D4.1 Operational profiles

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Chapter 1

Introduction

This document presents deliverable D4.1. within MoveIT project. It contains results and analysis of operational profile of an inland vessel. Measurements of operational profile have been done during six months on Veerhaven X. Results indicate strong influence of water depth on the performance of the ship and, ultimately, strong influence on the operational profile. Combining the results of the measurements with a dynamic model of the ship, it will be possible to investigate different power configurations and retrofit options, and evaluate their modelled performance regarding the exhaust emissions. Modelling and evaluation of different power configurations and retrofit options will be done in next deliverable.

Chapter 2

Veerhaven X

The 'Veerhaven X'[1] is shown in figure 2-1. The vessel is designed to navigate on inland waters with a maximum of six tug-pushed dumb barges. In order to have considerable propulsion power and optimum manoeuvrability in the generally busy, shallow, and windy inland waters the vessel is equipped with a triple screw propulsion configuration and three fishtail rudders. Also the vessel is equipped with two bow thruster units to have optimum manoeuvrability while manoeuvring.

Figure 2-1: Veerhaven XI, sister ship of the Veerhaven X

[1] The pushing boats owned by TK Veerhaven are named 'Veerhaven' with a corresponding roman number.

2-1 Main particulars

Table 2-1 represents the main dimensions and table 2-2 represents the main technical data of the vessel. The general arrangement plan is given in Appendix A.

Table 2-1: Main dimensions benchmark vessel

Main dimensions	Value
Length over all	40 m
Breadth over all	15 m
Depth	2.75 m
Draft	1.72 m

Table 2-2: Main technical data benchmark vessel

Principle particulars	Dimension
Propulsion power	3 x 1360 kW
Auxiliary power	4 x 315 kW
Harbor generator set	80 kW
Bow thrusters	2 x 400 kW
Fixed Pitch Propellers mounted in a nozzle	3 x 2.05 m

2-2 Push barge

The types of tug-pushed dumb barges (push barges) currently used by TK Veerhaven are the 'Europa II' barges. These are standardized barges, which first basic design was made around 1970 (Heuser [1985]). In table 2-3, the main characteristics of this type barge are presented.

Table 2-3: Main characteristics of Europe II push barge

Main dimensions	Value
Length over all	76.50 m
Breadth over all	11.40 m
Maximum Draft	4 m
Empty weight	450 ton
Load capacity	2800 ton

2-3 Power installation

The benchmark vessel is equipped with 3 identical direct drives, and four auxiliary engines, see figure 2-2.

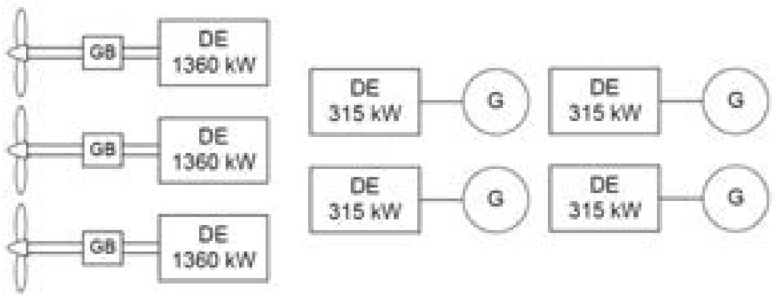

Figure 2-2: power arrangement of Veerhaven 10

2-3-1 Diesel engine

Figure 2-3 shows one of the diesel engines used for propulsion, a 8M 20 MAK diesel engine. This is a 8 cylinder in line 4-stroke medium speed engine, which has direct fuel injection, is turbocharged, intercooled, and non-reversible. The nominal operating point is 1360 kW at 900 rpm and the idle speed is 350 rpm. Figure 2-4 shows the engine's speed power characteristic, which is a third power curve.

