Sustainable, safe and economically feasible energy concepts and technologies for European Inland Shipping

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Abstract

The European Union (EU) project PROMINENT[1] - Promoting Innovation in the Inland Waterways Transport (IWT) Sector - which was launched in May 2015, is a multiannual research and innovation programme for inland navigation, funded by the Horizon 2020 programme of the European Union. Running until April 2018, and involving a number of important stakeholders of the IWT sector of the EU, the project focusses on:

- massive transition towards efficient and clean vessels by developing cost-effective solutions applicable to 70 % of the EU fleet and reduction of the corresponding implementation costs by 30 %;
- certification and monitoring of emission performance and development of innovative regimes;
- harmonisation and modernisation of professional qualifications and the stimulation of the further integration of IWT into sustainable transport chains.

Building upon the identification of the most promising greening technologies and the technical developments carried out in the project, several pilots were set-up and carried out, delivering a great number of interesting results of significance to the IWT sector. The pilots under consideration were:

- monitoring of exhaust gas emissions and operational profiles on existing, innovative vessels;
- demonstration of performance of standardised retrofit diesel after-treatment systems;
- demonstration of energy-efficient navigation;
- usage of liquefied natural gas (LNG) in inland waterway vessels – development and testing of a total hydrocarbon (90 % methane) reduction package, forming together with the elaborations on design improvements in WP2 of PROMINENT the basis for compliance with the emission limits of the Stage V of the Non Road Mobile Machinery (NRMM) Directive (*Regulation (EU) 2016/1628*) till 2020;
- logistics education, comprising usage of simulations and e-learning, demonstration of electronic Service Record Book (e-SRB) and electronic Logbook (e-Logbook), as well as demonstration of a Pilot Community of Practice (CoP) in logistics education.

In this report, the final results relating to the pilots listed above are presented and discussed, amending the mid-term evaluation report *PROMINENT D6.2 (2017)*.

[1] http://www.prominent-iwt.eu/

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Executive summary

Building upon the identification of the most promising greening technologies applicable to inland waterway transport (IWT) and the technical developments carried out in the H2020 EU project PROMINENT[2], several pilots were set-up and carried out, delivering a great number of interesting results of significance to the IWT sector. The pilots under consideration were:

- monitoring of exhaust gas emissions and operational profiles on existing, innovative vessels;
- demonstration of performance of standardised retrofit diesel after-treatment systems;
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- logistics education, comprising usage of simulations and e-learning, demonstration of electronic Service Record Book (e-SRB) and electronic Logbook (e-Logbook), as well as demonstration of a Pilot Community of Practice (CoP) in logistics education.

In this report, the final results relating to the pilots listed above are presented and discussed, amending the mid-term evaluation report *PROMINENT D6.2 (2017)*. Further, where applicable, the results are discussed considering the assessment criteria mentioned in the PROMINENT deliverable D6.1 - Evaluation guidance report with methodology and templates, *Muilerman et al. (2015),* in order to allow for a smooth continuation of the roll-out activities foreseen.

In the following the key findings are summarised.

a. Monitoring of exhaust gas emissions and operational profiles on existing, innovative vessels

Within PROMINENT, monitoring took place for about 20 vessels operating in the Rhine and Danube areas.

The on-board monitoring was focused on two main purposes:

- Estimation of NOx as Real Sailing Emissions (RSE), which is important for the In-Service Conformity (ISC) monitoring in the context of the NRMM Stage V pollutant emissions legislation , *Regulation (EU) 2016/1628*. But it can also be used as part of the type approval for Retrofit Emission Control devices (REC) or for Original Equipment Manufacturer (OEM) engines. In addition, it can even be considered as option for a single engine approval;
- Environmental Performance Monitoring (EPM):
  Monitoring in the context of (overall) environmental performance of the vessel, e.g. fuel consumption, CO_2, NO_X, etc. This is meant for clients of shipping companies, public stakeholders and shipping companies, focused on the performance of the whole vessel and her optimisation.

[2] http://www.prominent-iwt.eu/

- Monitoring of waterway characteristics, such as waterway depth and stream velocity combined with operational profiles of some vessels, see Chapter 4.

The precise procedure for the first one (RSE), should be further developed in cooperation with the European Commission, DG Growth and the JRC, as well as the engine manufacturers. PROMINENT shows several practical options in terms of equipment, measured parameters, data transmission, calculation procedures, metrics and the final presentation of the RSE results. In the past, it was observed that large differences occur between the formal laboratory test results and results derived under real world driving conditions. The Real Driving Emissions (RDE) test for heavy duty (HD) vehicles eliminated that problem. Also for the main engines (IWP) and auxiliary engines (IWA) of inland waterway vessels, a practical RSE test would likely reduce those risks enormously.

The second main purpose, the EPM, creates an excellent insight in the energy consumption, as well as greenhouse gas (GHG) and pollutant emissions of vessels in relation to their operational profiles. This information can be used for a range of optimisation options, such as:

- creating transparency in environmental performance to customers and authorities;
- development of standard emission factors (CO_2, pollutants);
- optimisation of the powertrain of the vessel (proper engine, hybrid, etc.);
- efficient navigation (prediction of energy consumption in relation to waterway conditions and Expected Time of Arrival (ETA)), see Chapter 4.

The data collected in PROMINENT is very suitable for further investigation on the subjects listed above.

Results of significant relevance to evaluation and modelling of the environmental performance of inland waterway vessels relate to the average engine load and the CO_2 emissions per tkm, which were much lower than commonly assumed up to now, resulting in a remarkably improved environmental image of the vessels considered. The average engine load and CO_2 emissions per tkm of the Rhine vessels (cargo) amounted to 17 % up to 31 %, as well as 8 g/tkm up to 10 g/tkm. For the Danube vessels, the respective values amounted to 31 % up to 47 %, as well as 6 g/tkm up to 8 g/tkm.

The hardware for on-board monitoring can be supplied by a range of suppliers, although not many have experience with emission sensors and the extensive calculation procedures necessary to transmit emission concentrations to g/h and g/kWh emissions.

The proposed hardware for both RSE and EPM includes (to be applied to main engines, as well as auxiliary engines):

- (automotive) NO_X/O_2 sensor or other types of $NO_X/O_2/CO_2$ sensors;
- data recording system suitable for storing months of data;
- interface/connection to engine CAN (for primarily engine rpm);
- interface/connection to fuel flow meter(s);
- interface/connection to logistics information (empty vessel or loaded vessel, in the latter case tonnes, or TEU transported);
- GPS for determination of location;
- data transmission via GPRS.

b. Demonstration of performance of standardised retrofit diesel after-treatment systems

Two types of exhaust after-treatment (EAT) systems were successfully installed in a pilot vessel comprising the pusher Donau. The first solution comprised the application of selective catalytic reduction only (SCR). For the second one, SCR and a diesel particulate matter filter (DPF) were used. It was illustrated that for CO, HC and NO_X, compliance with the emission standards of the Stage V of the NRMM Directive, *Regulation (EU) 2016/1628*, can be achieved using a retrofit solution. The results relating to particulate matter (PM) are under evaluation at the stage of writing this report. It is noted that the number of particles PN could not be measured due to the lack of on-board PN-measurement equipment. The cycle used was the ISO 8178 E3 cycle. In addition to the emission reduction achieved, the installation demonstrated that all different requirements, such as available space, integration into on-board alarm systems, allowable back pressure, etc., can be met with a retrofit installation. Cost reduction of the retrofit EAT system can be achieved by increasing the number of identical parts, allowing mass production thereof. Currently, Multronic is still in discussion about the price in association with larger volume supply. The initial target of 30 % cost reduction for 200 vessels/year is expected to be reached.

Future implementation of such systems will depend on the options to homologate these systems. The installation of the pilot vessel has drawn attention in the ship-owners community. Multronic has noticed an increased interest in such retrofit installations.

c. Demonstration of energy-efficient navigation

The evaluation of fuel-consumption savings achieved by an optimised sailing policy is extremely challenging in inland navigation as it depends on continuously changing framework conditions like hydrological parameters (water depth, flow velocity, etc.), the surrounding traffic, the sailing schedule and the ship's load-case, influencing the fuel consumption. Therefore, DST's simulation environment was adapted and used to quantify the influence of different sailing policies on fuel consumption decoupled from other effects. The vessels considered were the passenger vessel FGS Symphony and the motor cargo vessel Monika Deymann. Five different sailing policies were investigated comprising:

- sailing with constant speed through water;
- sailing with constant speed over ground;
- sailing with constant delivered power;
- sailing with constant rate of revolutions (rpm);
- sailing with minimised average Froude number based on the water depth (Fn_h[3]).

The simulations revealed that sailing with constant rpm results in the most significant fuel savings, depending on the sailing duration permitted. Similar results were obtained for constant delivered power, and the minimised average Froude number based on the water depth. For the container vessel Monika Deymann, the simulations revealed also that sailing 10 % longer than the minimum possible time results in a reduction of fuel consumption by 30 %. This impressive margin demonstrates the importance of voyage planning and the accurate estimation of the arrival time based on detailed knowledge of vessel and waterway condition. Therefore, increasing awareness of

[3] Fn_h = ship speed through water/(gravity constant • water depth)$^{0.5}$

these effects and making use of detailed real-time waterway data in tools like the ENAT app (see below) is expected to contribute significantly to increasing the energy-efficiency in inland waterway transport.

An assessment of the fuel-consumption-reduction potential was carried out also for a Danube vessel sailing between Regensburg and Budapest on the Upper Danube, using the modelling approach of Via Donau. The operational cases comprised:

- operation of a Johann Welker vessel (extended) as pushed convoy consisting of the motor cargo vessel under consideration and a lighter;
- operation of the motor cargo vessel as single vessel.

In all cases considered, the reduction of the brake power and the speed over ground lead to a significant reduction in fuel consumption, ranging from 8.7 % up to 25.5 %.

The result for the motor cargo vessel in single operation is highlighted: it showed an excellent relationship between increase in sailing time and reduction of fuel consumption. Roughly, one may say that 1 % increase in sailing time leads to a reduction in fuel consumption by 4 %. The relationship becomes less favourable for sailing at the highest navigable water level, as well as for the pushed convoy.

For three pilot vessels operating on the Rhine, wooden models were built at DST's workshops in the scale 1 by 17. The passenger vessel FGS Symphonie was used for resistance tests only. The shape of the stern section and experience from similar tests allow an educated guess for thrust deduction and wake fraction. The models of the single screw vessel Baden Wuerttemberg and the Monika Deymann, propelled by two ducted propellers, were equipped with scaled ducts, propellers and rudders and the corresponding measurement sensors. For the latter two vessels, open water, resistance and propulsion tests were carried out for different draughts at a greater number of different water depths. The results were used in the simulations described above, as well as for the evaluation of the proper working of the flow-velocity-measurement devices (how far away in front of the vessel the speed through water has to be measured). In addition, the model-test results were an important input to the ship performance model used for energy-efficient navigation, serving also its validation.

A user friendly web interface (energy-efficient navigation tool – ENAT) was developed and tested in order to help boatmasters on board or trip planners estimate fuel use and NO_X emissions for an upcoming trip, including alternative arrival times for corresponding fuel savings. Boatmasters can be provided with track advice in real time. The basis for ENAT is a simulation model that combines the technical specifications of the vessel with the water conditions along the track, and optimises the operation of the vessel along the track based on fuel consumption.

A tool for the evaluation of the ship performance has also been developed with interrelation to the on-board tool. This tool can be used in combination with the on-board monitoring (OBM) system for fuel consumption, as well as CO_2 and NO_X emissions.

Application of the ENAT model shows that optimisation of lock scheduling and ship waiting times can reduce fuel consumption by 13%. This result was obtained by comparing actual and optimal voyage planning on the lock abundant Rotterdam-Maastricht route, using maps provided by Rijkswaterstaat. This exercise has shown both the applicability of ENAT as an impact assessment tool, as well as the importance of voyage planning and the role of infrastructure in the emissions reduction.

At this stage, the tool may be applied for sailing only on the German Rhine. However, it can be extended to other waterways e.g.in the Netherlands or the Danube, provided the navigation conditions demanded are available. Further, the amount of vessel types which may be considered can be increased by provision of dedicated model test results for the power-speed relations or alternatively the usage or further development of generic evaluation methods for obtaining the afore mentioned relationships. Up to now only three vessels are considered.

Two vessels operating on the Rhine and ten vessels of NAVROM operating on the Danube were equipped with devices for on-board measurement of vessel speed through water and echo-sounder distance to the river bottom, allowing for the estimation of the associated flow velocities and water depths the vessels encountered.

For the two Rhine vessels, in general, a very good agreement between surveying and on board measured results for water depth was obtained. Taking into account corrections for pitch and roll, the overall averaged difference between the on-board measurements and multi-beam soundings of the year 2014 amounts to 2 cm. However, due to their spatial resolution, the measurements cannot replace professional echo soundings with a multibeam-system. In areas where professional echo soundings are not available or the time between echo soundings is too long, ship-based measurements can significantly improve the data basis, providing additional information for navigation or route planning. The same applies to areas with high morphological activity.

For the flow velocities at mean water level, a rather good agreement of the on-board measurements with the ones derived from a hydro-numerical-model is obtained. The results obtained at the equivalent water level (GlW) show greater deviations from the modelled ones, due to unreliable results for the magnitude of the flow velocities because of small under keel clearances together with a small immersion depth of the ADCP.

The described procedure for measuring and transmitting the data is promising. However, further developments relating to automatic plausibility check and processing of the collected data, as well as provision of it in a suitable manner to the boatmaster or shipping company are necessary.

Since January 2016, on-board monitoring has taking place for a group of ten vessels of the Romanian shipping company NAVROM sailing mainly on the Middle and Lower Danube. The measurements performed aimed at analysing the engine performance of the vessels and navigation conditions such as waterway depth and flow velocities. The measurements collected were stored in a database with over 100,000 hours of data utilised in this pilot for estimation of the waterway depths at the city of Corabia in Romania, which is considered a bottleneck due to the shallowness of the Danube there.

In general, the on-board measurements give plausible results for the water depth. The agreement with the surveying results (single beam) is good at several points, although at some points maximum deviations of up to 1 m occur. The deviations may be explained by lack of consideration of sinkage and trim of the vessels, different densities of measurement points across the fairway as well as different time periods between the on-board measurements and the surveying results.

The costs to be covered by the ship-owner (based on pilot costs for Romanian Shipping company NAVROM) amount to 30,000 euro per vessel for installation and around 400 euro per month for maintenance, handling of mobile equipment and transmission of the data. Before the pilot took place there was a large uncertainty on the price levels of this equipment.

The usefulness of the data and the quality of the depth estimates indicate that the method developed may be suitable to be used in other bottlenecks of the Danube as well. In a further step, it may be thought of extending the procedure for the creation of a waterway map with depth contours, demanding, however, a significant amount of efforts and resources. A meaningful processing of the flow-velocity measurements could not be performed.

The systems developed for the Rhine and the Danube provide an improved knowledge of the fairway conditions as well as at which locations significant changes of the river-bottom topography occur, demanding maintenance works. Thereby, the systems contribute to an improved waterway infrastructure and usage of it by vessels, resulting in more reliable services, better choice of the route and loading of the vessel, as well as reduced fuel consumption related to tonne kilometre. In addition, the systems can be used for the provision of input to tools like the ENAT, giving advice on efficient ways of sailing the vessel, affecting this way the reduction of fuel consumption.

d. Usage of liquefied natural gas (LNG) in inland waterway vessels

An extensive measurement campaign on board the vessel RPG Stuttgart was carried out in April of 2018. This measurement campaign aimed to quantify the total hydrocarbon (THC) emission reduction achieved by upgrading the gas engine control system with an advanced software package. The THC emissions contain 90 % methane.

Some difficulties were experienced during the baseline measurement, necessitating the use of an earlier baseline measurement conducted on the same engine during factory acceptance. The Comparison of speed load, fuel consumption and NO_X emissions between both baseline measurements showed that the alternative (pre FAT) baseline was valid to be used as basis for the comparison to be carried out.

Significant THC emission reductions were measured, up to 3.9 g/kWh in the most important load point in practical operation, which is during upstream operation of the vessel. Total greenhouse gas emission reduction of the upgrade per vessel over the vessel lifetime is expected to be equivalent to over 3688 tons of CO_2. An indicative calculation of the actual greenhouse gas reduction showed that the upgrade of one single vessel has an impact similar to taking 132 cars off the road.

More in detail, the following conclusions can be drawn:

- Baseline and post-modification measurements were valid for use in comparisons;
- The upgrade has no adverse impact on NOx emissions;
- The upgrade has no adverse impact on fuel consumption;
- The upgrade has a big positive impact on THC emissions, with a 2.9 g/kWh reduction over the E3 cycle and a 3.9 g/kWh reduction at the most important load point in the real operation of the vessel;

- Although an impressive reduction in THC was achieved, meeting the THC limit of the NRMM Stage V in all four measuring points of the E3 cycle could not be achieved. However, taking into account all improvements of PROMINENT on the design (Wp2 and WP5), full compliance of the engine with the NRMM Stage V requirements can be achieved, even without usage of any after-treatment. The results elaborated in PROMINENT allow WAR to deliver an LNG propulsion solution till 2020 which will be fully compliant with NRMM Stage V requirements.

As a secondary benefit, engine loading response was improved which leads to more stable gas operation. In practice, this means that the vessel will trip less often to diesel operation. As emissions are much lower when the vessel is running on gas, this means that the actual real-world emissions are lower also because of this.

e. Logistics education

Within the task pilot simulations, three e-learning modules were developed, dealing with:
- energy and cost-efficient navigation;
- vessel stability; and
- handling of dangerous goods.

The modules dealing with energy and cost-efficient navigation, and vessel stability were completed. This refers to the content, interactive elements and visual consistency. The text for the voice over was drafted in English, and it was undertaken a professional language check. After that, the voice was recorded and close captions implemented. Both modules, in their entirety, were finalised for the pilot tests.

