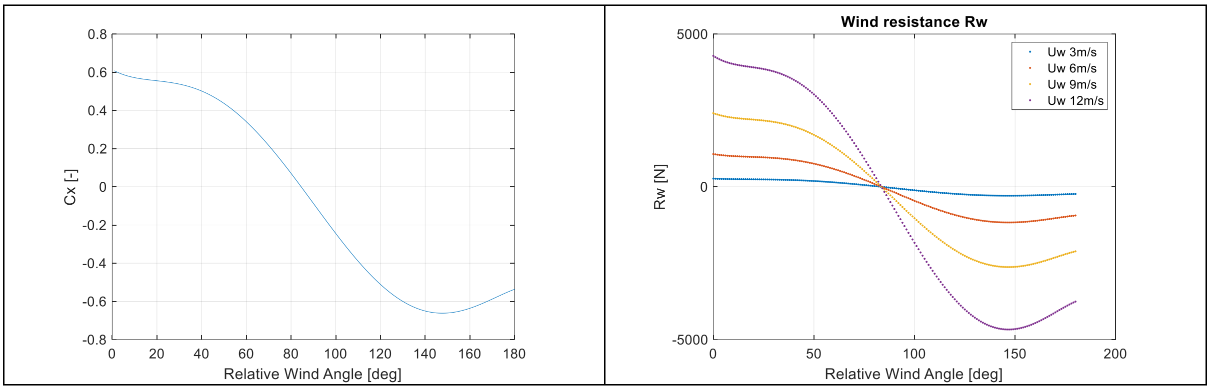

Figure 10. Left: The axial wind force coefficient. Right: The The axial wind force. (Hoejestene).

The relative wind is measured by an anemometer on board the ferry Hoejestene. Figure 11 shows the distribution of the relative wind parameters, direction, and speed, for the year 2020. Left figure shows the wind for passage through the channel “Hoejestene”, the right for the passage of the sound between Funen and the Island Taasinge. It can be seen that westerly winds are dominant, and that the vessel will be in the lee of land when passing the sound.

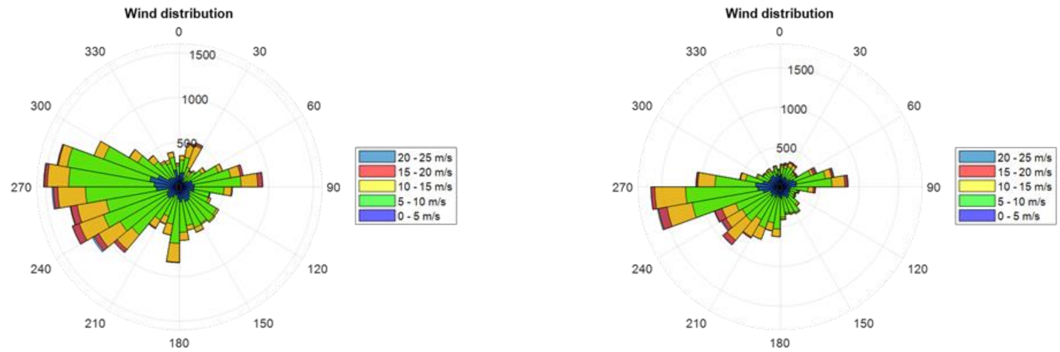


Figure 11. Wind distribution, relative wind – left channel, right sound.

The extra power due to the wind resistance can be determined

$$\Delta P = R_x \cdot \mathrm{V} \tag{3}$$

Unfortunately, no SFOC curves are available for the engines on board but knowing the engine type and size a good estimate can be made for the extra fuel consumption due to wind. Figure 11 shows the fuel consumption as function of the vessels speed. The baseline is shown together with two examples of sailing in head wind with a measured relative wind at 6 and 12 m/s respectively. The figure shows that sailing at 10 knots and measuring a relatively wind from ahead of 12 m/s (corresponding to an absolute wind speed of 6.9 m/s ~ Beaufort 4) the fuel consumption will increase with approximate 8%. If a relative wind of 6 m/s is measured (~Beaufort 1) the increase will be approximately 3%.

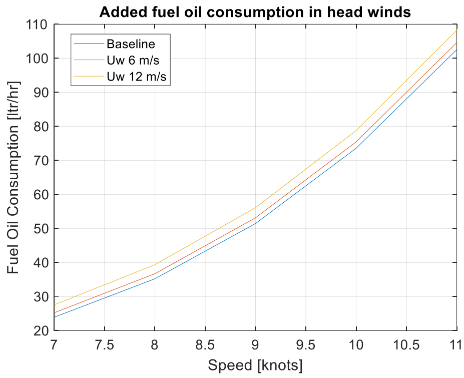


Figure 11. Fuel consumption as function of vessel speed, baseline and in head wind.