Figure 2-3: Diesel engine shaft line

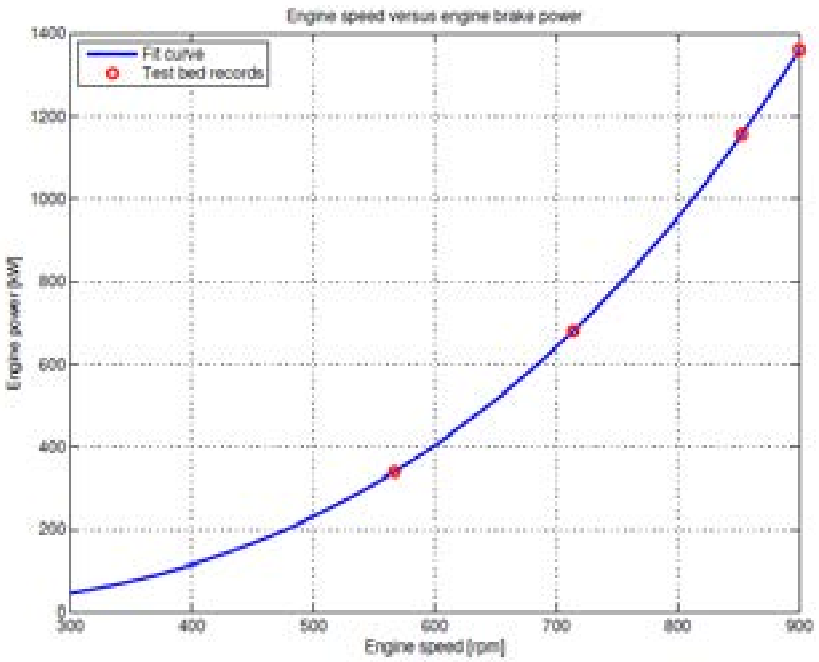

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Figure 2-4: Enigine characteristics, measured and fitted values

2-3-2 Propeller

Each drive train is equipped with a fixed pitch propeller (FPP). The propellers are fitted in nozzles from Lips/Wärtsilä. The HR nozzles each have an inner stainless steel covering over the complete length of the nozzle. In table 2-4 is listed the main propeller data.

Table 2-4: Main propeller data

Principle particular	Value
Number of blades	5
Diameter	2.05 m
Disc area ratio	0.95
Weight	1075 kg

Chapter 3

Ship performance

The operating conditions are influenced by a number of factors and are included in the following groups:

- Environmental conditions; factors like: wind, current, water depth, and width of the fairway.
- Operational modes: sailing river upstream, sailing river downstream, or manoeuvring.
- Loading conditions; include the amount of cargo, draft and size of the pusher-barge combination.
- Operating the vessel; indicates how the vessel is operated by the crew.

3-1 Environmental conditions

The Dutch Rhine delta, the Rhine to Duisburg, and some tributaries to Belgium is the operating environment of the pusher. The pusher has the following destinations:

- Amsterdam.
- IJmuiden.
- Flushing.
- Terneuzen.
- Antwerp
- Gent.

However, most of the time the pusher is operating between Rotterdam and Duisburg. Consequently, the route from Rotterdam to Duisburg and vice versa is considered for the operational profile. The sailed distance between Rotterdam and Duisburg is approximately 230 km.

Figure 3-1: Rhine states

3-1-1 Current

The strength of the current depends on a number of factors:

- The tide; around Rotterdam and even a long way river upstream the presence of the tide is significant. The tide gives advantages in terms of speed when sailing upstream at rising tide, and sailing downstream at outgoing tide.
- Rain; which causes an increased volume flow of carried off water.
- Melting water. In spring the river depths are generally higher than other seasons.

There is not really an indication of the river's current, as only the speed over ground is available from measurements.

3-2 Operational modes

The voyage was divided in the following operational modes:

- Upstream mode – (full) barges are carried upstream from Rotterdam to Duisburg.
- Downstream mode – (empty) barges are carried river downstream from Duisburg to Rotterdam.

- Manoeuvring mode – the barges are coupled and uncoupled at the place of destination.

3-2-1 Upstream

The voyage from Rotterdam to Duisburg is the upstream mode in which is normally sailed with either 6 barges or 4 barges. When sailing with 6 barges it will be in a 3 (length) by 2 (breadth) barge configuration, while sailing with 4 barges is done in a 2 by 2 barge configuration. Normally the barges are full, or loaded as full as possible.

3-2-2 Downstream

The voyage from Duisburg to Rotterdam is the downstream part of the voyage. Just as in the upstream part, the pusher sails either with 6 barges or with 4 barges which depends on the availability of the barges in Duisburg. With 6 barges the pusher sails in a 2 (length) by 3 (breadth) barge configuration, while with 4 barges in a 2 by 2 configuration. Generally, in the downstream part the pushed barges are empty. In the downstream mode the engines are mainly operating at part load, since the ship is operating in relatively low operational conditions.

3-2-3 Manoeuvring

The manoeuvring mode is defined as the part between the upstream and downstream voyage. In this mode the vessel in mainly manoeuvring to uncouple the transported barges from the pusher at the place of their destination and to couple new barges for the next voyage. In Rotterdam the uncoupled barges will be loaded with cargo for the next voyage and in Duisburg the fully loaded barges are unloaded.