The creation of the module on handling of dangerous goods was completed. The competence plan and large parts of the content were elaborated, based on the outcome of a thorough enquiry. The module was finalised and translated into English, as well as, finally, it was implemented in the e-learning software.

Within the task, pilot e-SRB and e-Logbook, interconnected prototypes of a European electronic Service Record Book (e-SRB) and a European electronic Logbook were created. In mutual agreement with the Joint Research Centre (JRC) of the European Commission, the PROMINENT project team selected four use cases as the basis for the development of the e-SRB and E-Logbook prototype.

The four use cases are:
- voyage initialization & end (UC3);
- crew embarking & disembarking (UC4);
- control / inspection by the competent authorities (UC5);
- working time registration (UC9).

By means of these functions, the vessel unit is used for checking and recording the qualifications of the crew, the sailing time, the working time and the operation of the vessel. Using the Vessel unit leads to less administration, reduction of fraud (level playing field) and efficient inspection.

The development of the prototype was based on the relevant actors, current procedures and possible eIWT assisted procedures. The prototype is based on proven technology, which means that most of the required functions are already used in other industries and services. Besides, existing techniques and data-sources are used, such as existing systems like GSM, GPRS and GPS. In addition, the inland navigation sector has seen many technological projects in the recent past, which have created useful sources such as RIS.

The prototype was tested on ten inland vessels in the Rhine region and the Danube region. The period during which the pilot was executed lasted from November 2017 till March 2018. The main objective of this pilot was to show and test how the prototype works during daily practice on board inland vessels.

Within the task, pilot Community of Practice (CoP) logistics education, Train-the-Trainer workshops and pilot courses for testing the developed capstone courses were held by FHOO, IMST and STC. Feedback was collected during the workshops and the pilot courses to facilitate an evaluation of the task. A questionnaire was developed for the pilot courses, which was handed out to participants before and after the pilot course to survey their attitude towards inland waterway transport and to collect feedback concerning the course. Within the workshops, discussions were used to gather feedback from the participants.

Since the pilot courses from FHOO and IMST took place at the same time, students from both universities were told to exchange information during the pilot course using a blog. The blog is integrated in the online Community of Practice (CoP) in addition to the developed learning materials and case studies (CoP: http://ines-danube.info/goto.php?target=crs_1244). The students provided updates on their elaborations on a regular basis (e.g. before presentations, after study visit, etc.), and it was possible to ask questions and to provide feedback during the pilot course. Furthermore, a Skype meeting between students from IMST and FHOO was organised at the beginning of the course to provide students the opportunity to exchange information concerning their tasks within the courses.

Follow-up Train-the-Trainer workshops were organised by each partner in his country of origin. In addition, in Duisburg (Germany), a Train-the-Trainer workshop took place in October 2017. In the course of the final event, six students from FHOO, IMST and STC worked together on the Pöttinger Case Study. The task was to elaborate a sustainable transport strategy for the Ukrainian market of the company. From March to April 2018, the students communicated via Skype and WhatsApp and used the Community of Practice (CoP) to share their elaborations (e.g. SWOT Analysis). During the final event – from the 15^{th} – 17^{th} of April 2018– the students had again time to work on the case study in Vienna. The solution was presented to the participants of the final event.

1. Introduction

The EU project PROMINENT[4] - Promoting Innovation in the Inland Waterways Transport (IWT) Sector - which was launched in May 2015, is a multiannual research and innovation programme for inland navigation. 17 Parties from five European countries are collaborating to green the inland navigation industry. Running until April 2018, the project foresees the forward-looking approach bringing together the economy, the environment and safety for inland navigation with a clear focus on reduction of greenhouse gas emissions and increased environmental friendliness of navigation as well as an increase of competitiveness of inland navigation in logistics networks.

PROMINENT has been addressing the key needs for technological development, as well as the barriers to innovation and greening in the European inland navigation sector. PROMINENT thereby is fully in line with the objectives of the European action programme NAIADES-II, *COM/2013/0623 final*, and ultimately aiming at providing solutions which make inland navigation an ever more competitive alternative to road transport in terms of air pollutant emissions by 2020 and beyond. In parallel, PROMINENT aims at further decreasing the energy consumption and carbon footprint of inland waterway transport, an area where it already has a strong advantage compared to road transport.

PROMINENT focusses on:

- massive transition towards efficient and clean vessels by developing cost-effective solutions applicable to 70 % of the EU fleet and reduction of the corresponding implementation costs by 30 %;
- certification and monitoring of emission performance and development of innovative regimes;
- harmonisation and modernisation of professional qualifications and the stimulation of the further integration of IWT into sustainable transport chains.

In PROMINENT, the involvement of stakeholders played a key role. Consultation with the project Advisory Board, presentation of project results in expert groups, as well as interviews with representatives of the shipping industry - users and shippers – served the verification of the results. Fleet families, operational profiles, the selection of the greening technologies and concepts, as well as the assessment of technology-specific barriers and facilitating factors, all these have been assessed by the stakeholders.

Building upon the identification of most promising greening technologies and the technical developments carried out in the project, several pilots were set-up and carried out, delivering a great number of interesting results of significance to the IWT sector. The pilots under consideration were:

- monitoring of exhaust gas emissions and operational profiles on existing, innovative vessels;
- demonstration of performance of standardised retrofit diesel after-treatment systems;
- demonstration of energy-efficient navigation;
- usage of liquefied natural gas (LNG) in inland waterway vessels – development and testing of a total hydrocarbon (90 % methane) reduction package, forming together with the elaborations on design improvements in WP2 of PROMINENT the basis for compliance with

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the emission limits of the Stage V of the Non Road Mobile Machinery (NRMM) Directive (*Regulation (EU) 2016/1628*) till 2020;

- logistics education, comprising usage of simulations and e-learning, demonstration of electronic Service Record Book (e-SRB) and electronic Logbook (e-Logbook), as well as demonstration of a Pilot Community of Practice (CoP) in logistics education.

In this report, the final results relating to the pilots listed above are presented and discussed, amending the mid-term evaluation report *PROMINENT D6.2 (2017)*. Further, where applicable, the results are discussed considering the assessment criteria mentioned in the PROMINENT deliverable D6.1 - Evaluation guidance report with methodology and templates, *Muilerman et al. (2015),* in order to allow for a smooth continuation of the roll-out activities foreseen.

2. Monitoring of exhaust gas emissions and operational profiles on existing, innovative vessels

a. Description of pilot

i. General description and objective

Monitoring of exhaust gas emissions and operational profiles is being proposed for different reasons by different stakeholders. Some of them are focused on pollutant emissions in connection with the engine type approval and/or permission to sail in (future) environmental zones. Others are focused on optimisation of the energy consumption and greenhouse gas (GHG) emissions (and being transparent about this) by monitoring the operational profile and energy consumption.

Within PROMINENT, the following two main purposes for on board monitoring are distinguished:

- monitoring of Real Sailing Emissions (RSE): equivalent to Real Driving Emissions (RDE) for automotive vehicles, monitoring in the context of EC Regulation 2016/1628, focused on the engine in its applications;
- Environmental Performance Monitoring (EPM): monitoring in the context of (overall) environmental performance of the vessel, meant for clients of shipping companies, public stakeholders and shipping companies, focused on the performance of the whole vessel and its optimisation;
- monitoring of waterway characteristics, such as waterway depth and stream velocity.

The first two are extensively described in *PROMINENT D5.8 (2017)* and also *PROMINENT D3.2/3.3 (2016)*. For further elaboration, also see the overview in the table below. The metrics options for RSE are generally engine work related (g/kWh). Alternatively, CO_2 can be used as reference parameter (g/kg CO_2). This has several advantages such as a) more constant across the load range (does not go to infinity at idle or zero power output) and b) easier to measure. The metrics of EPM are related to ship performance: g/km and g/trip. The emissions are also related to the transport performance in tkm, whereby the respective value for the transport performance was estimated and not measured. Although the estimation involves uncertainties relating to the payload carried, it allows for a first interpretation of the meaning of the emissions measured. Further, first information on the order of magnitude of the emissions per tkm is obtained, allowing for approximate evaluation of the possible range of the emissions per tkm.

For a number of vessels operational profiles were combined with the monitoring of waterway conditions, such as depth and flow velocity.

Table 1: Overview of the two main monitoring options: Real Sailing Emissions (RSE) and Environmental Performance Monitoring (EPM).

	Real Sailing Emissions RSE	Environmental Performance Monitoring EPM / OBM
Context	Suitable for EC Regulation 2016/1628 Inland Waterway Propulsion (IWP) and Inland Waterway Auxiliary (IWA) engines For pollutant emissions.	Voluntary Overall environmental performance for clients
Monitoring of	Engine in its application	Overall ship environmental performance
Duration	1 day to 1 week (can be longer)	Usually meant for permanent monitoring
Parameters & dimensions	NO_X in g/kWh or g/kg CO_2 PN in #/kWh	NO_X in g/km, g/tkm, g/trip CO_2 in g/km, g/tkm Fuel consumption in l/km, l/trip
Purpose(s) of monitoring (options)	- Official monitoring in the context of EC Regulation 2016/1628 (article 9) - As part of a type approval of Retrofit Emission Control devices (REC) - As part of the type approval procedure to assess Off Cycle Emissions (OCE) - As single engine approval: alternative to type approval	Proof of overall environmental performance to clients of shipping companies and regional government[5] (focus air quality) Ship owners: 'know your ship' and optimisation for lower energy consumption; mandatory for certain subsidy programs

ii. Ship specifications

The specifications of the vessels monitored are given in the table below.

Within PROMINENT, monitoring took place for about 20 vessels. The results were used as important input to the work carried out in several sub-work packages of Work Package 5 (WP5). For all vessels operational profiles and driveline load profiles were evaluated, *PROMINENT D5.7 (2018)*. On about 9 vessels monitoring took place with actual continuous measurement of exhaust gas emissions (NO_X). For the vessels without NO_X measurement, achievable NO_X levels with exhaust after-treatment were modelled.

The average payload is an important parameter for determination of the emissions in g/tkm. The average payloads for the motor vessels are based on the maximum load capacity and an average payload density of 70 %. See *PROMINENT D1.1 (2015)*. The average payload density includes empty trips, although most of the vessels analysed in D1.1 had also loaded return trips. The maximum payload of the Danube pushers depends on the amount of lighters (a pushed non-motorised vessel

[5] The monitoring results are used within the Global Logistics Emissions Council (GLEC http://www.smartfreightcentre.org/glec/what-is-glec) for elaboration of improved emission factors for inland waterway transport. Here, GLEC and PROMINENT are interlinked.

used for transportation of goods) moved by the pushers. In the D1.1 report, the maximum payload ranges between 6 400 and 17 400 t. The average payloads used, as shown in the table below, are based on this range in combination with the vessel's engine power. It is noted that the payloads used for the calculation of tkm are estimated values and not measured ones, allowing, however, for approximate evaluation of the possible range of the emissions per tkm.

Table 2: Overview of the vessels monitored and their specifications used for presentation of results referred to tkm. EPA Tier 1 is equivalent to CCNR I.

ID	Cargo	Length (m)	Operation area	Maximum payload (t)	Estimated average Payload [t]	Emission class / drivetrain	Number of engines	Total power[6] (kW)
1	Containers	110	Rotterdam - Basel	3200	2240	CCNR 1 + SCR / DPF	1	1500
2	Containers	135	AR - Cologne	5200	3640	CCNR 1 + SCR	2	2100
3	Containers	135	Antwerp to Mainz	5600	3920	CCNR 2	2	2300
4	Dry Bulk	135	ARA + Rhine + Danube	4400	3080	CCNR 2	2	1700
5	Push Boat	20	Danube	-	3000	EPA Tier 2	2	600
6	Push Boat	35	Danube	-	8000	EPA Tier 1	2	1900
7	Push Boat	35	Danube	-	8000	EPA Tier 1	2	1900
8	Push Boat	35	Danube	-	8000	EPA Tier 1	2	1900
9	Push Boat	35	Danube	-	10000	EPA Tier 1	2	2500
10	Push Boat	35	Danube	-	10000	EPA Tier 1	2	2500
11	Push Boat	35	Danube	-	10000	EPA Tier 1	2	2500
12	Push Boat	35	Danube	-	10000	EPA Tier 1	2	2500
13	Passengers	110	Rhine + Danube	-	-	CCNR 1	3	1350

[6] Brake power of main engines.

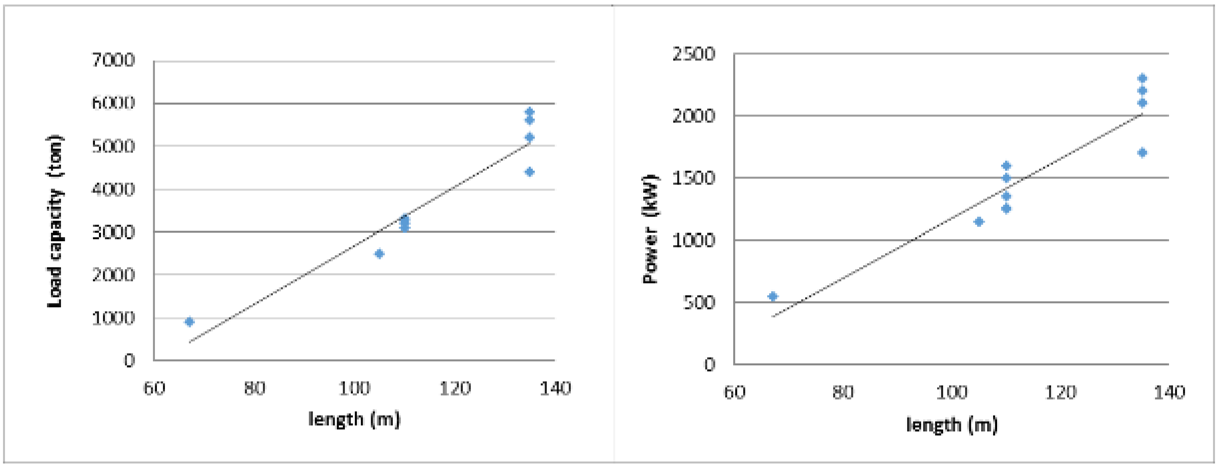


Figure 1: Overview of ship specifications: load capacity and total propulsion power (brake power) as function of the ship length.

An overview of the typical routes of the vessels monitored is given in the figure below.

Figure 2: Voyages of the vessels monitored.

iii. Overall monitoring system

The on-board monitoring results were automatically transmitted to a central database via GPRS and the internet to an FTP server (see Figure 3). The monitoring frequency was flexible. Within PROMINENT, it ranged from 1 Hz to once per minute (1/60 Hz). Due to the relatively constant power operation, also 1/60 Hz was fine. For many purposes, this monitoring frequency can also be reduced to say once per 15 minutes or even once per hour.

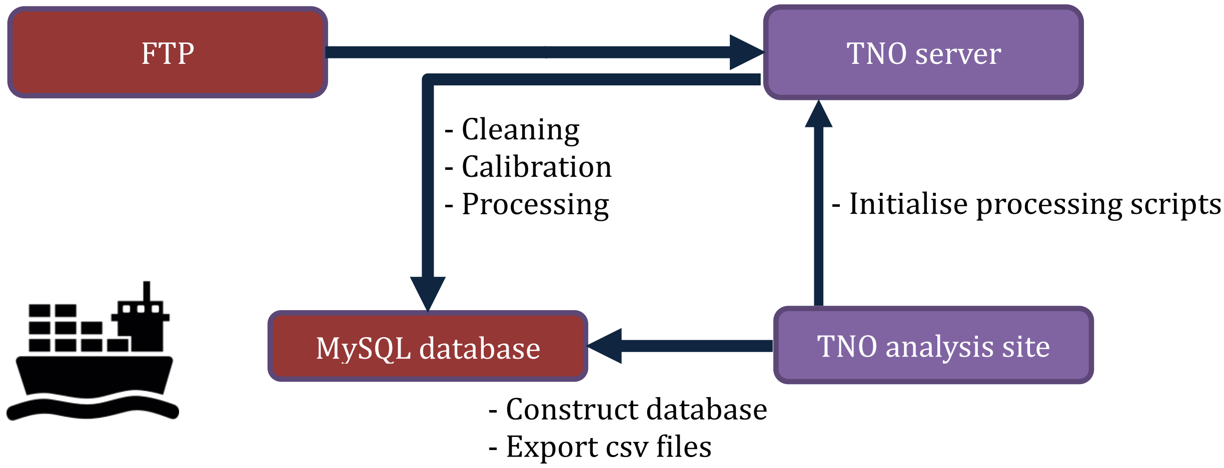


Figure 3: Processing and inserting data into the database.

b. Results

i. Fuel consumption, carbon footprint and pollutant emissions

The results of the on-board monitoring of the regular vessels and pushers are presented in the tables below. The results are split in three categories:

- operational profile: this includes the parameters Speed over Ground (SOG) and average (brake) power of the main engines (in kW and %);
- Real Sailing Emissions (RSE): these results are expressed in typical engine metrics, and they can be compared with the engine emissions type approval;
- Environmental Performance Monitoring: these are results for the entire vessel, expressed in g or kg per km and tkm. The tkm are based on assumptions of the average cargo carried by the vessel. See Section 2.a.ii. Therefore, these values have to be taken with some caution.

The emissions in the tables below are presented for the propulsion engines only (main engines). In order to include the auxiliary engines, it is recommended to add about 13 % to the g/km fuel consumption and emissions. The approximated value is a total average, including the contribution of auxiliaries when the vessel is not sailing. See *Hulskotte (2012)* and *Schweighofer et al. (2013)*. Both report auxiliary energy consumptions in the range of 5 % up to approximately 20 %. Hulskotte recommends to use 13 % as an average. More accurate assumptions may be possible by differentiation between vessel types and sizes.