### 4.4. Time schedule analysis

Analysing all voyages during 2020 shows that for voyages Drejoe-Skaroe-Svendborg (both directions) the average fuel consumption is between 90 and 96 litres and the transit time used is below 70 minutes. There can be reasons for not using the scheduled 75 minutes e.g. because of extended harbour stay due to many passengers in summer vacation. The main reason is probably that the crew onboard are not aware of the sailing condition for the whole coming voyage and therefore sail with a slightly higher speed than necessary to avoid being late for the next arrival. Today the crew does not have any instruments available that can help them to evaluate the coming voyage and thereby adjust the speed to arrival “just-in-time”. Data shows that the ferry arrives about 5 minutes to early in most voyages. If these in-effective minutes are converted to sailing time – the speed of the vessel can in average be reduced from 10.2 to 9.3 knots and the fuel consumption by not less than 20%. Here the baseline curve for speed versus fuel consumption, see section 4.1, is used for estimation.

The analysis shows that if the island Skaroe is skipped, see table 1 in section 3.3, the fuel consumption can be reduced by nearly 30%. Additionally, for these voyages the scheduled voyage time is not fully used, and the vessel will often arrive more than 10 minutes before scheduled.

### 6. Discussion

To improve the performance or the energy efficiency of the ferry requires that the crew has tools to help them estimate the fuel consumption and to be able to identify and evaluate energy-savings and cost-effective initiatives. The present study has shown that it is possible to provide a relative old ferry with enough information to estimate their performance. The crew did not have any information related to the fuel consumption and they relied on their assumptions about parameters influencing the operation. The study has shown that with just measuring a few data systematically, it is possible to provide the crew with valuable information.

The baseline curves for speed and engine relationship were created. These curves are of greatest importance when estimating the vessel performance. The baseline curves are very illustrative, and they give the crew information about how even smaller speed reductions can reduce the energy consumption dramatically. Sailing at shallow water at some areas of the route must be taken into account when planning the whole voyage. The shallow water analysis clearly shows that it is important to consider the speed setting through the area. The external environment conditions as wind, sea and current are unchangeable and the crew must adapt to the conditions at the present time of the voyage. As the route normally is short and the time relatively fixed, it will in most cases not be possible to change the navigational conditions much, but it is of most importance that the crew know the influence.

It must be remembered that the crew is very busy navigating the ship and has only limited time for voyage evaluation or optimisation. Furthermore, for the crew energy efficiency is secondary to safety on board - in operations where there is limited manoeuvrability due to traffic congestion and complex navigation, the focus is, and will always be, on safety first. Therefore, the above information is valuable for the crew and a great fuel reduction can be achieved by studying curves and evaluating the sailings, but to have the fully effect of the information a decision support tool would be preferable. The tool must be very simple to use – just a few inputs and outputs – like using an APP at their mobile phone.

Not having a decision support tool, the different speed settings can be very difficult for the crew to estimate and they will probably be sailing too fast, which the analysis also showed. The crew is not aware of the conditions for the coming voyage in total and therefore sail with a little higher speed than necessary to avoid being late for the next arrival. The tool can help the crew to adjust the speed to a suitable level. If this is done properly the vessel will arrive in due time and will not use unnecessary energy because of sailing too fast. The ferry has a schedule with fixed timeslots, therefore reducing the speed in some areas will also result in a necessary speed increase in others. During shallow water passages the speed must be reduced, increase during deep water passage, increased during strong head wind slowed down during tail wind etc.

Re-considering schedules is today an overlooked issue for smaller ferries and a lot of energy can be saved allowing for longer time at sea. Keeping the time intervals and making room for a more dynamic planning as e.g. shorter harbour stays in periods with less passenger and cargo allowing for a longer sea passage or even skipping voyages with only few passengers will reduce the fuel consumption significantly. Also, a smart and effective booking system may be useful, as knowing the number of passengers beforehand will give the crew good information about time required for the coming harbour stay.

Training the crew in being aware of energy consumers on board and in the use of digital performance tools can contribute to the savings. The importance of training the energy awareness and educating the crew within the subject has been emphasized by e.g. Banks (2015), Jensen et al. (2018) and Hansen et al. (2020). Focus at energy communication is also an issue that requires training and special awareness (Jensen et al., 2018). Sharing knowledge and experiences is important for finding and develop new shaving initiative and keeping the crew involved and motivated.

## 6. Conclusions

The study has shown that digitalization of ship operations, even with very few data point, can be of great value when evaluating the performance of a ship.

The operational of a nearly 25 years old ferry with a length of 31 meter transporting a maximum of 98 passengers have be analysed and great energy savings potentials are found.
The wind effect and the shallow water effect has been analysed and the importance of taking these factors into account have been illustrated.

The importance of using the available time – not coming too early – is shown. Currently, the vessel typically arrives 5 minutes too early - if these minutes are converted for sailing, the fuel consumption can be reduced by not less than 20%. The effect of having a good booking system have also been demonstrated. If there are no passengers for the middle Island “Skaroe”, the arrival can be skipped, and the energy can be reduced by nearly 30%. Allowing for shorter harbor stays and converting harbor time to sailing time will be of great importance. The analysis showed that if the vessel can reduce the speed by e.g. half a knot – from 10.5 to 10 knots – the energy consumption is reduced by approximately 20%.

The study has been conducted upon data from a small ferry sailing in Danish waters, but it is assumed that the findings can be used as guidance for smaller ferries and vessels with shorter sea passages worldwide.

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