3-3 Loading conditions

The draft and the amount of barges of the pusher barge configuration are dependent on the water level and the expected water level (regarding the rain or dryness) on the Rhine. The following points determined the draft and the barge configuration:

- Ruhrort.
- MGD Waal (Minst Gepeilde Diepte Waal), which is the lowest sounded point of the Waal.
- Lobith.

The draft of the barges are loaded based on the water level from Ruhrort and MGD Waal. The barges are loaded till a maximum draft of 3.90 meter. This is because of the fact of flowing water through the gangway, which gives an increase in resistance. When Lobith indicate water levels between 7,50 and 13,50 meter it is allowed to transport 6 barges. When this water level is lower than 7,50 meter a maximum of 4 barges is allowed. This only applies to upstream voyages.

3-4 Operating the vessel

As shown in Figure 2-2, the ship is equipped with three propulsion lines. It depends on the captain whether 2 or 3 engines are used. Reasons for switching one engine off are:

- Maintenance carried out during the voyages.
- Postponing of maintenance. The engine with the highest running hours will be switched off.
- Reducing the time in part for the engines, which gives more favourable combustion and higher efficiencies.

Reasons for keeping all three engines running are:

- To maintain maximum redundancy.

Bunkering is usually done while sailing.

Chapter 4

Measurements

Measurements of variables from the benchmark pusher were made available by the company. The measured variables were logged during operation of the vessel and consist of:

- Fuel rack position in %.
- Ship speed over ground in kn.
- Ship position in deg and min.
- engine rpm.

In total 6 months of data was available with average sampling rate of 18 minutes. This data included all voyages from Rotterdam to Duisburg, Duisburg to Rotterdam, and voyages having other destinations. This report will only investigate measurements between Rotterdam and Duisburg, in total 73 voyages.

4-1 Fuel rack to engine power demand

The OP was formed using the measurements of the fuel rack position of the 3 propulsion engines. The choice of using fuel rack for the OP was made since this study focused on exhaust emissions and fuel consumption. Besides, it was needed to derive engine power from fuel rack to analyse the benchmark vessel's power demand of the propulsion installation. Fuel rack was translated to engine power. In figure 4-1 the process from measured fuel rack to power delivered is schematically presented. From the figure it can be observed that first the measured fuel rack was matched with the actual fuel rack from the fuel pump. Since the actual fuel rack directly determines fuel mass flow, and fuel mass flow is a measure of engine power for a specific operational condition, it was possible to relate the measured fuel rack with engine power of the test bed records.

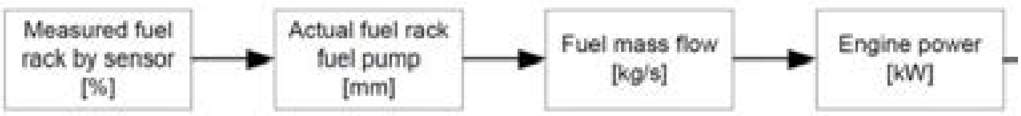


Figure 4-1: From logged fuel rack to power delivered

Matching measured fuel rack with actual fuel rack fuel pump

The fuel rack sensor gives the position of the fuel rack as a percentage of the nominal fuel rack, which is the fuel rack position at 100% load. The actual fuel rack is the position in mm. Figure 4-2 shows the actual fuel rack in mm. Nominal fuel rack is at a value of 27 mm, while the stationary value is around 10.5 mm. The fuel rack from the sensor is approximately 40% at stationary, while it approaches 100% at full load condition. A fit curve for each specific engine was used to translate the sensor measurements to the actual fuel rack position indicated by the fuel pump. Deviating data points can be a result of errors in the sensor's measurement.