Most of these vessels sailed on rivers with current. In *PROMINENT D5.7 (2018)*, the complete set of results is given including the average results split in upstream, downstream and canal sailing.

Table 3: Average operational performance of motor vessels dry cargo and one passenger vessel (vessel 13). All vessels were sailing on the Rhine, the passenger vessel also on the Danube.

Parameters		Vessel 1 Container 110 m	Vessel 2 Container 135 m	Vessel 3 Container 135 m	Vessel 4 Dry Bulk 135 m	Vessel 13 Passenger 110 m
Average cargo mass (t)		2240	3640	3920	3080	-
Operational profile	Total time [h]	924	1173	1681	2379	413
	SOG [km/h]	12.5	12.3	13	10.7	14.4
	Power [kW]	435	544	707	371	588
	Power [%]	29	26	31	22	44
Real Sailing Emissions (RSE)	NOx [g/kWh]	4.2	4.5		8.5	-
	NOx/ CO_2 [g/kg]	6.4	6.9		12.2	-
Environmental Performance Monitoring (EPM/OBM)	NOx [g/km]	147	199		294	-
	NOx [mg/tkm]	66	55	-	95	-
	Fuel [l/h]	108	138	177	96	152
	Fuel [l/km]	9	11	14	9	11
	CO_2 [kg/km]	23	30	36	24	28
	CO_2 [g/tkm]	10	8	9	8	
Indicative / modelled NOx emissions	NOx with SCR [g/kWh]	-	-	0.8	2.8	1.4
	NOx (CCNR II) [mg/tkm]	-	-	88	-	-
	NOx with SCR [mg/tkm]	-	-	12	29	-

Table 4. Average operational performance of Rhine vessels, group 2: 2 motor vessels dry cargo, 2 tankers and 2 push boats. All vessels were sailing mainly on the Rhine. The displayed results include sailing and idling. Vessel 14 is the pilot vessel of SWP 5.3.*For Vessel 18, the sampling window of average speed does not correspond to the sampling window of the other parameters. **SCR system has been out of order for a period during sampling.

Parameters		Vessel 14	Vessel 15 (CCNR 2)	Vessel 16 (CCNR2)	Vessel 17	Vessel 18	Vessel 19 Star board engine**	Vessel 19 Port engine	Vessel 19 both engines
Type of ship, Dry Cargo, TAnker, Push Boat		PB	PB	DC	DC	TA	TA	TA	TA
Aftertreatment		SCR + DPF	--	--	SCR	SCR + DPF	SCR	SCR	SCR
Operational profile	Speed over ground [km/h]	9.2	10	10	8.9	7.6*	10	10	10
	Power [kW]	412	1203	93	386	350	244	266	510
	Power [%]	28	22	17	24	28	22	24	23
Real Sailing Emissions (RSE)	NO_x [g/kWh]	2.9	6.5	8.6	6.1	5.9	8.8	3.8	6.3
Environmental Performance Monitoring (EPM)	NO_x [g/km]	370	825	82	266	200	214	101	315
	Fuel [l/km]	11	33	2.5	10.9	8	6.5	7.2	14

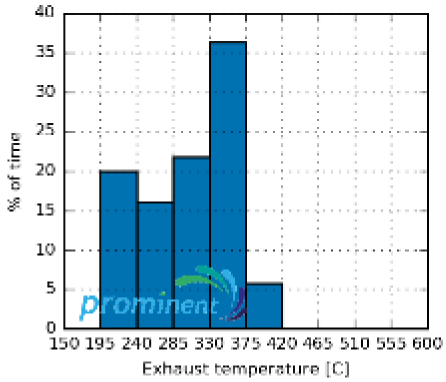
Table 5: Average operational performance of pushers, all sailing on the Danube.

Parameters		Vessel 5 Pusher 600 kW	Vessel 6 Pusher 1900 kW	Vessel 7 Pusher 1900 kW	Vessel 8 Pusher 1900 kW	Vessel 9 Pusher 2500 kW	Vessel 10 Pusher 2500 kW	Vessel 11 Pusher 2500 kW	Vessel 12 Pusher 2500 kW
Operational profile	Total time [h]	6961	6124	5722	6268	2310	5485	3681	6107
	SOG [km/h]	10.1	7.3	7.7	7.3	7.7	8.7	8.4	7.8
	Power [kW]	281	678	643	645	834	766	767	822
	Power [%]	47	36	34	34	33	31	31	33
Environmental Performance Monitoring (EPM/OBM)	Fuel [l/h]	74	170	162	162	207	191	191	204
	Fuel [l/km]	7	23	21	22	27	22	23	26
	CO_2 [kg/km]	20	62	56	60	72	59	61	70
	CO_2 [g/tkm]	7	8	7	7	7	6	6	7
Indicative / modelled NOx emissions	NOx with SCR [g/kWh]	1.0	1.4	1.3	1.4	1.5	1.7	1.7	1.6
	NOx (CCNR II) [mg/tkm]	62	113	102	109	104	86	89	102
	NOx with SCR [mg/tkm]	9	16	14	15	17	15	15	17

ii. Graphical presentation

For each vessel monitored, a standard graphical presentation of the results was performed. An example for a container vessel is presented in the figure below (see next page).

The standard graphical presentation includes a number of ‘bin’ graphs. The total range of parameters, like NO_X, power, SOG, fuel consumption and exhaust gas temperature, is divided in about 5 to 13 equal parts, named bins. The percentage of time is indicated for each bin. This time can then be subdivided in different sailing conditions: upstream, downstream and ‘other’. E.g. for NO_X in g/kWh, the average NO_X per bin is given in the fourth chart in the figure below. In *PROMINENT D5.7 (2018)*, the standard graphical presentation presented below is given for each vessel considered.



ID	Vessel 1 Container 110m
Build year	2005
Power[kW]	1492
Num. engines	1
Brand	Caterpillar
Type	3516
Features	CCNR 1-SCR / DPF
Area	Antw./Rot.
DWT	3200
Modelled	-
Hours	15

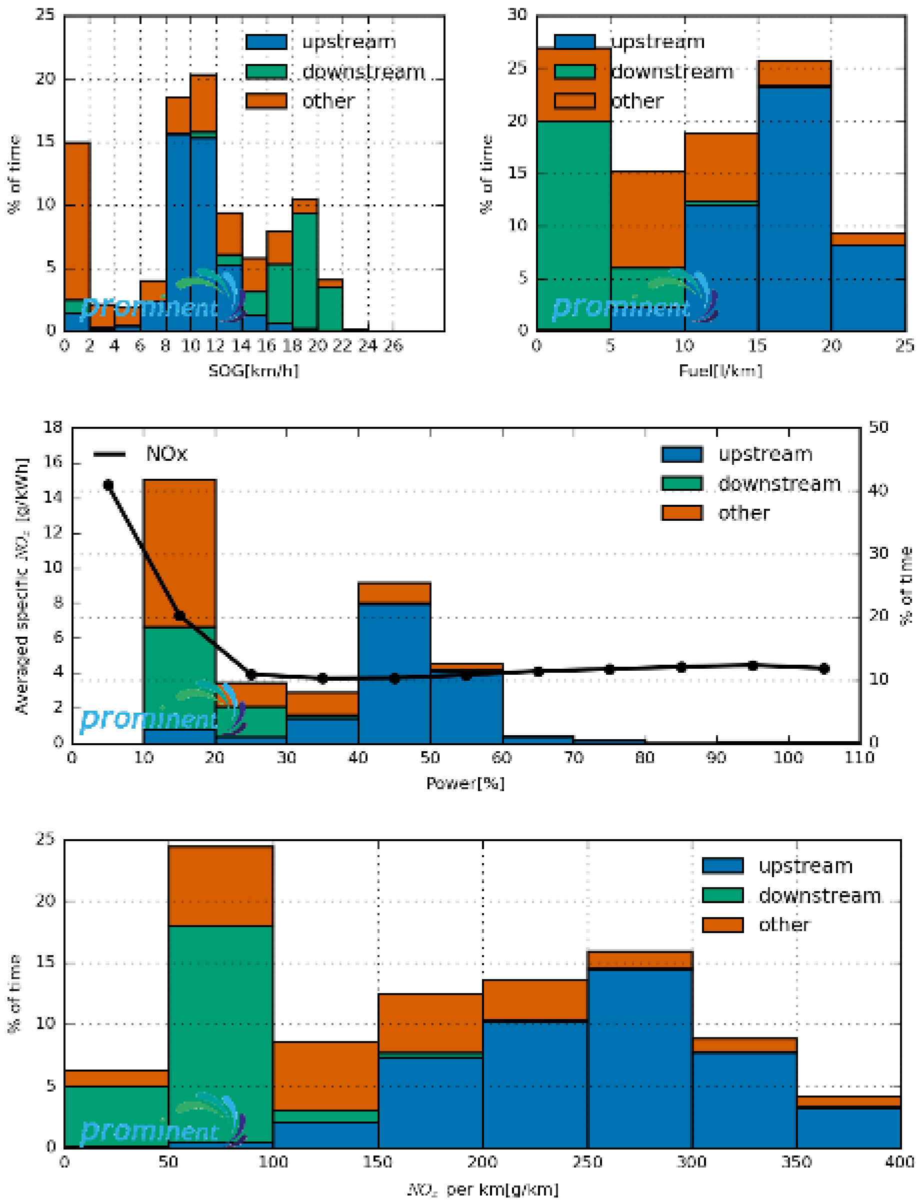


Figure 4: Fact sheet, example of data representation taken from *PROMINENT D5.7 (2018)*.

c. Other relevant information

i. Repeatability (accuracy) and transferability of test results

The accuracy of the sensor based on-board monitoring was compared with on-board measurements with Standard Reference Material (SRM), as well as also with laboratory measurements (see *PROMINENT D5.8 (2017))*. For on-board monitoring, the maximum uncertainty is dependent on the metric of the emissions and the different parameter options, for NOx emissions in:

g/h: ±8 %
g/kWh: ±7 %
g/kg CO_2: ±6 %

ii. Cost related impacts

The costs related impacts of Environmental Performance Monitoring (EPM) were reported in *PROMINENT D3.5 (2016)*.

The costs of In-Service Conformity (ISC) monitoring of Real Sailing Emissions (RSE) were estimated in a range from 6 000 to 20 000 EUR per vessel, depending on the extensiveness of the test procedure. The measuring period can range from several days up to two weeks.

EPM includes the continuous monitoring of NO_X, fuel consumption, CO_2, location and distance. In addition, it will be necessary to monitor also the payload carried in order to allow for a proper estimation of the transport performance and emissions related to tkm as one of the most important characteristics for evaluation of the environmental performance of a vessel.

The annual costs were estimated to be within a range between 3 400 and 8 200 EUR per year, depending on the number of engines and operating hours of the vessel. These costs are including installation costs, maintenance costs and data-transmission and storage.

iii. Relevant benefits

The benefits of on-board monitoring can be summarised as follows:

- demonstrate compliant real world NO_X emissions in the context of In-Service Conformity of emissions legislations;
- provision of input for proper Emission Factors (CO_2, pollutants) for inland vessels (used for national and regional air quality modelling);
- creation of transparency in environmental performance of inland waterway transport to customers and authorities;
- optimisation of the powertrain of the vessel;
- provision of information for efficient navigation tools.

iv. Implementation barriers

The following implementation barriers are expected.

In general, for on-board monitoring, large amounts of data are created. Quality checks of this data on errors, faulty signals, out of range, missing records have to be done very carefully, otherwise conclusions on averages and overall trip performances could have serious deficiencies.
More specific implementation barriers are:

For Real Sailing Emissions (RSE):

- No legal requirement for continuous on-board monitoring:
    - RSE could be implemented as formal In-Service Monitoring (ISM) or formal In-Service Conformity (ISC) for inland navigation (IWT) under EU 2016/1628, or
    - it could be implemented in combination with an independent test on board, as alternative to a type approval.

For Environmental Performance Monitoring (EPM):

- finalisation and general acceptance of precise presentation format by several stakeholders;
- costs of monitoring: cost predictions for EPM range from 2 000 to 5 000 EUR per year, constituting a significant cost;
- privacy: EPM gives or can give economic insight in the operation of the vessel, including sailing speed, locations, resting times of the ship personnel.

3. Pilot on standardised retrofit diesel after-treatment systems

a. Description of pilot

i. General description and objective

The objective of the task was the development, installation and testing of two types of exhaust after-treatment systems comprising:

- selective catalytic reduction (SCR) only: the system only reduces NO_X emissions. It is referred to as SCR-only since it does not carry diesel particulate matter filters (DPFs);
- SCR + DPF: the system reduces NO_X emissions and filters particulate matter (PM).

Both systems were equipped with a diesel oxidation catalyst (DOC) reducing hydrocarbon (HC) emissions and an ammonia slip catalyst (ASC) reducing ammonia slip.

The focus was on the following targets:

- achievement of compliance with the emission requirements of the Stage V for inland waterway vessels of the most recent version of the Non-Road-Mobile-Machinery Directive (NRMM Directive, *Regulation (EU) 2016/1628*);
- maximisation of usage of standard components (standardisation) in order to achieve a reduction of implementation costs by 30 % for the ship owner.

ii. Description of systems developed

In order to maximise the production and installation efficiency, one system was designed in which the DPF filters could be added or removed. This allows a ship-owner who invests in a SCR-only system to upgrade his installation to a system that is compliant with the emission requirements of Stage V of the NRMM Directive by adding a DPF to it.

The system developed consists of three major technical blocks:

1. DOC housing including diesel injection: this part is placed before the DPF + SCR/ASC housing. It is scaled based on the size of the engine (Figures 5, 7 and 8);
2. DPF + SCR/ASC housing: this housing contains the DPF and the SCR/ASC blocks. The urea (AdBlue) injectors can be mounted on the inlet side of this module (Figures 6, 7 and 8);
3. Hydraulic + electric package: the control and distribution of AdBlue and diesel injection into the system (Figures 7 and 8).

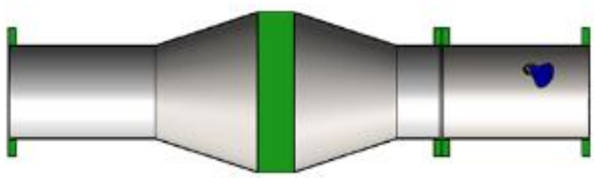


Figure 5: Standard DOC housing.

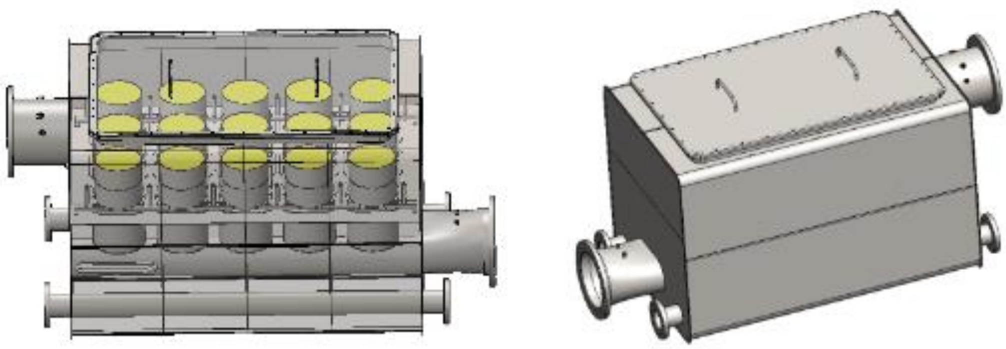


Figure 6: DPF + SCR + ASC housing.

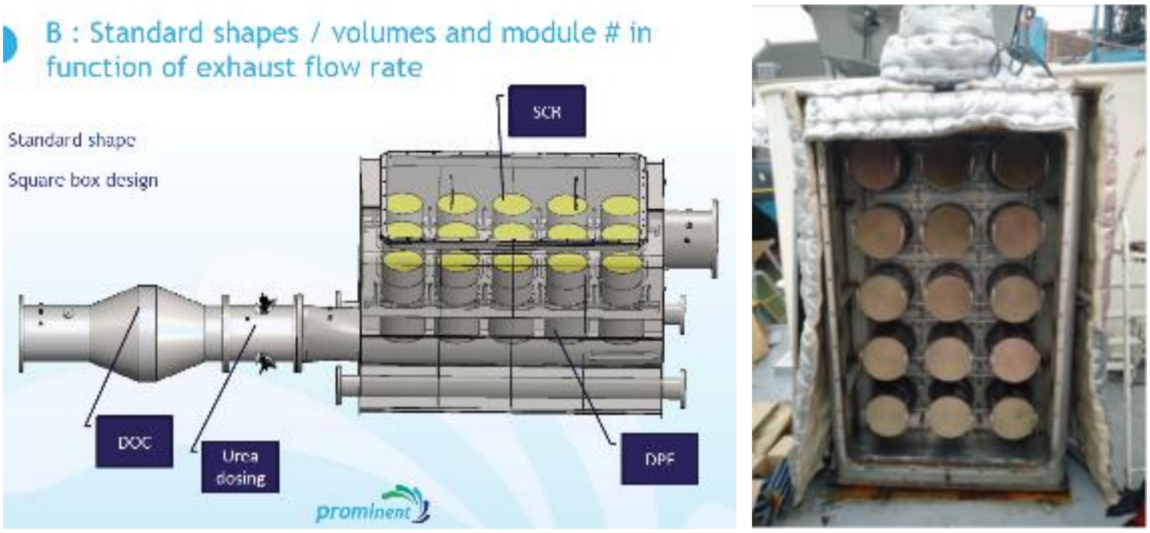


Figure 7: Assembly of DOC, urea dosing, DPF and SCR (left). Manufactured housing with modular standard DPFs, SCR and ammonia slip catalysts (right).

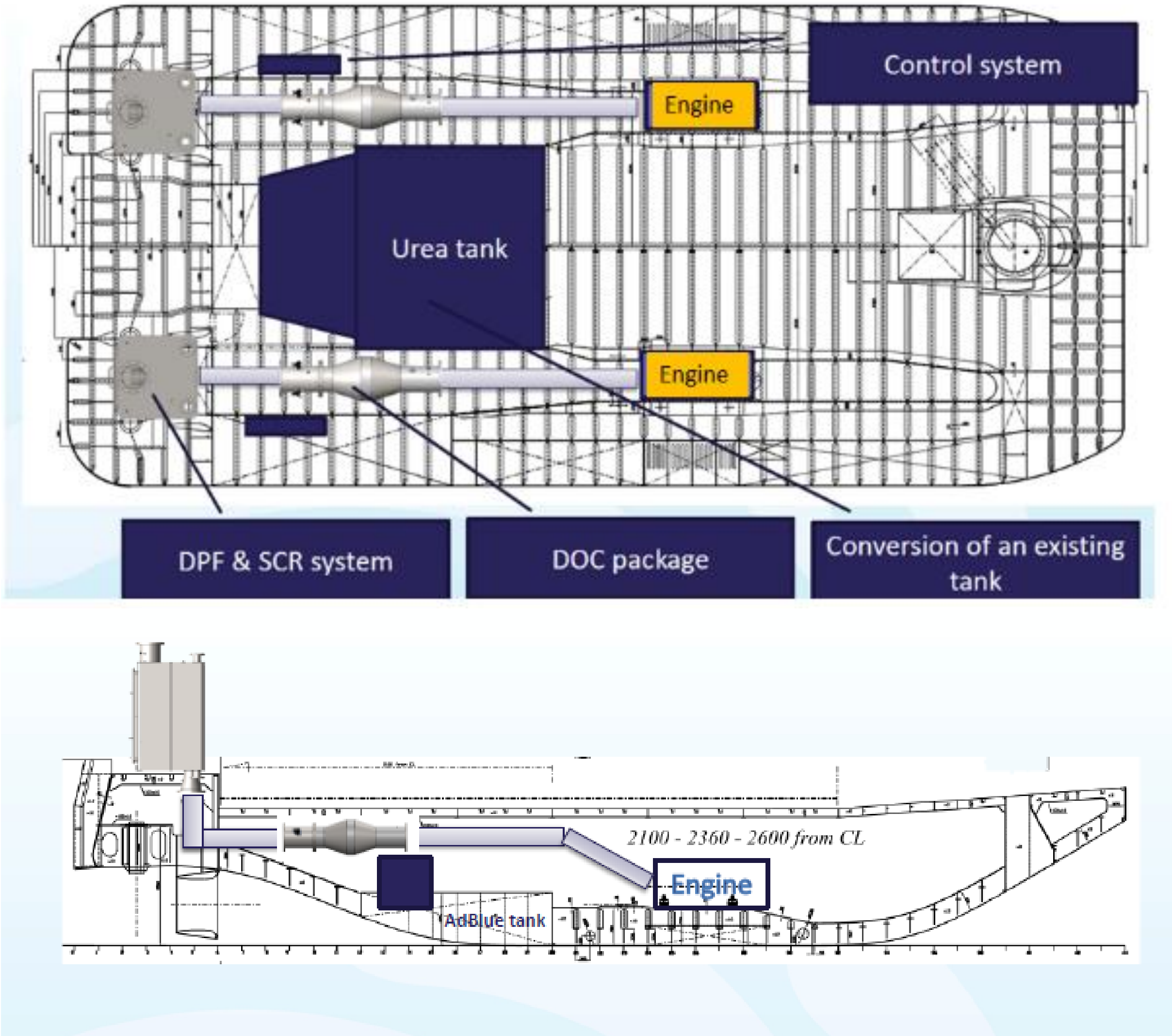


Figure 8: General arrangement of the engine room of the pilot vessel Donau with after-treatment installations.

Based on the conclusions derived in PROMINENT, a new standard housing design was developed consisting of standard modules for DPF, SCR and ASC as shown in the previous figures. The number of modules used can be adjusted to the power of the most common engines, allowing for a series production of the modules in large scale, and reducing thereby the production costs. In addition, the hydraulic and electrical packages were upgraded in order to be more cost efficient, safer and easier to install and manage.

iii. Ship specifications and installations

The selected vessel was the pusher Donau, equipped with two Caterpillar C3508B engines of 746 kW. On average, the pilot vessel pushes two lighters in the Netherlands and the Antwerp area (Figure 9).

Figure 9: Operational area of the pilot vessel.

Starboard the vessel was equipped with the DPF + SCR setup, while portside it was equipped with an SCR-only system. The installation took place in February 2017, and a test period took place in March 2017. Emission performance was tested by SGS on March 22, 2017.

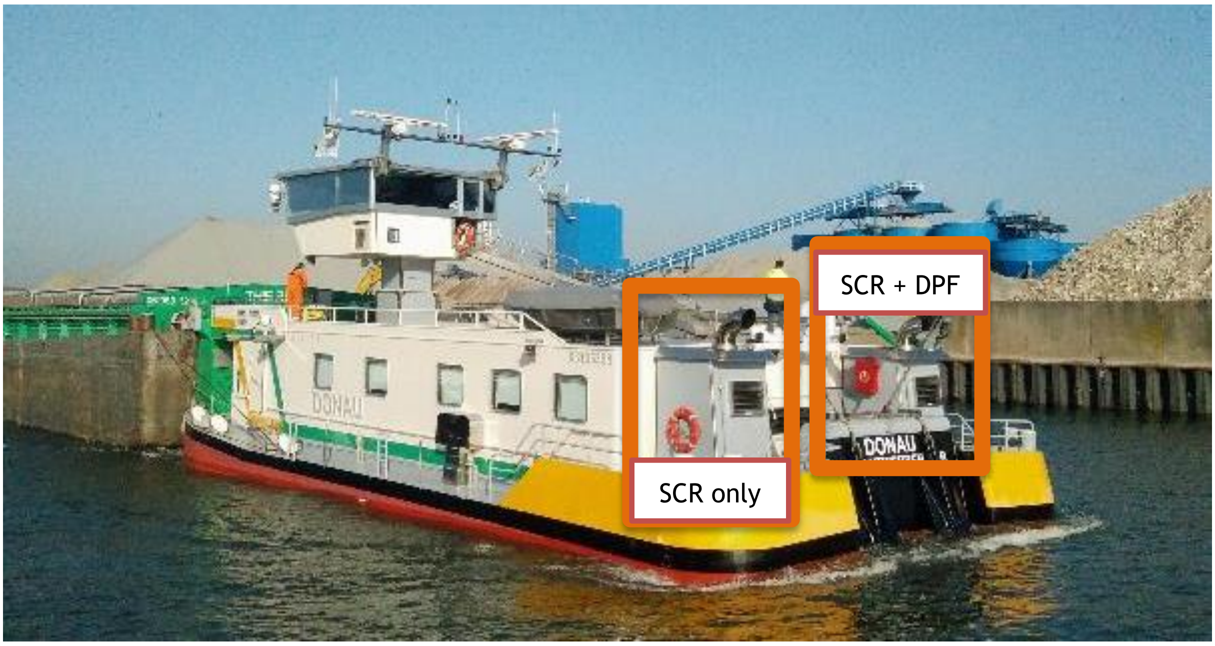


Figure 10: Completed installation of two after-treatment systems on board of the pusher Donau.

b. Results

The main evaluation parameters for the installed systems were emissions performance, back pressure, ease of installation and future maintenance and cost reduction when produced in larger numbers.

The observations for both pilot systems are identical with the only difference relating to the quantity of emissions reduced.

i. Emission performance

Both systems achieved the target reductions (1.8 g/kWh for NO_X) with an engineering safety which was larger than planned, *Creten and Van Mullem (2017)*. It was illustrated that for CO, HC and NO_X, compliance with the emission standards of the Stage V of the NRMM Directive, *Regulation (EU) 2016/1628*, can be achieved using a retrofit solution. The results relating to particulate matter (PM) are under evaluation at the stage of writing this report. It is noted that the number of particles PN could not be measured due to the lack of on-board PN-measurement equipment. The emissions were measured by SGS using PEMS. The cycle used was the ISO 8178 E3 cycle.

ii. Back pressure

The back pressure of an exhaust after-treatment system is a critical characteristic. The back pressure of the installed systems was well below the target values (66 mbar), and it corresponded to the predications derived from the CFD calculations performed.

iii. Ease of installation and future maintenance

A significant improvement was made on the ease of electrical installation. The hydraulic installation was not altered. A number of components was improved, resulting in longer lifespan and less maintenance cost. A system allowing fast replacement of the DPF's was successfully developed.

iv. Cost reduction

The sizing of the substrates (DPF, SCR, ASC, DOC) allows the use of mass produced elements. This results in a significant cost saving. The use of standard interfaces and components results in lower installation and maintenance costs. Currently, Multronic is still in discussion about the price in association with larger volume supply. The initial target of 30 % cost reduction for 200 vessels/year is expected to be reached.

c. Other relevant information

i. Repeatability (accuracy) and transferability of test results

The results of both systems were very comparable and corresponded to the results of the CFD calculations. An installation of a standard system of smaller size took place in June 2017. The field results from this installation were used to further evaluate the CFD calculations performed.

ii. Cost related impacts

Installation costs make up a large part of the total cost (around 20 %). Due to the in-situ nature of retrofit installations on inland waterway vessels, a lot of time and effort is lost when installing these systems. These costs could be further reduced by creating a better knowledge of the exhaust after-treatment (EAT) systems by the ship yards. This would allow them to carry out the installation more efficiently and independently.

The use of mass produced filters and catalysts would result in a strong cost reduction of these components. In the developed standard solution, smaller filters and catalysts were incorporated. This allows for cheaper mass production when ordered in larger badges.

Cost of maintenance could be reduced by carrying over regular maintenance activities done by specialised EAT companies, such as Multronic, to the ship owner or the ship yard.

iii. Relevant benefits

At this moment, there is not yet an official procedure to homologate the engine with the EAT system as being a NRMM stage V engine, however this is expected to follow in the near future. Currently, the benefits are limited to the achievement of locally accepted certificates, such as the 'Green Award'. A number of authorities, e.g. the Port of Rotterdam, accept these certificates and give advantages to the ship-owners. Also customers show an increasing interest in these types of 'green' labels.

From an environmental and a macro economical perspective, the benefits are significant. Particulate matter emissions, NO_X emissions, as well as CO and HC emissions have a negative impact on the heath of humans. In addition, negative environmental impacts, e.g. eutrophication or biodiversity loss, are caused amongst others by NO_X emissions. Due to the considerable reduction of the emissions mentioned, positive impacts on human health and environment will take place, resulting in a respective reduction of external costs caused by inland waterway transport.

iv. Implementation barriers

The high costs associated with installing and operating an EAT system having no significant payback model form a large barrier.

Secondly, the lack of regulation to homologate the EAT system as a retrofit NRMM Stage V system is a barrier. A ship-owner who installs an EAT system after his existing (non-Stage V) engine, will not receive the NRMM Stage V certification for his setup. Currently the only way to upgrade to Stage V is to renew the engine with an engine which was certified in an engine lab. In addition, there are possibilities for the type-approval of a combination of an engine (family) with an after-treatment system. However, it is not possible to get the after-treatment system separately type-approved. Due to the large investment required for an engine upgrade and the remaining lifetime of a large number of engines, ship-owners will continue using old engines in their current state. This keeps a large number of outdated engines with classic exhaust-outlet lines in the field, in particular CCNR II engines. This lack of homologation of aftermarket greening technologies can lead to a delay of their implementation.

4. Pilot on energy-efficient navigation

a. Simulations

i. Rhine

The evaluation of savings achieved by an optimised sailing policy is extremely challenging in inland navigation. The accuracy achieved by comparing voyages directly is strongly limited due to changing conditions. Not only the hydrological parameters like water depth and flow velocity change permanently, but also the surrounding traffic, the sailing schedule and the ship's load-case influence the energy consumption. Therefore, DST's simulation environment was adapted and used to quantify the influence of different sailing policies decoupled from other effects.

It is a well-known fact that a vessel sails more fuel- and cost-efficient in confined waters when the speed is varied according to the local water depth. The disproportionate rise of power demand and fuel consumption is significantly pronounced by shallow-water effects. Fuel can be saved by sailing slower in sections with less water depth and compensation of the loss in time by going faster in deep water to keep the sailing time of the entire voyage constant. Most sailing policies close to the behaviour of real boat-masters like constant rpm or sailing with almost constant Froude number[7] based on the water depth already imply a speed reduction in shallow sections. To compare the benefits, the following sailing policies were implemented in the boat-master model of the simulation environment.

Constant speed over ground can be easily realised by the boat-master based on the GPS velocity available on all vessels. It is limited to moderate changes in water depth and flow velocity as the maximum speed of the vessel through water is limited by available power and hydrodynamic effects. However, this sailing policy offers the easiest way to estimate the time of arrival at the destination. Constant speed through water seems almost as simple at first glance. However, the speed through water is usually not known to the boat-master in inland navigation. With the massive influence of the displacement current determined by the waterway cross section and ship loading condition there is no standard measurement system available to sense the relative flow velocity sufficiently far ahead of the vessel. In the PROMINENT pilot, this was done with advanced, remote sensing acoustic Doppler sensors on the passenger vessel FGS Symphonie and the container vessel Monika Deymann (see Section 4 e).

Constant rpm can also be applied on a vessel conveniently as most engines today are controlled at a set rpm value. Constant power approach is used by some boat-masters based on the instantaneous fuel consumption computed by the engine-control unit and displayed on the bridge. However, it requires manual changes of the rpm with rising propeller torque in reduced water depth.

Constant Froude number based on the water depth can be roughly estimated by visual control of the ship's wave pattern as the Havelock half angle of the wedge is determined by the water depth at sufficient speeds. A simple optimisation approach that can be implemented without detailed knowledge of the vessel is the minimisation of the averaged Froude number based on the water depth for the whole voyage.
When the ship performance model has all information regarding the vessel and her propulsor(s), a complex optimisation can be applied to minimise the fuel consumption. At a given sailing time, an

[7] Froude number based on the water depth = ship speed through water/(gravity constant • water depth)$^{0.5}$

optimal solution with minimal fuel consumption is calculated. Therefore, the discretised function for the fuel consumption:

$$Fuel\ consumption = \sum_{i}^{Sections} (be\ PD\ \Delta t)_i$$

is minimised with the specific fuel consumption be and the delivered power PD.

The influence of sailing policy was evaluated for the Rhine test stretch between St. Goar (rkm 556.1) and Nierstein (rkm 481.1). It was chosen as BAW provided high resolution 2D data (see Appendix A) for this stretch, which is not available in most other parts of the river today. This waterway data was combined with ship performance model data from dedicated model tests (see Section b of this chapter), and they were used to simulate the upstream voyages of the passenger vessel FGS Symphonie and the cargo vessel Monika Deymann on this 75.0 km long stretch. The mean water level (MW) discharge was used for the cargo vessel and the equivalent water level (GlW) discharge for the passenger vessel. Figure 11 shows the water depth averaged over the width of the fairway corresponding to the equivalent water level for the whole 75.0 km with a resolution of 100 m as provided by BAW ("water depth"). In addition, for comparison, the "aimed depth"[8], relevant rather for loading of the vessels than for propulsion, is shown, too. Figure 12 gives the corresponding data for the mean water level. Due to the averaging and unevenness of the waterway bottom, the depths are usually higher than the "aimed depths" at different gauges shown by the red line. The black dotted line represents the averaged flow velocities at the given discharge conditions (flow velocity).

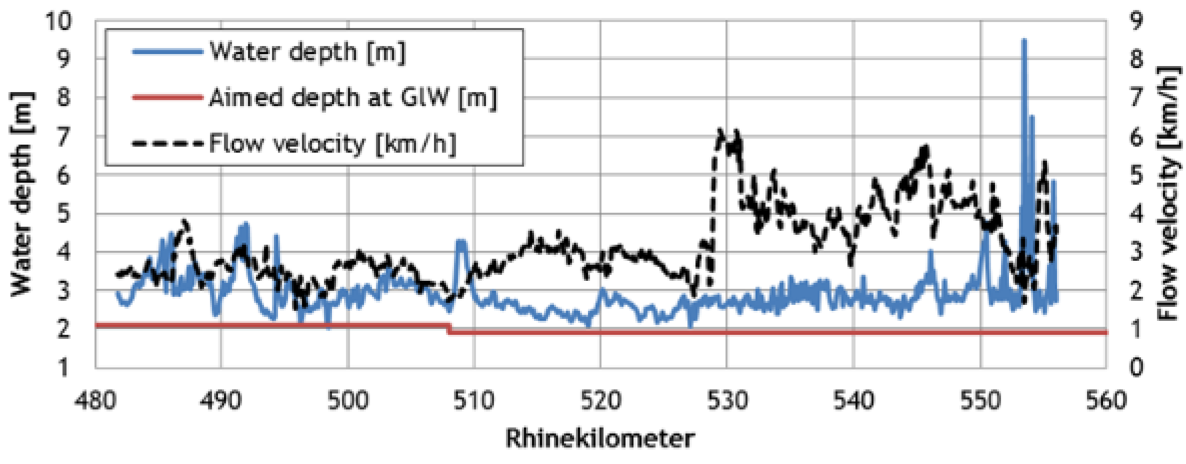


Figure 11: Water depth and flow velocities used in the simulations for the passenger vessel Symphonie (blue and black lines).

[8] The "aimed depth" at e.g. GlW is the minimum water depth at GlW the German waterway authorities seek to provide by waterway management activities.