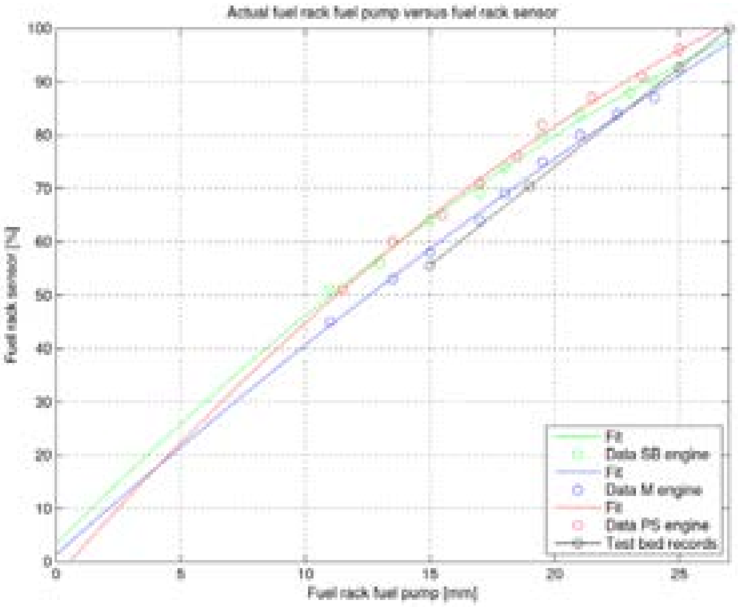


Figure 4-2: calibration of fuel rack sensor

From actual fuel rack to fuel flow

Figure 4-3 indicates the relation between fuel rack position and fuel flow. This proportional relation is a consequence of the geometry of the plunger (helix shape) inside the fuel pump. The plunger is cam driven and rotates to a position that is set by the fuel rack. The position of the plunger determines the amount of fuel injected in the cylinder per 2 cycles (indicating by a graph).

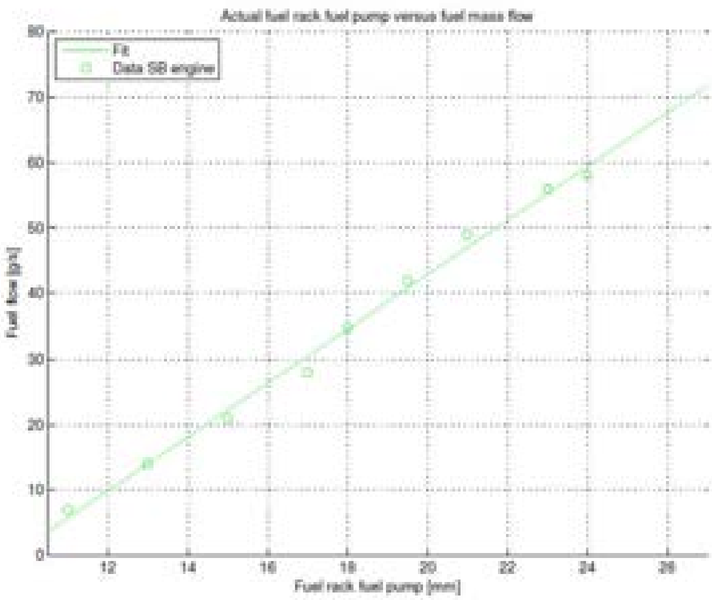


Figure 4-3: fuel rack position vs. fuel flow

From fuel flow to engine power

Figure 4-4 shows a proportional relation between fuel flow and engine power. This relation is explained with:

$$P_B = \dot{Q} \cdot \eta_e$$

Where heat flow ($\dot{Q}$) is rewritten as:

$$\dot{Q} = \dot{m}_f \cdot h^l$$

And:

$$P_B = \eta_e \cdot m_f \cdot h^l \cdot \frac{n_e \cdot i}{k}$$

Where the lower heating value h^L is a constant and by assuming η_e to be constant over the complete range of operational speeds n_e the delivered power is proportional to engine speed and the injected fuel per cylinder per cycle.