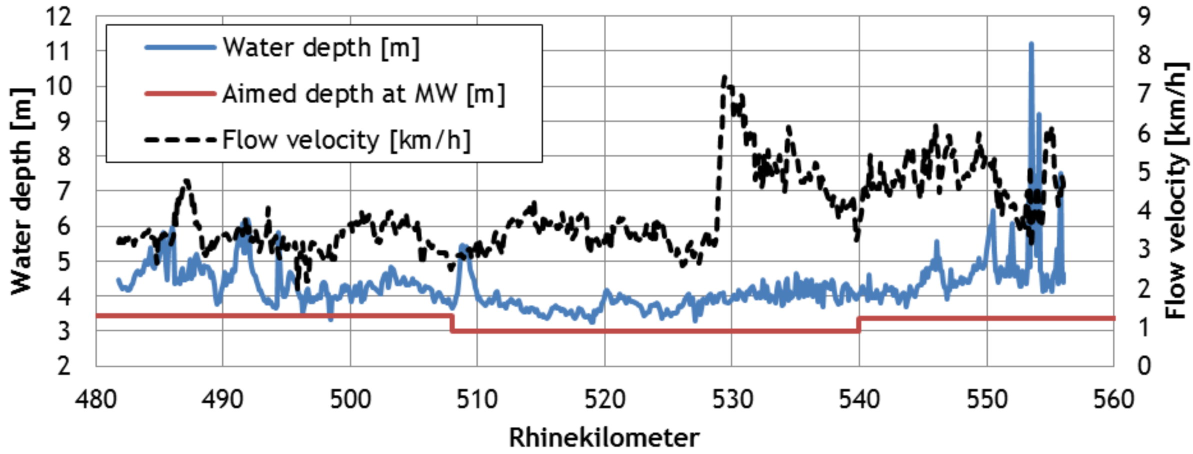


Figure 12: Water depth and flow velocities corresponding to MW discharge used in the simulations for the Monika Deymann (blue and black lines).

Propulsive power curves were calculated based on the model test results. Wake fraction, open water characteristics and thrust deduction were estimated for the passenger vessel to derive rpm and power. For the cargo vessel, self-propulsion tests were performed at some water depths in DST's shallow water basin. To avoid unrealistic results, some restrictive conditions were introduced. Besides the power capacity of the engines, the speed of the passenger vessel was limited by a maximum Froude number based on the water depth and the speed through the water $Fr_h = 0.75$. For the Monika Deymann, Fr_h=0.7 was used. A minimum velocity was defined with 5 km/h both over ground and through the water. These limits in combination with the given discharge conditions lead to a minimum calculated sailing time of 6.77 h for the passenger vessel and 6.22 h for the cargo vessel at higher water depth. Manoeuvring and surrounding traffic were ignored here. All sailing policies gave the same results, and no margin for fuel savings was left, as in all sections the speed was kept at the upper limit.

Increasing the sailing time, i. e. sailing slower on average, allows adapting the power and corresponding speeds to the local environmental conditions. For identical increase in sailing time each sailing policy results in different overall fuel consumption. The advanced optimisation gives the lowest possible values and is used as a reference in Figure 13, where results obtained for the container vessel Monika Deymann are displayed. The comparison includes the policies constant speed through water (StW), constant speed over ground (SoG) and constant rate of revolutions (RPM). Sailing with constant RPM results in the lowest increase of fuel consumption. Similar results were obtained for constant delivered power (PD), and the minimised average Froude number[9] based on the water depth (Frh avg), not displayed here. Results for the passenger vessel at reduced water depth are similar. However, due to the smaller draught the possible savings are smaller.

[9] The average Froude number based on the water depth is the arithmetic or weighted mean of the Froude numbers based on the water depth corresponding to each section (e.g. with a section length of 100m) of the discretised stretch considered.

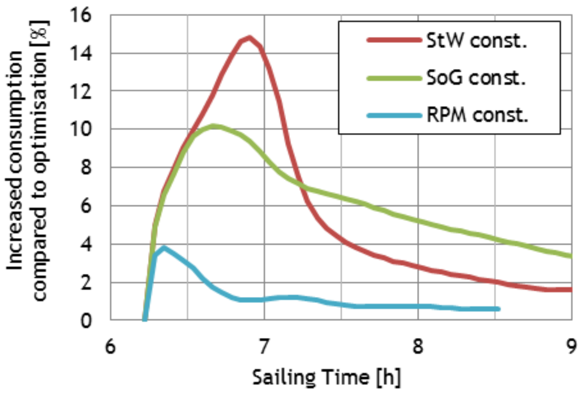


Figure 13: Possible increases of fuel consumption compared with optimum sailing at a given sailing time presented for the container vessel Monika Deymann.

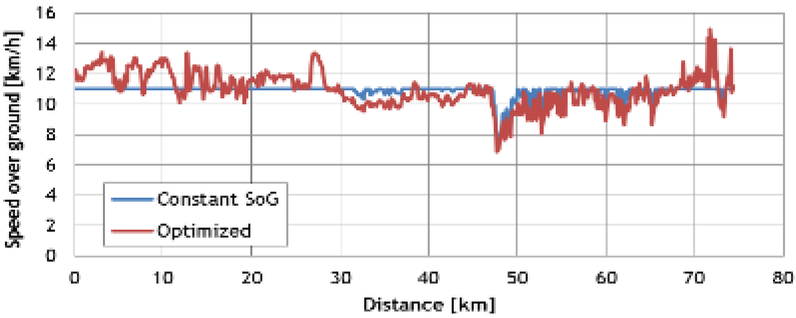


Figure 14: Variation of the speed over ground for the policies constant SoG and after optimisation.

Increasing the sailing time helps to reduce fuel costs in general. Figure 15 shows the fuel savings plotted against the increase in sailing time for optimised voyages of the container vessel Monika Deymann. Sailing 10 % longer than the minimum possible time results in a reduction of fuel consumption by 30 %. This impressive margin demonstrates the importance of voyage planning and the accurate estimation of the arrival time based on detailed knowledge of vessel and waterway condition. If a boat-master sails in a fuel-efficient manner for the first section of a voyage, and he has to increase the speed later to avoid arriving late, the savings are usually more than undone. The same holds for the opposite approach of collecting a time buffer in the first part of a trip.

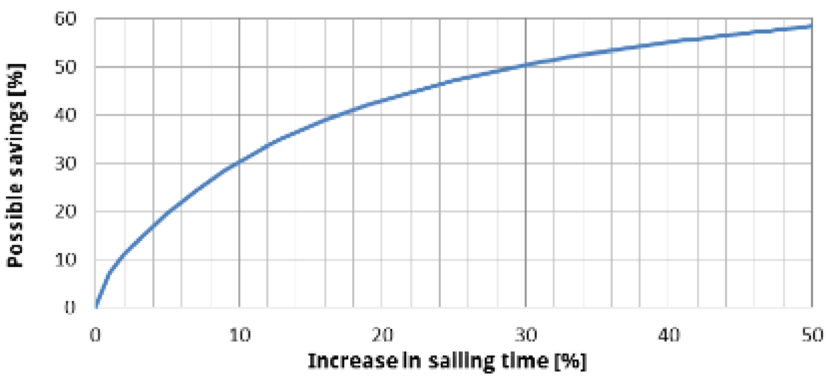


Figure 15: Possible saving of fuel consumption with increasing sailing time for the voyage from St.Goar to Nierstein.

For other vessels sailing on other stretches and in other discharge conditions, the results may look significantly different with higher or lower saving potentials. The quality of the results is strongly coupled to the available data for the vessel and the waterway. Even with the best models some uncertainty has to be accepted, especially, when the algorithms are used to compute real-time advice aboard. Propulsive power curves were calculated based on model test results. Though the extrapolation from scaled tests to full scale operation is a well-proven procedure some influencing factors were neglected here. The even bottom of the towing tank may have a different impact on the power demand than the changing river bed. The additional losses due to steering and ship-ship interaction can at best be included using a flat allowance. Fluctuations in the speed and direction of the current introduce further uncertainties.

In addition to the use as backend of on-board advisory tools, simulations can help in early design of new vessels and for the conversion of a drive-train. However, the performance of vessels in confined waters is extremely diverse, even for same sized vessels. *Friedhoff et al. (2017)* have shown speed power profiles for different hull shapes in different water depths. Vessels with similar performance in one water depth were measured with a factor of two in power demand at another water depth with similar probability of occurrence. This either causes high uncertainties or additional costs, when e.g. dedicated model test have to be conducted. For waterways where no consistent hydrological model exists the barrier to the usage of simulations is even higher.

ii. Danube

Up to now, no indications regarding the fuel-saving potential with respect to energy-efficient navigation have been given for vessels sailing on the Danube. In the framework of PROMINENT, a respective assessment was carried out for a Danube vessel sailing between Regensburg and Budapest on the Upper Danube, using the modelling approach of Via Donau. All details of the investigation are described in *Schweighofer and Suvačarov (2018)*. The operational cases comprise:

- operation of a Johann Welker vessel (extended) as pushed convoy consisting of the motor cargo vessel under consideration and a lighter;
- operation of the motor cargo vessel as single vessel.

The results comprise sailing time and fuel consumption derived for three different constant delivered power values representing the most significant power range the vessel is being operated, as well as three different speeds over ground when sailing downstream. The entire set of the calculations contains seven different delivered power values, not presented in the publication mentioned above due to space limitations. They were evaluated for 15 characteristic sections of the Upper Danube when sailing upstream, as well as downstream. The afore-mentioned results were given for three different water levels: the Low Navigable Water Level (LNWL), an artificial Mean Water Level (MWL) and the Highest Navigable Water Level (HNWL), and they were combined to different sailing strategies comprising sailing with different constant brake powers upstream and speeds over ground downstream.

In all cases considered, the reduction of the brake power and the speed over ground lead to a significant reduction in fuel consumption, ranging from 8.7 % up to 25.5 %.

The motor cargo vessel in single operation showed an excellent relationship between increase in sailing time and reduction of fuel consumption. Roughly, one may say that 1 % increase in sailing time leads to a reduction in fuel consumption by 4 %. The relationship becomes little less favourable for sailing at HNWL.

For the pushed convoy comprising the motor cargo vessel and the lighter, the reduction in fuel consumption derived by reduction of the maximum delivered power and the maximum speed over ground permitted ranged from 8.7 % up to 25.5 %. However, these reductions in fuel consumption could be achieved only by rather high increases in sailing time, becoming highest for sailing at HNWL. 1 % increase in sailing time lead to approximately 1.5 % reduction in fuel consumption at LNWL and MWL.

Considering the composition of the Upper Danube fleet, it could be concluded that the cases considered were representative for the majority of the Upper Danube fleet. Therefore, a transfer of the results to the most common ship types of the Upper Danube is possible, provided the operational profiles, brake powers and sizes are similar.

b. Towing tank tests carried out for evaluation of ship performance

The advanced optimisation of the sailing policy in terms of energy-efficient navigation requires a detailed ship performance model. To evaluate the consumed fuel for each discretised section of the voyage, detailed waterway data and the speed-power profiles of the vessel are required. The power demand and the corresponding fuel consumption are determined by numerous factors including speed and loading condition, as well as the dominant external factors water depth and flow velocity. To be able to quantify the savings and to get the maximum benefit out of the pilot on energy-efficient navigation extensive model tests were conducted for the three pilot vessels on the Rhine at DST's test facilities.

As the ship model implemented by TNO in the ENAT is based on the ship's resistance and all components of the propulsion system are modelled afterwards, most test runs were used for model resistance tests. However, the calculation of the fuel consumption and corresponding propulsive power requires information about the interaction of the hull and the propulsor. Therefore, for the motor cargo vessel Baden Wuerttemberg and the container vessel Monika Deymann also model self-propulsion and open water tests were done. Facilities, models, test procedures and results are described in the following.

i. Models

For the three pilot vessels operating on the Rhine wooden models were built at DST's workshops in scale 1 by 17. The passenger vessel Symphonie (see Figure 16) was used for resistance tests only. The shape of the stern section and experience from similar tests allow an educated guess for thrust deduction and wake fraction. Additionally, the propulsion concept with three podded drives with small propeller diameter of 1.125 m would require a large model to reduce viscous scale effects. The models of the single screw vessel Baden Wuerttemberg (see Figure 18) and the Monika Deymann propelled by two ducted propellers (see Figure 17) were equipped with scaled ducts, propellers and rudders and the corresponding measurement sensors. Table 6 shows the propulsion systems and the dimensions of the full scale vessels and the models including the tested load cases.

Table 6: Principal dimensions and characteristics of full scale vessels (LS, BS, TS) and test models (LM, BM, TM).

Vessel	Propulsion	LS	BS	TS	M#	LM	BM	TM
		[m]	[m]	[m]	[-]	[m]	[m]	[m]
Symphonie	3 podded drives	110	10.14	1.30	M2050	6.47	0.596	0.076
Baden Wuerttemberg	single shaft ducted propeller	105	11.40	Ballast 2.70 3.20	M2058	6.18	0.671	0.101 0.159 0.188
Monika Deymann	twin shaft ducted propellers	135	14.20	2.30 2.55 2.80	M2049	7.94	0.832	0.135 0.150 0.165

Figure 16: The scaled passenger vessel Symphonie, DST Model M2050, being filled and faired in the workshop (left) and ready for the tests with photo grid and woollen tufts for flow visualisation (right).

Figure 17: The scale model of the container vessel Monika Deymann, M2049, prepared for the resistance tests.

Figure 18: The cargo vessel Baden Wuerttemberg, DST Model M2058, in different states of the manufacturing process in the wood workshop (left) and ready model self-propulsion tests with propeller, duct and rudders.

ii. Test facilities

All model tests were carried out in DST's large shallow water basin with a length of 200 m and a width of about 10 m. The water depth is adjustable up to a maximum of 1.2 m. This basin is operated using two towing carriages which can be used separately and simultaneously. The large conventional carriage is used for most standard tests up to model speeds of about 6.5 m/s, while the unmanned high speed carriage is capable of speeds up to 20 m/s. For the tests described here towing speeds did not exceed 1.7 m/s, and the tests were conducted with the conventional carriage. The observation window underneath the towing track is used to visualise the flow characteristics at the hull using woollen tufts captured by high speed or conventional cameras. Figure 19 shows the carriage with the model of Monika Deymann in the large shallow water basin.

Figure 19: Scale model of the container vessel Monika Deymann being towed by the carriage in the large shallow water basin of 200 m length and 10 m width.

iii. Tests

Day-to-day work in the towing tank mostly consists of research projects looking into specific details and model tests for commercial customers. The latter campaigns combine model resistance, self-propulsion and open water tests of vessels before the production is started. These tests focus on very few sailing conditions in terms of speed, load case and water depth being subject-matter of the contract between shipyard and owner. The tests are used to check the attained speed and the corresponding power demand. Additionally, unfavourable hydrodynamic effects and potential room for optimisation are sought.

The test campaigns for the three pilot vessels in the Rhine region were different even though the used test procedures were the same. As all three vessels are already sailing at full scale, no changes can be implemented based on the test results. However, the advice tool and the underlying optimisation require a ship performance model covering all speeds, water depths and load cases without the need of uncertain extrapolations. Additionally, usual tests focus on the determination of the power demand and use the resistance and open water tests for additional information on hull-propulsor interaction and detailed dimensioning of the propulsor system. The ship model implemented in the advice tool to date is based mainly on the total resistance.

To match these requirements in the most effective way, it was agreed with the project partners to focus on resistance tests covering a maximum range of speeds, load cases and water depths. The characteristic quantities describing the interaction of hull and propulsor, being mainly the wake fraction and the thrust deduction coefficient, were determined in few propulsion tests or taken from experience available from other projects at DST. Considering the waiting times between consecutive test runs required to calm the water in the basin and to change test conditions like ballast or water depth, a maximum of two tests per hour can be done. With conventional stationary tests using one parameter combination per run and the test matrix spanned by the variables (three vessels, propulsion or resistance, different load cases, speeds and water depths), this would result in an enormous test campaign beyond the scope of this project. Therefore, the number of runs was reduced by means of quasi-steady resistance tests with constant acceleration during each test run. This allowed testing seven different water depths for the Symphonie with her constant load case, five for the Baden Wuerttemberg and four for the Monika Deymann with three loading conditions each. Table 7 lists the corresponding test parameters.

Table 7: Vessels tested and main parameters of model tests carried out.

Vessel	**Tests**	**Full scale draughts**	**Water depths**
	[-]	[m]	[m]
Symphonie	Resistance	1.30	17.2, 5.0, 3.0, 2.5, 2.0, 1.8 and 1.6
Baden Wuerttemberg	Open Water Resistance Propulsion	Ballast 2.70 3.20	14.55, 7.5, 5.0, 3.5 and 3.0
Monika Deymann	Open Water Resistance Propulsion	2.30 2.55 2.80	14.0, 7.5, 5.0 and 3.5

All tests were documented with pictures of the wave profiles at bow and stern taken from the port side and underwater pictures from the observation tunnel. Figure 20 shows some impressions of the different tests and installations. The following quantities were measured during all test runs:

- towing speed;
- longitudinal force between carriage and model;
- dynamic floating position (i.e. trim and sinkage);
- propeller rate(s) (open water and self-propulsion tests);
- propeller torque(s) (open water and self-propulsion tests);
- propeller thrust(s) (open water and self-propulsion tests);
- thrust(s) of the duct(s) (open water and self-propulsion tests).

Figure 20: Various pictures of models and installations taken during the extensive model test campaign.

The knowledge of the flow velocity in the waterway and the corresponding speed through water are of utmost importance for the trip advice tool and the underlying computations. Therefore, the pilot vessels at full scale were equipped with flow sensors measuring the one- or two-dimensional flow speed ahead of the bow. It is a well-known fact, that the displacement current induced by a vessel sailing in confined conditions also affects the flow ahead. However, there is little to no information on the distance where this influence becomes negligible. Therefore, additional test runs were performed with an inductive flow sensor mounted at half draught depth in different longitudinal positions ahead of the bow of M2049.

iv. Results

The extensive results were extrapolated to full scale and prepared for the implementation in the software for the trip advice tool. For gradient based optimisation algorithms it is very important to avoid undesired intersections of curves and sharp bents, where the optimisation might get stuck. Therefore, all profiles were smoothened and adjusted using a complex semi-empirical regression. The following plots (Figure 21 up to Figure 23) show exemplary resistance profiles for the most important load case of the three pilot vessels.