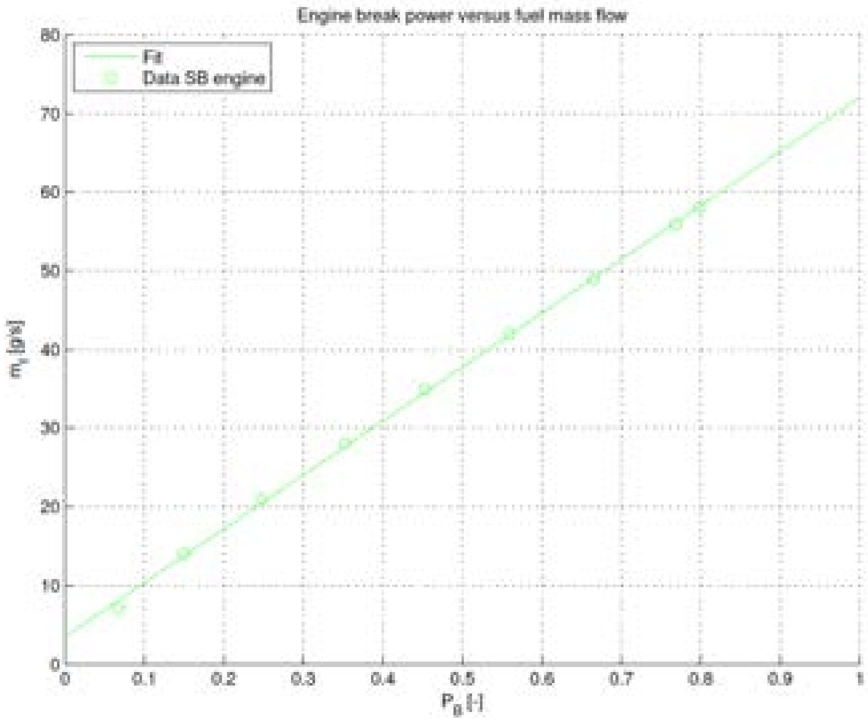


Figure 4-4: engine power vs fuel flow

Chapter 5

Results

Measurement results were used to make an operational profile of the ship. Figure 5-1 (left) shows operational profile of the ship during six months. Figure 5-1 (right) shows operational profile during same period but only for voyages made between Rotterdam and Duisburg (73 voyages in total). The figure shows the distribution of power demand [kW] as a function of time. In the figure also a cumulative percentage line is shown. This line gives an indication of the contribution of each bar to the total amount on the right y-axis.

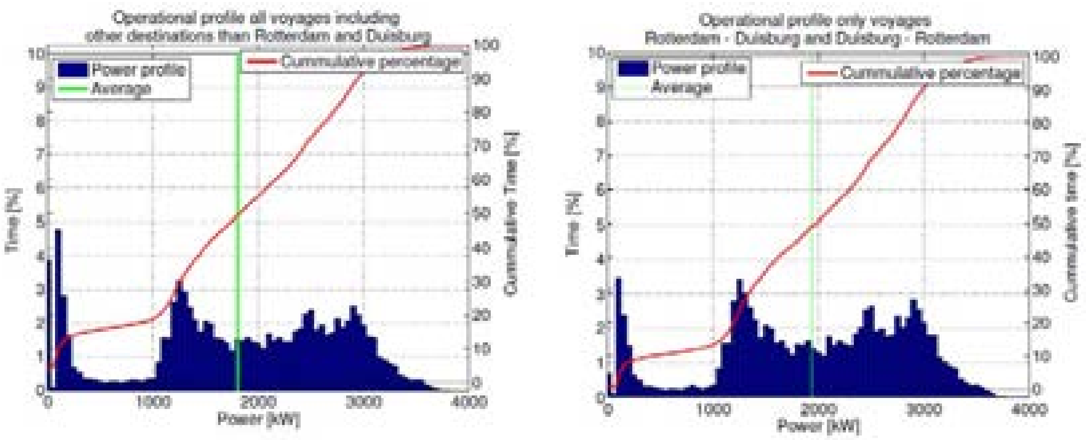


Figure 5-1: Six months operational profile of the ship from all voyages (left) and only from Rotterdam-Duisburg voyages (right)

In Chapter 3, three operational profiles have been defined. Figure 5-2(left) shows operational profile of the ship from 73 voyages regarding the operational modes. The cumulative percentage is around zero at zero power and 100% near full power. The reason that the cumulative percentage line is not completely zero is because of the first bar of the histogram, which already contributes to a percentage equal to the deviation from zero. In the figure the green line indicates an average power demand of 1934 kW, which is around 47% of nominal load. Figure 5-2(right) shows total time percentage of time spent for each operational mode. It can be observed that the vessel was 59% of the time sailing upstream, 31% of the time sailing downstream and 10% of the time manoeuvring.