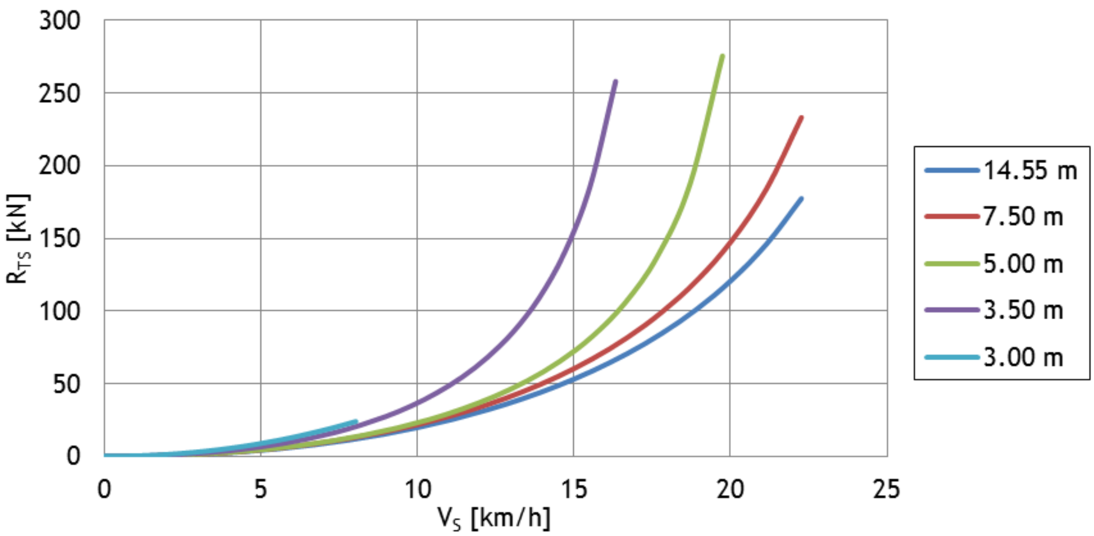


Figure 21: Exemplary resistance profiles for the cargo vessel Baden Wuerttemberg with 2.70 m draught in different water depths.

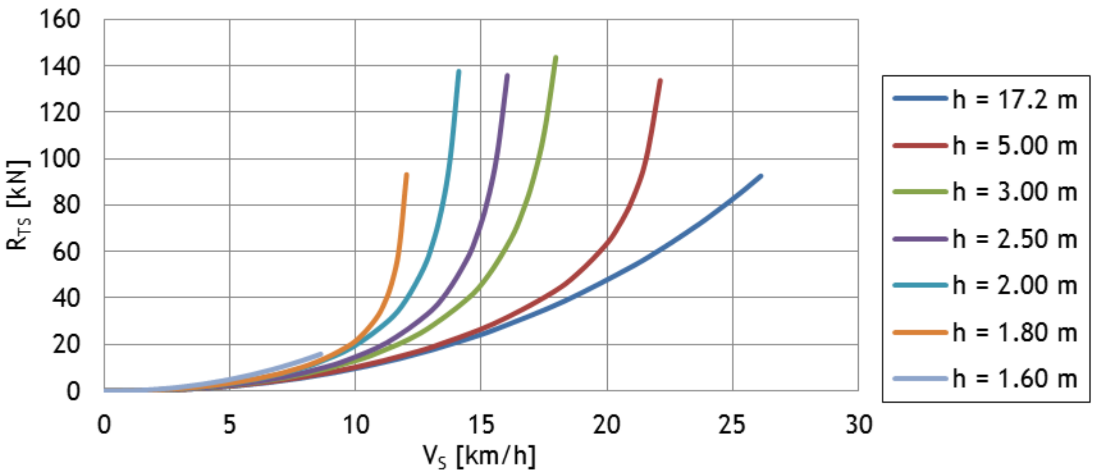


Figure 22: Exemplary resistance profiles for the passenger vessel Symphonie with 1.30 m draught in different water depths.

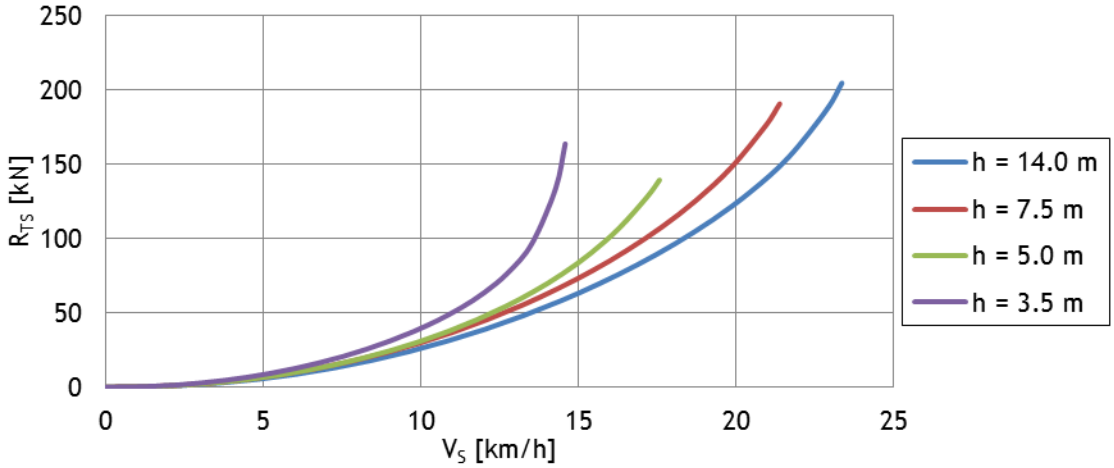


Figure 23: Exemplary resistance profiles for the container vessel Monika Deymann with 2.30 m draught in different water depths.

The measurements of the relative axial flow with an inductive flow sensor positioned at different distances ahead of the model clearly showed the influence of the displacement current on the local speed against water. Figure 24 shows the standardized flow velocities plotted against the distance from the bow for three different water depths and two draughts. At ten metres distance ahead of the bow and the most confined condition (purple line), the relative flow velocity is about 15 % smaller compared to the speed over ground. The reason for this massive influence is the shallow water effect of the vessel sailing at a draught of 2.8 m at a water depth of 3.5 m. The higher the water depth and the smaller the draught the less influence can be observed. At a distance of about 50 m the influence becomes negligible. Within a reasonable speed range, the influence of the absolute ship speed can be neglected. The displacement current is dominated rather by the geometry than by kinetics.

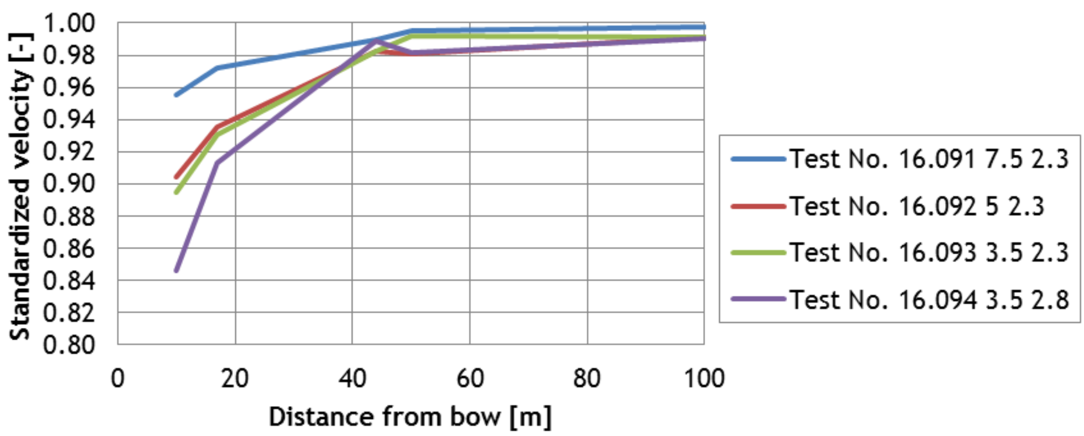


Figure 24: Effect of displacement current on relative velocity. Standardized velocities plotted against distance from bow for different blockage ratios for the container vessel Monika Deymann.

When no towing test info is available, the ENAT can make use of generic models (along with some calibration/fitting points). The parameters of the ship geometry needed are: length, draft and the beam. The draught will be given a default value for the vessel, but in the ENAT it has to be entered by the skippers as well (for each trip). Note that when towing tank tests have been performed, these geometry parameters (length and beam) are not used as they are implicitly available from the ship model.

The propeller is defined by its diameter, pitch over diameter ratio, ratio of the blades area surface and propeller disk, number of blades and the water density. The propeller models for open and ducted propellers differ, and the latter need additional information. Both ducted as well as open propellers can be used, and if needed, additional or customized propellers can be implemented easily.

c. Tool for energy-efficient navigation - ENAT (on-board tool)

The ENAT aims at a reduction of fuel consumption and emissions. This is achieved by predicting the vessel's performance for the trip ahead in time, comparing different sailing policies. From the offered information, the skipper assesses policies with respect to his needs and chooses the most relevant option. The ENAT supports the skipper in operating the vessel because it considers important factors like flow velocity and shallowness of the water. These factors are locally and temporally variable, demanding rather complex procedures for the evaluation of the respective performance of a vessel. Therefore, the skipper cannot accurately assess the effects of the prevailing navigation conditions on his vessel's performance. This may lead to the choice of a sailing policy with an earlier arrival time, however, constituting also a less fuel-efficient sailing policy. The ENAT helps the skipper to make the most efficient choice regarding the sailing policy. The advice is presented very quantitatively by displaying the expected fuel needed for the trip.

In Figure 25, a schematic overview of the databases and servers is shown. Shortly explained: the land-based and the ENAT tools are websites acting similar to apps, and they are found on www.iwtnavigator.eu. Access is restricted to known users. TNO is the admin. Graphical development is outsourced to a web development company, while the server hosting the algorithms and ship data is managed by TNO.

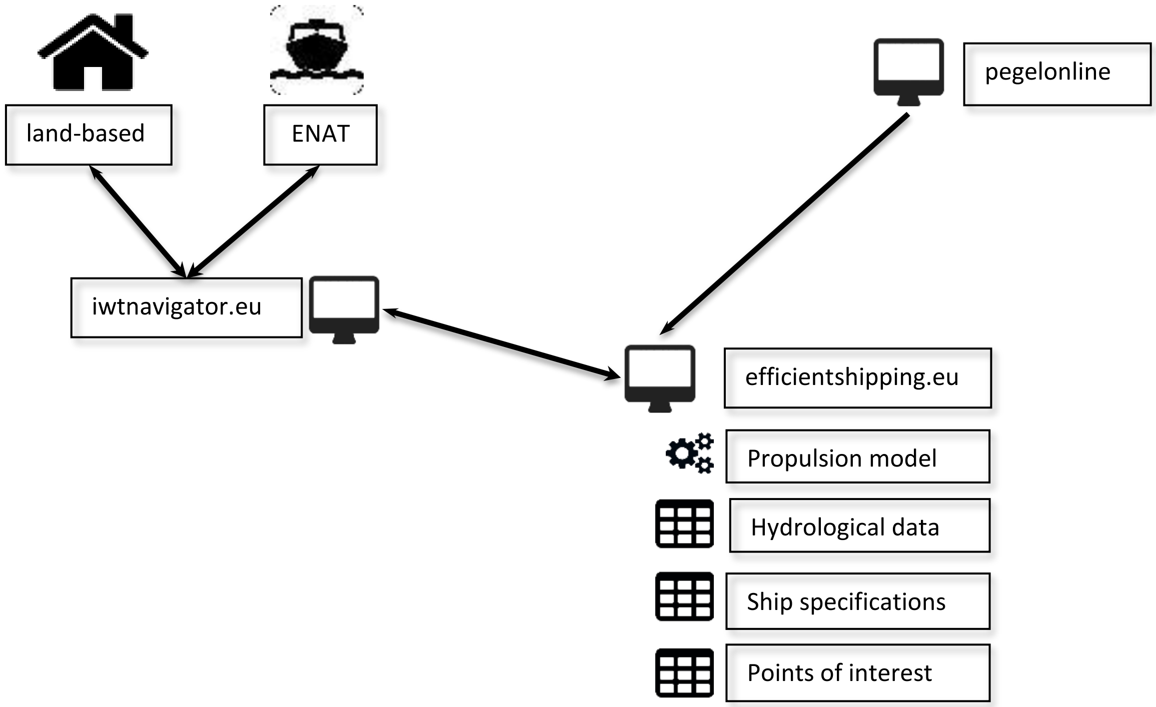


Figure 25: Graphical interpretation of the user, database and server configuration.

i. Graphical user interface (GUI), devices and scaling

The ENAT user interface is a website which is graphically optimised for browsers on mobile devices such as phones and tablets. When starting ENAT, it is checked if the browser has access to the GPS, and whether the GPS is turned on. If this is not the case, the user is asked whether he/she agrees to allow access to the GPS antenna.

The start screen is shown in Figure 26, which appears after the user logs in. On top, the implemented vessels are listed, which may be more than one vessel per account. First, the vessel that will sail is selected. As the vessel resistance strongly depends on the draught, the loading condition needs to be chosen. Depending on whether GPS is enabled, the option “current location” is available. For the destination, a list of points of interest can be chosen. The list can be extended on request of the user. Instead of using the GPS, two waypoints may be chosen to define the trip, for which immediate departure is assumed. The option of two waypoints is especially interesting when the vessel performance is studied without requiring real time advice, such as during planning. For planning purposes, there is no need to go to the detailed advice (Figure 27 (right)).

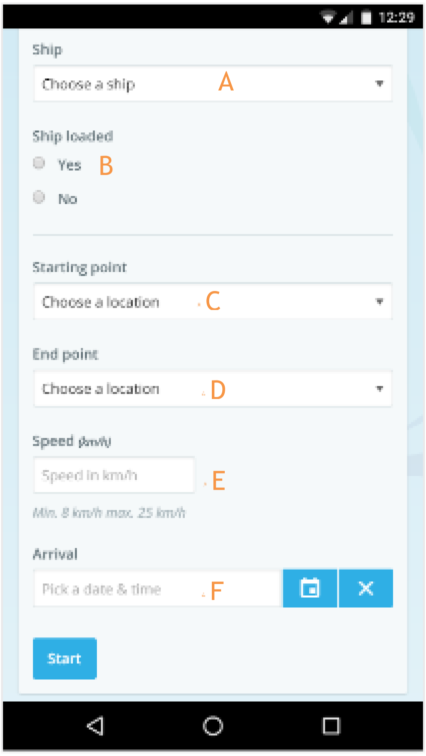


Figure 26: Route selection requires: choice of ship (A), loading condition (B), start location or GPS (C), destination (D), desired cruising speed (E) or arrival date and time(F).

Optimising the route takes approximately 15 s, and three (or more) advices are displayed (Figure 27 (left)). Three options with alternative arrival times and corresponding expected time of arrival (ETA) (A), fuel consumption (B), NO_X (C) and CO_2 (D) emissions. From the ETA and fuel consumption difference, the benefits of slow sailing, or price of fast sailing can be compared. Tapping/clicking on one of the options opens the route overview on the right.

The advice per section is shown in Figure 27 (right), for an example route. The different forecasted variables are advised engine speed (A), ship speed (B), expected flow velocity (C) and water depth (D) corresponding to the waterway data used in the ship performance evaluations. Note: the provided water depth is not the minimum water depth of the section if e.g. 1D data is used. The overview of the whole route helps the boatmaster view where strong currents or shallow water will be encountered, and on which stretches he is expected to catch up again. This information would otherwise not be available, as currently only the local water depth or keel clearance is available on board. Because the forecasted local vessel speed is available, together with the arrival times at which the vessel is expected at waypoints along the route, the boatmaster can check the result with his actual position and speed. He can then build up confidence in the correct functioning of ENAT for the particular journey and vessel.