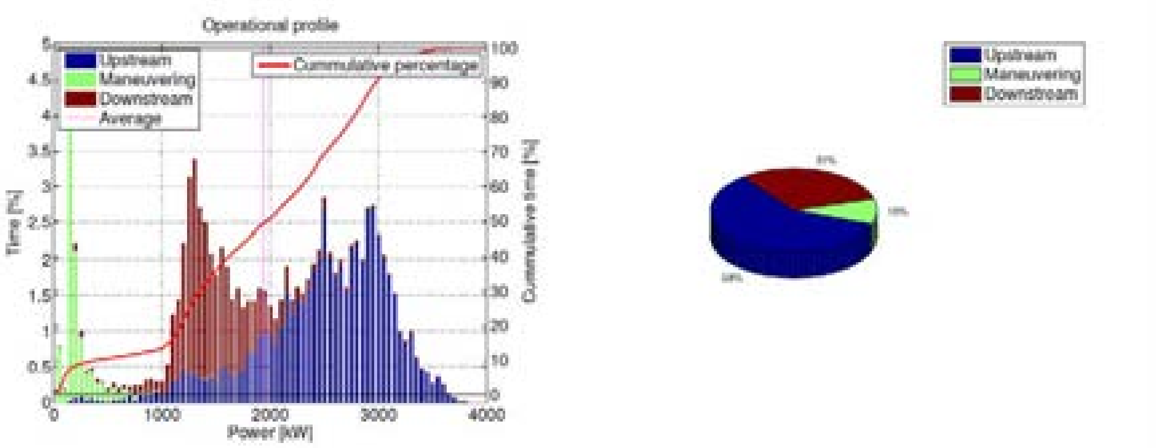


Figure 5-2: Operational profile of 73 voyages between Rotterdam and Duisburg: power distribution (left), total time spent per operational mode (right)

Further, Figure 5-3 shows power distributions for three operational modes and average power values per mode.

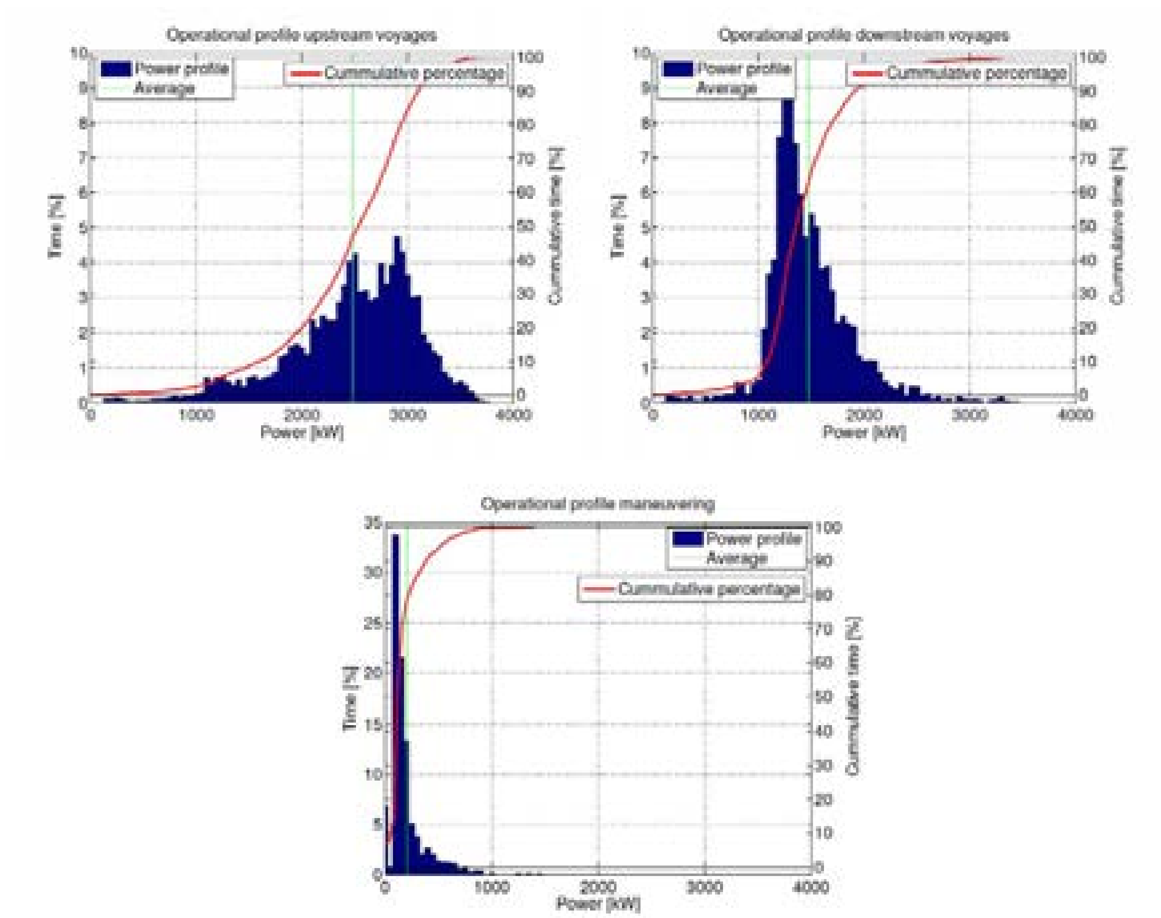


Figure 5-3: power distribution per operational mode

Besides measurements of power and operational profile, records from ship's logbook were also available. Records from the logbook contain values of the cargo transported and fuel consumed. Figure 5-4 shows ratio of fuel spent per voyage and cargo transported per voyage.

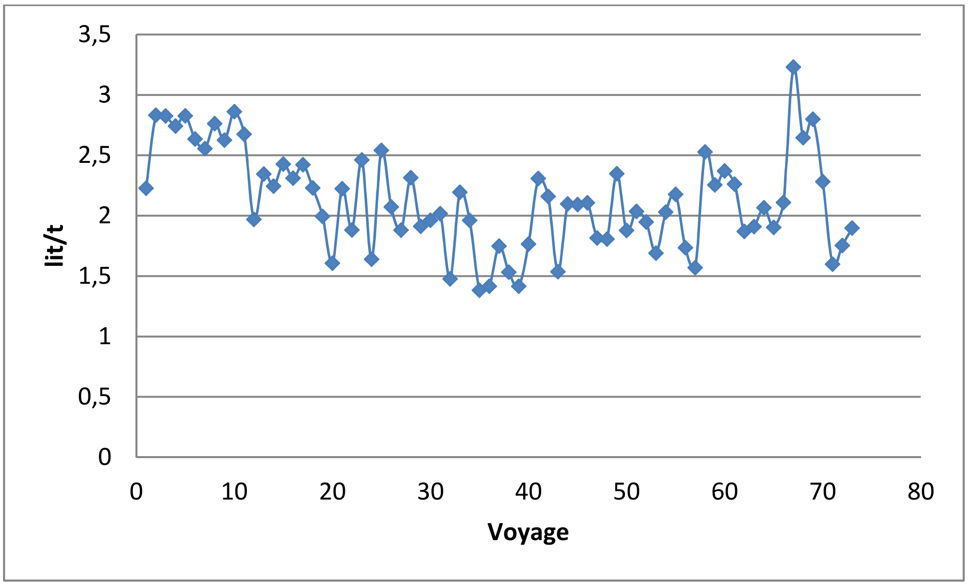


Figure 5-4: amount of fuel spent per ton transported on 73 voyages Rotterdam-Duisburg

Influences on the accuracy of measurements of the OP are:

- Rounding off of values.
- Processing errors. Errors that occur while processing the data.
- Logged intervals were 18 minutes and 18 seconds on average. The chance that after a measurement the power was increased or reduced is considerable and will influence the accuracy.

Chapter 6

Analysis

Figure 5-4 indicates transport efficiency to be between 1,5 litres of fuel per ton and 3 litres per ton. Figure 6-1 shows comparison of recorded water levels and transport efficiency.

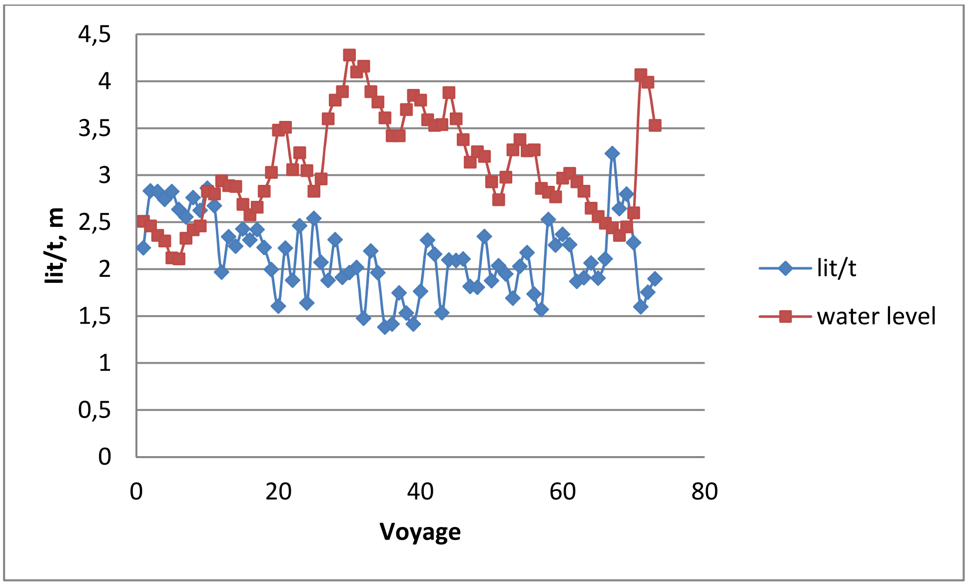
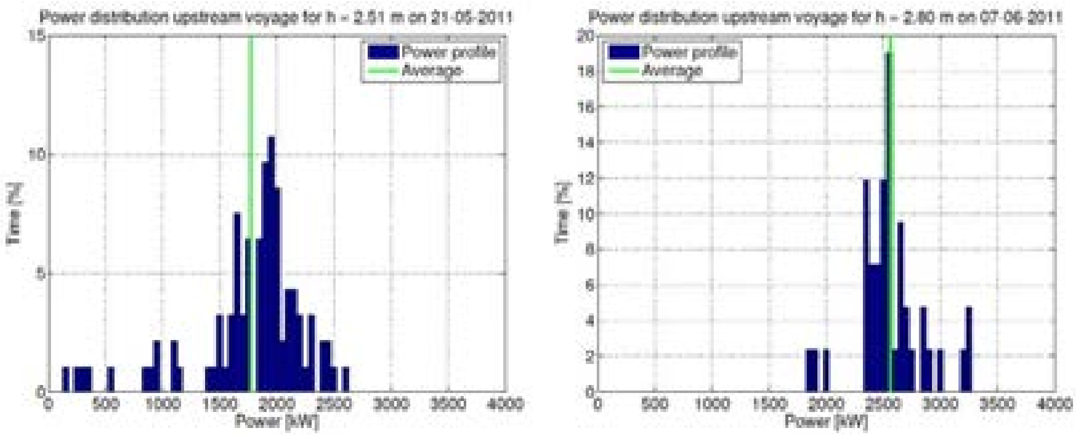