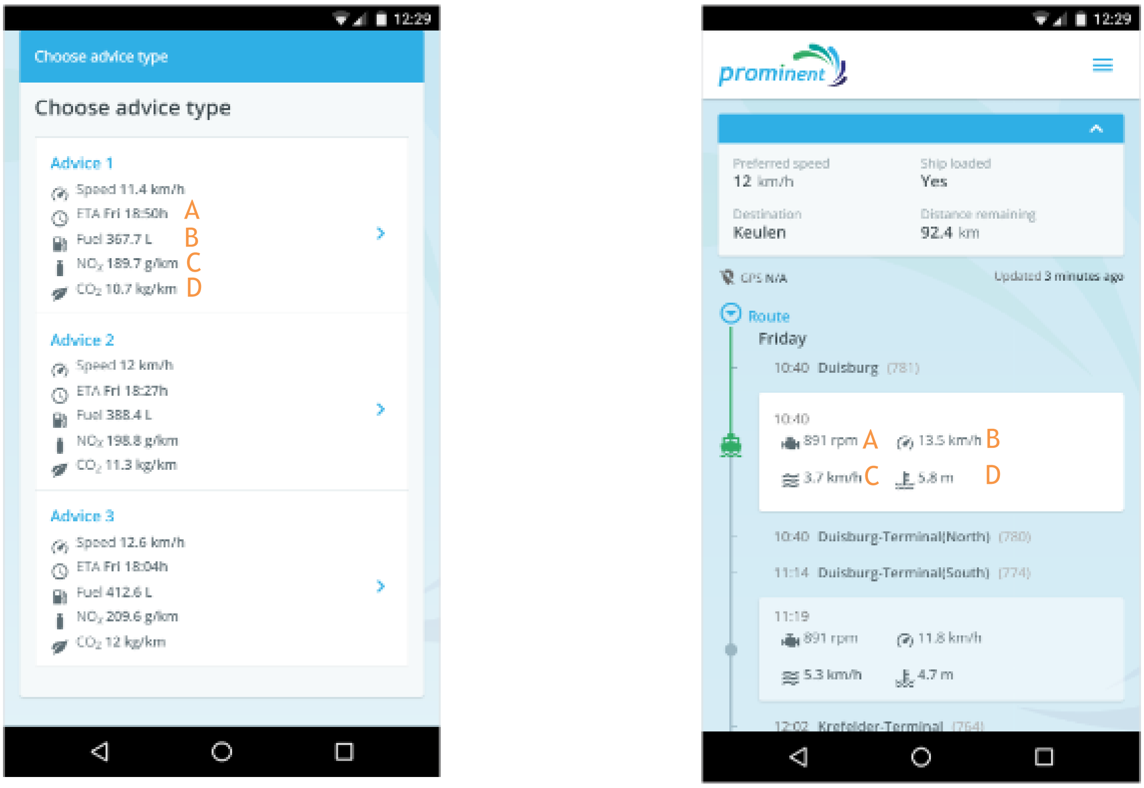


Figure 27: Left: Three options with alternative arrival times and corresponding expected time of arrival (ETA) (A), fuel use (B), NO_X (C) and CO_2 (D) emissions. Tapping/clicking on one of the options opens the route overview on the right. Right: Section wise overview of the route with advised engine speed (A), ship speed (B), expected flow velocity (C) and water depth (D) corresponding to the waterway data used in the ship performance evaluations.

ii. Optimisation

In order to model the delivered / required power of the vessel as a function of river conditions, the translation from river conditions to the delivered power of the vessel is made. This is done via the interaction with the vessel hull via resistance curves, which are derived from tank tests (see previous section). From the vessel resistance, the translation to the driveline is made using the energy model developed in Work Package 2 (see *Abma et al. (2017)* for details), which can handle a large variation of driveline types such as multiple propellers and hybrid vessels. A schematic overview is given in Figure 28. Depending on the engine type and emission class installed, NO_X and fuel use forecasts differ.

When the ship driveline is defined, the model first makes a set of runs of the track using different constant speed-over-ground values. The results of these test runs are first used to optimise the trip based on constant power, keeping the arrival time as desired. Then the trip is cut into sections based on constant rpm, while again keeping the arrival time constant. The choice for constant rpm is made in order to make the advice workable for the boatmaster, as constant power may imply that the engine speed has to change often. The constant rpm advice is given for sections of several kilometres (>10-20 km).

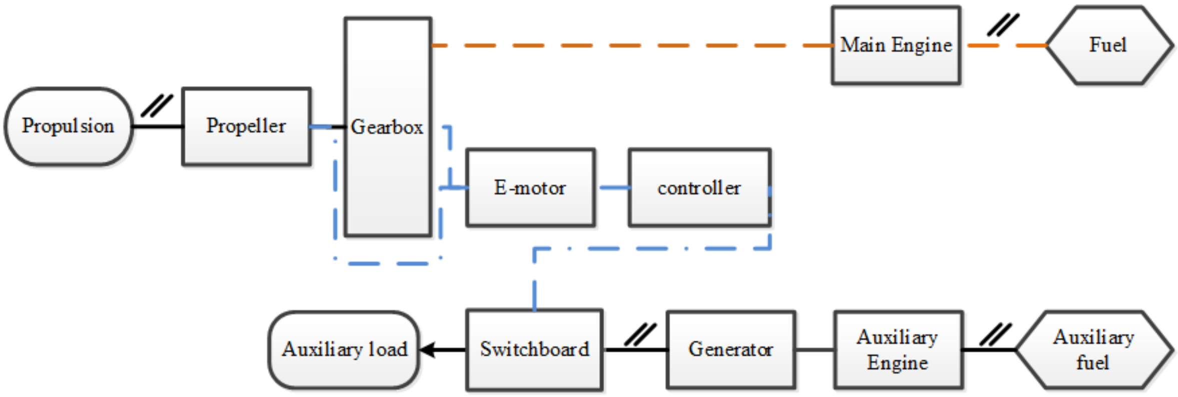


Figure 28: Generic ship energy model for conventional (orange/dashed), full electric (dash dot) and hybrid drives (both). The extent of electrification depends on the relative dimensioning of the electric part. See *Abma et al. (2017)* for a detailed explanation.

iii. Results

The hardware and software relating to energy-efficient navigation has been successfully developed. Unfortunately, comparative test runs for validation purposes could not be performed on vessels in operation during the life-time of PROMINENT so far due to the extensive development work carried out and differences in waterway conditions provided to ENAT and present under real-life conditions. However, it was possible to collect some user feedback, being presented in the following.

Interviews

In particular, two very distinct boatmasters were extensively consulted with respect to the ENAT tool. In general, they acknowledge the importance of efficient navigation for the environmental impact of their business. The parameters that are presented to the boatmaster match generally with the choices that they can make with respect to engine speed and sailing speed. However, they notice that there are still features lacking which they find essential in their daily operations, mostly concerning interaction with other traffic and lock passing. Furthermore, they indicate that they know from experience and their personal interest how to limit fuel consumption and, therefore, they recommend aiming at unexperienced boatmasters as a target audience for ENAT. ENAT has to be very reliable and proven with respect to fuel savings and operations before they would consider using it.

Barriers to setting up and usage of the tool

Setting up the tool requires a couple of actions before an advice can be given. The first is the technical specification of the vessel, which contains the interaction of the vessel with the environment via the speed-resistance curves for different depths. These curves need to be determined individually for each distinct vessel type, for example by tank test for different depths. However, tank tests are expensive and rarely performed for inland navigation vessels. Therefore, the consideration of alternative ways of estimating the requested resistance curves (or even power curves) should be taken into account. Then the technical specifications for the propellers, gearboxes and engine need to be determined. In case of a hybrid vessel, parameters of the electrical driveline are needed as well, including electromotor and generator sets. Then, if it is the first time that a vessel (type) is used in ENAT, a comparison needs to be made of the predicted vessel performance and propeller speed, with observations of on-board measurements or the boatmaster's experience. This is used as a validation of the implementation. As a last action, the boatmasters need to be instructed and given a login access to ENAT.

If the sailing area of the vessel is not yet available in ENAT, detailed parameters for depth and flow velocity need to be retrieved. Accordingly, waypoints and routing need to be added to the user interface. Currently, ENAT is specialised in the German Rhine, while it is desirable to add the Dutch and Belgian waterways as well. If water levels are not constant, such as in rivers, real time coupling to conditions may be made using gauges or otherwise. This is of course unnecessary if conditions are constant such as in lakes or canals. If the tool is to be used as voyage planner or for the estimation of the estimated time of arrival for long stretches with different characteristics, then also the impact of possibly present locks and terminals has to be included.

d. Tool for evaluation of ship performance

i. Description

Ship performance is approached from both efficient navigation as a predictive method, and the monitoring of performance data as a historical tool. The ship performance evaluation tool has been split into two components:

- the ENAT route planning, based on the algorithms of ENAT;
- access to on board measured performance data.

Ideally, these tools would be combined into a single tool that automatically compares the realised vessel emissions with the modelled performance, though such a system will be complex to be set-up and it will need a lot of maintenance when the on-board monitoring (OBM) system or ENAT tool changes. A comparison between the ship performance results of ENAT and the ones of the OBM system was performed for the motor cargo vessel Baden Württemberg, resulting however in no valid conclusions due to the differences in waterway conditions used by ENAT and present in the test section.

Both components contribute directly to raising awareness of the benefits of modified sailing behaviour.

ii. Results of applications

ENAT route planning

In the ENAT tool for trip planning, the first two windows are identical to the ones in Figures 26 and 27 (left). The workflow is equal to the workflow for the on-board tool, but instead of the current location, two waypoints are chosen. Then the second screen gives the planner an overview of the fuel and emissions that will be obtained by sailing e.g. slower.

On-board monitoring (OBM) website

The data from the Smart Emissions Measurement System (SEMS) installations can be accessed by end users using a website. The main goal of this is to allow users to obtain data easily, giving them insight in the data that is gathered on board of their vessels. The website provides the following main functionalities:

- securing of data so that only users with the right permission can access these;
- provision of a summary of average CO_2 and NO_X emissions per km;
- ability to download per-second data, e.g. CO_2/s, for further processing.

TNO innovation for life

ENGINE AQUAMYRA 1 INFO

Available measurement sessions AQUAMYRA 1

Zip contains discription of variables.

Merged csv | Zip

Download	CO2[g/km]	NOx[mg/km]	Distance[km]	Start time	Duration
☐	26270.1	186330.4	7.3	07 Nov '17 23:16	1h 00m 00s
☐	39900.1	428446.1	7.1	07 Nov '17 22:16	0h 59m 59s
☐	19194.3	239918.3	7.5	07 Nov '17 13:58	1h 00m 00s
☐	21216.1	210215.6	7.4	07 Nov '17 12:58	0h 59m 59s
☐	17542.8	113954.5	8.4	07 Nov '17 10:38	0h 54m 28s
☐	24720.7	150819.1	10.0	07 Nov '17 09:38	1h 00m 00s
☐	26500.3	268979.5	7.9	07 Nov '17 08:38	0h 59m 59s
☐	19337.0	197882.8	6.9	03 Nov '17 23:41	1h 00m 00s
☐	16747.1	158780.4	10.6	03 Nov '17 22:41	1h 00m 00s
☐	16044.7	133447.7	9.5	03 Nov '17 21:41	1h 00m 00s
☐	17486.6	126403.1	10.0	03 Nov '17 20:41	1h 00m 00s
☐	17077.7	129405.8	10.1	03 Nov '17 19:41	1h 00m 00s
☐	12762.4	77036.1	15.6	03 Nov '17 18:41	1h 00m 00s

Figure 29: Example of screenshot of OBM results derived for the vessel Aquamyra 1.

Evaluation of fuel saving potential of measures that change sailing behavior between locks

The application of the ENAT model showed that optimisation of lock scheduling and ship waiting times can reduce the fuel consumption by 13 %. This result was obtained by comparing actual and optimal voyage planning on the lock abundant Rotterdam-Maastricht route, using maps provided by Rijkswaterstaat. Fuel use was minimised when all waiting time is eliminated, leading to lower sailing speed. This exercise showed both the applicability of ENAT as an impact assessment tool, as well as the importance of voyage planning and the role of infrastructure in the emissions reduction.

Figure 30: ENAT: fuel savings between locks: route considered between Maastricht and Rotterdam with locks at Born, Maasbracht, Heel, Belfeld, Sambeek and Weurt.

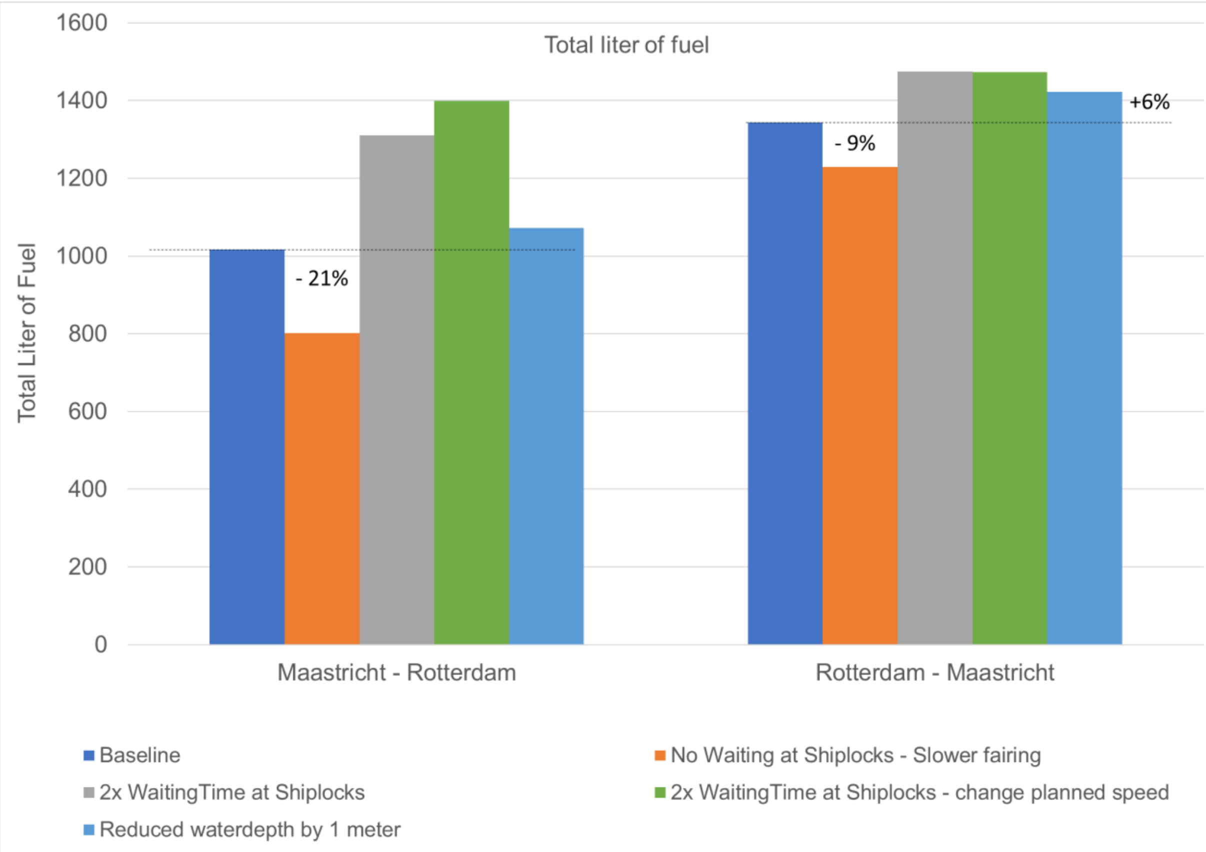


Figure 31: ENAT: fuel consumption given for different scenarios for sailing between Maastricht and Rotterdam. Between Maastricht and Rotterdam, a reduction by 21 % was obtained, compared with baseline. Between Rotterdam and Maastricht a reduction by 9 % was obtained.

Barriers

While setting up the land based tool, the barriers are practically the same as for the on-board tool, though there are several differences:

- For the land based tool, the results for total fuel consumption and arrival time are of main importance. Therefore, the focus is not on the per-section fuel consumption. However, the per-section optimisation is needed to calculate the totals;
- While boatmasters can activate the on-board tool for a short stretch of the river, the on-board planning tool needs to cover longer trips. Therefore, it needs much more fairway data, and a system to combine the fairway data into routes, including locks and terminals.

e. On-board measurements of water depth and flow velocity

i. Rhine vessels

Description of systems implemented

Accurate hydrological data of the waterways is of utmost importance for energy-efficient navigation. Precise knowledge of the relevant water depth for loading a vessel allows for improving the efficiency by increasing the operational draught and amount of cargo of the vessel under consideration. The optimisation of the sailing policy, e.g. with the on-board assistance tool, is also based on authoritative forecasts of water levels and flow velocities.

Schedule-keeping requirements may cause excessive sailing speeds as a result of uncertainties regarding the waterway condition. Additionally, fuel savings due to an optimised choice of speed can only be validated for comparable trips or if the differences are measured accurately.

Though the objective of the pilot application was energy-efficient navigation, the criteria for the selection of vessels were diverse. The pilot vessels should sail frequently on the test stretch between Nierstein (Rhine-km 481) and St. Goar (Rhine-km 557) where hydrological data with high temporal and spatial resolution could be provided by the BAW. The operators should be highly motivated to apply the recommended sailing policies for improved energy-efficiency. As the pilot vessels were equipped with precise echo sounders and optional sensors for the relative flow velocity, they helped to improve hydrological data outside the test stretch. Therefore, vessels sailing the same routes as often as possible and covering long distances are beneficial. A constant draught with low risk of air bubbles in the vicinity of the echo sounders is also helpful. Vessels chosen were the passenger vessel FGS Symphonie and the large inland cargo vessels GMS Monika Deymann and GMS Baden-Württemberg.

Devices for measuring flow velocities in inland waterway areas on-board a vessel had to be installed in a way that the water volume to be measured is not influenced by the sailing vessel itself. The vessel’s return current, bow wave and propeller jet have an impact on the flow around the vessel, especially in confined inland waterways. To avoid any influence the flowmeter or ADCP (Acoustic Doppler Current Profiler) should be installed at the vessel`s bow in a way that it performs the measurements several meters in front of the vessel. The beam spreading of the ADCP should be small, so that the beams touch neither the bottom nor the surface of the river to avoid incorrect measurements and to extend the profiling range. A one- or two-beam horizontal ADCP (H-ADCP) was best suited for this task.

The used H-ADCP on-board passenger vessel FGS Symphonie (Aquadopp 600 kHz, Nortek, Figure 32) measured the flow velocities in two dimensions (North- and East-components) at approximately 1.2 m below the water surface. The beam angle was 25 degrees. Evaluations indicate a collection of data up to about 40 m in front of the bow.

Figure 32: Flowmeter (Aquadopp, Nortek) at the bow of the passenger ship FGS Symphonie.

The area of disturbed flow conditions (i.e. influenced by the vessel's movements) depends on multiple factors like water depth, draught and the vessel's shape. According to the experience of BAW, undisturbed flow conditions can be found at a distance of 10 m up to 15 m in front of the bow. Therefore, the H-ADCP on-board the FGS Symphonie was configured to measure the velocities in the range up to 40 m in front of the bow. This measurement range was divided into 20 measurement cells with a cell size of 2 m.

The recorded bottom heights and flow velocities have to be assigned to an exact position. Furthermore, the measured velocities through water have to be corrected by the velocities over ground to obtain the flow velocities. For this purpose a heading device consisting of two dGPS receivers using real-time corrective services was installed on deck to get highly accurate data of position, height and velocity over ground, Figure 33.