Figure 6-1: comparison of water levels and transport efficiency

Water level influences transport efficiency in two manners: it limits the draft of the ship (i.e. cargo loaded), and it adds to the ship resistance through squat effect. To further investigate this, Figure 6-2 shows power distribution and average power for different voyages and water levels.



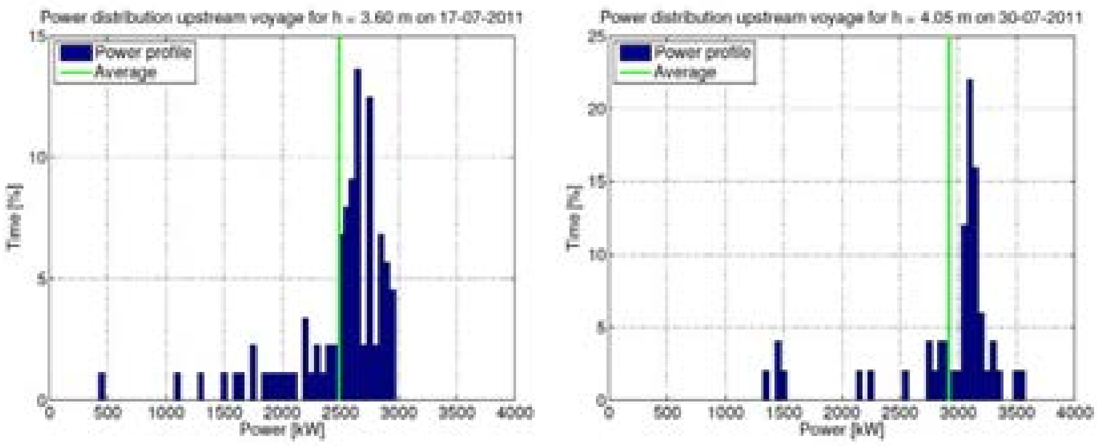


Figure 6-2: power distribution for four voyages

It is evident that the transport efficiency increases with increase of water depth. This is because power used in higher water levels aproaches to the nominal point where engine efficiencies are higher than in part loads. In low water levels engines run on part loads and are less efficient.

Conclusions

The measured operational profile shows a wide variety in power demand which is mainly between 27-78% of total installed power. This 'wide' range and relatively 'small' power demand can be explained by the following:

- The data showed a reasonably steady power demand per voyage. In practice the power demand was only varying when the vessel was manoeuvring, or when it needed to overtake another vessel. However, the main reason for the wide variety of power demand are the operational conditions, which are very different from voyage to voyage. The required power is dependent on the thrust of the propeller and is for each specific voyage mainly dependent on the environmental conditions and loading conditions.
- Higher propulsion power was expected in the upstream mode. The relatively low power demand is a consequence of the design point of the propeller. The design point a compromise between bollard pull and free sailing condition. In practice, the highest power demand takes place when the vessel is operating closest to bollard pull condition, thus the condition that requires highest thrust. This only occurs when the vessel is accelerating under the heaviest conditions, that is when the barges are fully loaded in combination with minimum under keel clearance (T_{barge} = 3.90 m and h = 4.00 m).
- The relatively low power demand gives enough room for improvement in order to design an alternative concept for the propulsion configuration of a future pusher.