Figure 33: GPS array installed on the passenger ship FGS Symphonie.

The corrective service (AgCelNet, geo-konzept) used on-board the FGS Symphonie is a commercial service which provides correction data with NTRIP via GSM. This service improves the accuracy of positioning in the order of centimetres.

The FGS Symphonie was equipped with one built-in echo sounder at the bow. It was used to determine the bottom heights.

A terrestrial surveying of the positions of all sensors used was conducted at the shipyard according to the guidelines of the BfG, *Brüggemann (2014)*. Hence, all sensors could be displayed in a local coordinate system of the vessel which is required when geo-referencing the measured data and when precisely determining the bottom heights.

All data was processed, stored and submitted in a central data acquisition system (DAQ) on-board the vessel. In addition to the recorded information about flow velocities and bottom heights, the available engine data (such as rate of revolutions, rudder angle, fuel consumption, engine load, oil temperature etc.) of the main engines was stored and transmitted.

The DAQ on-board the passenger vessel FGS Symphonie was similar to the system on-board the cargo vessels GMS Monika Deymann and GMS Baden-Württemberg. The DAQ was designed to collect measurements from the two main engines and from various sensors. Some of which were installed specifically for the PROMINENT-project while others were part of the standard navigational equipment of an inland waterway vessel. To ensure the proper functioning of the navigational equipment, as well as the main engines, the interfaces and the power supply of the data acquisition system have to be chosen appropriately. The DAQ system on-board the GMS Monika Deymann consisted of two control cabinets (the main cabinet in the engine room and a smaller one in the forepeak), and a HSPA modem which was installed in the wheelhouse for better cell phone coverage. The two control cabinets had separate power supplies due to the long distance (approx. 100 m) between them. Each control cabinet consisted of one DC/DC converter and one AC/DC converter, whose 24 V outputs were coupled through diode modules. These converters supplied voltages which were galvanically separated from the power system of the vessel. Two independent power supplies in each cabinet guaranteed redundancy. The control cabinet in the main engine room consisted mainly of a modern PLC (programmable logic controller) with several DAQ modules attached. The PLC and its DAQ modules were all approved by GL (Germanischer Lloyd) and could, therefore, be used on-board of vessels. Apart from the FlowScout600 sensor, the rate of turn indicator, a centimetre-accurate GPS compass, four echo sounders, and the loading instrument of the vessel were all connected to the PLC.

The sensor system for the acquisition of bottom heights, position and flow velocities envisaged for the cargo vessel GMS Monika Deymann was much more comprehensive than the one installed on board the passenger ship FGS Symphonie, Figures 34 and 35. Eventually, data resulting from one flowmeter, four echo sounders, GPS and GPS compass, as well as engine data and information from any other available data source (such as ROT indicator, loading instrument, AIS) should be integrated into the system for further use. Therefore, the conception and coordination with the shipyard (TeamCo shipyard, Heusden, NL) already began during the construction phase of the vessel in the first half of 2016.

The flush mounting of a flowmeter within the hull could not be realised because this kind of installation takes too much time and effort. Therefore, it was decided to install the flowmeter inside the bow thruster channel of the cargo vessel. Due to the chosen location the installation of the sensor was minimally invasive and it is possible to access the sensor without a diver when the vessel is not loaded. Accessing the sensor could be necessary for cleaning because of bio-fouling or replacement.

Figure 34: GMS Monika Deymann in operation.

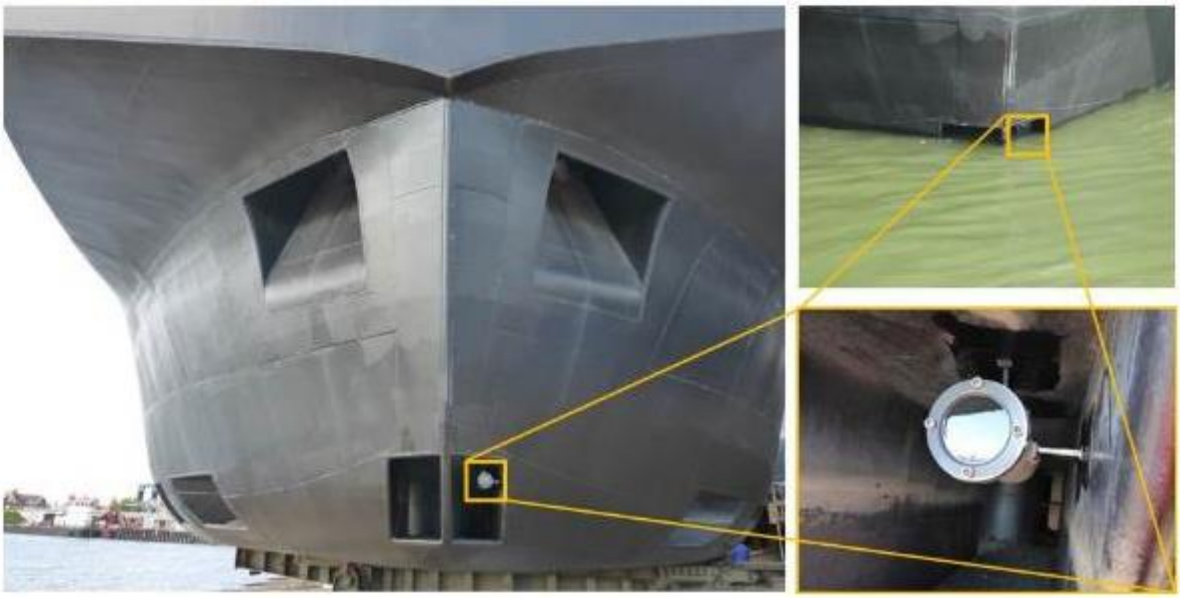


Figure 35: 1D-flowmeter installed in the bow thruster channel of GMS Monika Deymann.

The sensor had to be surrounded by a special steel case to be protected against high velocities resulting from the use of the bow thruster. However, a compact design was necessary to ensure the performance and efficiency of the bow thruster. For this reason, a 1D ADCP (FlowScout600, LinkQuest Inc.) in a special configuration was used. It only measures the flow component along the longitudinal axis of the vessel (i.e., along the vessel's direction of motion). Thus, in straight stretches of the river the measured velocity component corresponded to the longitudinal and dominating component of the river flow. When navigating through bends, however, the river velocity was underestimated with this approach. The data collected can also be used for calculating the vessel's resistance, which is significantly influenced by the measured flow component.

As acoustic flowmeters should not be used outside the water for a longer period of time, the operation of the sensor had to be linked to the vessel's draught. This was achieved by integrating the loading sensors into the DAQ.

In an initial configuration, the flowmeter was set up to measure flow velocities from a distance of 5 m in front of the bow with a resolution of 5 m. When considering typical draughts of the cargo vessel, it was possible to measure flow velocities up to 40 m in front of the bow.

The vessel GMS Monika Deymann was equipped with two built-in navigational echo sounders at bow (port side) and stern (starboard). Mountings (standpipes) for two additional echo sounders were installed at bow (starboard) and stern (port side) and equipped with hydrographic echo sounders. Because of the standpipes the echo sounders can be replaced in case of damage or malfunction if the draught of the vessel is small. Therefore, a total of four echo sounders was used within the PROMINENT-project.

Position and true heading was measured by a dGPS array consisting of two GPS antennas near the bow and the stern of the vessel. The antennas are located as close as possible to the position of the echo sounders in longitudinal direction of the vessel. Nevertheless, these distances at the stern between the position of the GPS antenna and the position of the echo sounder were up to 14 m in longitudinal direction of the vessel and up to 10 m in lateral direction. These distances imply an induced heave at the echo sounders in case of pitch and roll of the vessel.

The GPS receiver itself was placed in the engine room next to the data acquisition system. It could be accessed and configured via mobile network. The GPS data was corrected in real time using the SAPOS HEPS service, which is only available in Germany. Therefore, the transmission of data can only be realised in Germany. The SAPOS HEPS service was transferred with NTRIP via internet and GSM, and it improved the accuracy of the measurement of the position up to the order of centimetres.

Since the beginning of 2017, the GMS Baden-Württemberg has also been equipped with measurement devices. Additionally to the two on-board echo sounders, two hydrographical echo sounders (one near bow and one near stern), a precise navigation system and a DAQ system for merging, storing, processing and transmitting the collected data have been installed.

Results and validation of the measurements performed

FGS Symphonie

Due to the observed vessel speeds of about 12 km/h when navigating upstream and of about 18 km/h when navigating downstream through the test stretch and a sampling rate of 1 Hz of the DAQ one measured value was taken every 3 to 5 meters.

Measured bed levels were verified by comparing them to an existing digital terrain model (dtm) for the investigated stretch. For this purpose, the location of the measured bottom heights had to be converted into the Gauss-Krüger-system and their height into NHN.

The comparison revealed a deviation of the measured values from the terrain model of about 0.1 m. When evaluating this deviation, it has to be taken into account that the terrain model is based on multibeam soundings (mbes) of the year 2012. In the meantime, spatially limited changes of the riverbed could have occurred that could explain the deviation. Therefore, the comparison of the bed levels does not represent the achievable accuracy, but rather rates them as plausible. The permanent availability of correction data is, however, a precondition for high-precision measurements of the river bed heights.

In Figure 36, the measured flow velocities are compared with numerical data of the flow velocities for the test stretch. Gaps in the data are generally caused by a poor GPS quality due to the loss of corrective services or a poor reception. The velocities through water are measured with the Aquadopp and transformed into real flow velocities by the DAQ-system. The lower graph in Figure 34 shows the two components of the flow velocity (North and East), whereas the upper graph depicts the magnitude of the flow velocity. The red dotted line in both graphs is the measured data while green is a moving average over 100 m of the measured data. The measured data is compared to the flow velocities calculated numerically with TELEMAC 2D, *Hervouet and Bates (2000), Wurms et al., (2010)*, which are represented by the blue line in the graphs below. While the Rhine discharge at the time of the measurement amounted to 2770 m^3/s on average, the comparative data resulting from TELEMAC calculations corresponds to a discharge of 2750 m^3/s. The flow velocities were measured 25 m in front of the vessel's bow.

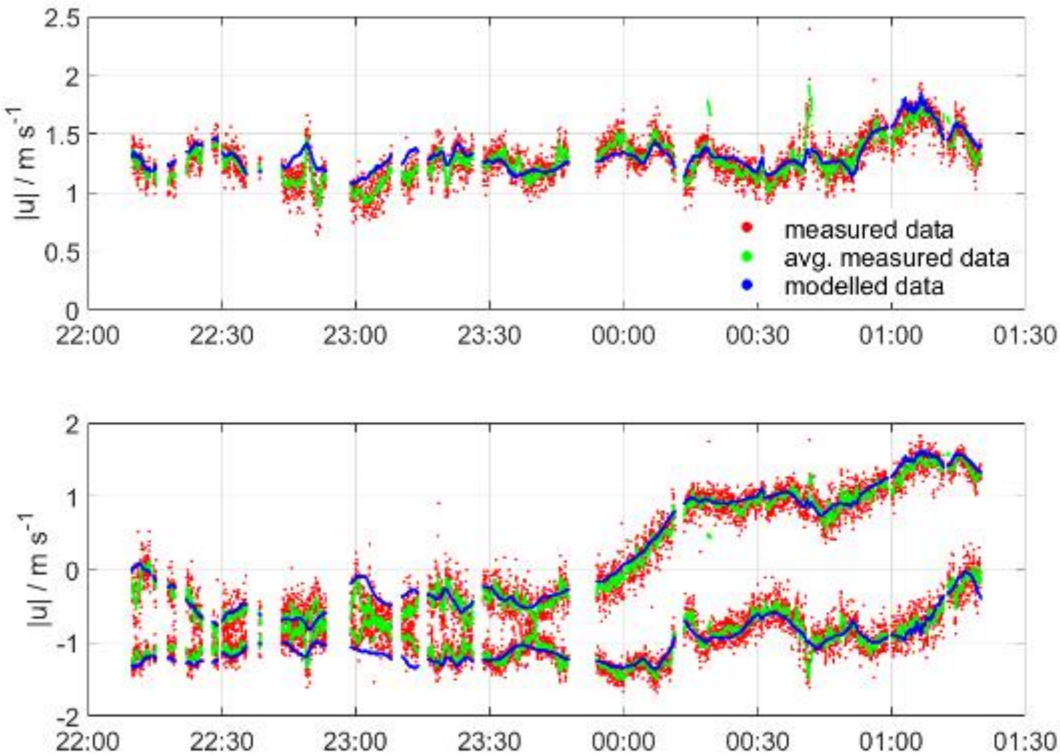


Figure 36: Comparison of measured (red), modelled (blue) and averaged (green) velocities. Top: magnitude of velocity; Bottom: both components (North and East) of the current velocity
Data set from 2 July to 3 July 2016 while navigating upstream.

As shown in Figure 36, the measured values closely match the values calculated with the hydro-numerical model. This indicates that the flow velocities measured on-board the passenger vessel Symphonie, which are calculated and transmitted by the DAQ, can be regarded as plausible. It is recommended to smooth the data over longer segments.

GMS Monika Deymann

The calculation of the bottom heights on GMS Monika Deymann is done in the same way as on FGS Symphonie. Due to the location of the four echo sounders and the GPS antennas there is a greater longitudinal and lateral distance (lever arms) between these sensors. This leads to an induced heave due to pitch and roll and, therefore, to a greater uncertainty of the measurements. An inclinometer was installed to compensate the induced heave and to further improve the data accuracy.

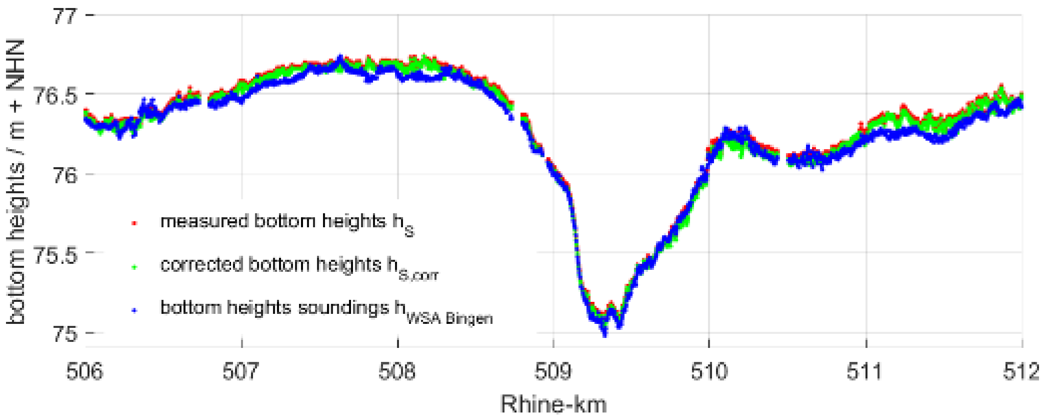
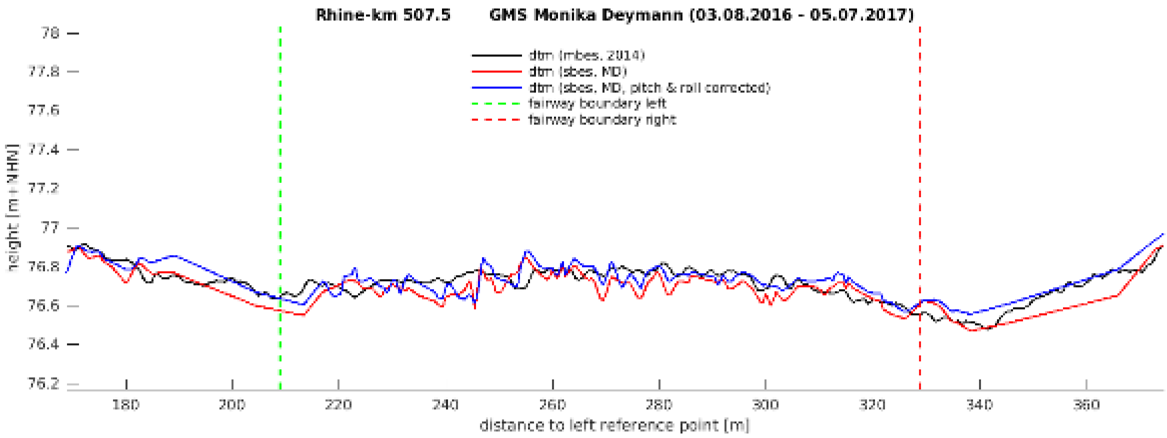


Figure 37: Comparison between the measured river bottom height (red), bottom heights compensated with inclinometer data (green) and the multibeam sounding from WSA Bingen done in 2016 (blue).

The four echo sounders used on-board the GMS Monika Deymann provide information on the river bed topography for the entire vessel path and, especially, for the outer sides of bends. Hence, the coverage is much better than on FGS Symphonie where the outer bends are not covered. Figure 37 shows a comparison between the measured river bottom height (red), bottom heights compensated with inclinometer data (green) and the multibeam sounding from WSA Bingen done in 2016 (blue). The measurements are in good agreement considering, amongst other things, the fact that the measurements on-board the vessel took place in 2016 and the terrain is based on echo soundings of the year 2016. A maximum averaged deviation of 4 cm is observed.

Figure 38 shows a comparison of the dtm from single-beam soundings of the Monika Deymann (sbes) and a dtm based on professional soundings with multi beam echo sounders (mbes) from 2014 for the cross-sections of the river Rhine at km 507.5 and 539.2. It is in very good agreement with the dtm based on mbes as the overall averaged difference between the two models for the whole test stretch is only 6 cm. The pitch/roll-compensation improved the dtm based on sbes further reducing the overall averaged difference to 2 cm. With the measurement concept, developed within the framework of the project PROMINENT, the automated collection of highly accurate data of river bed topography is possible.



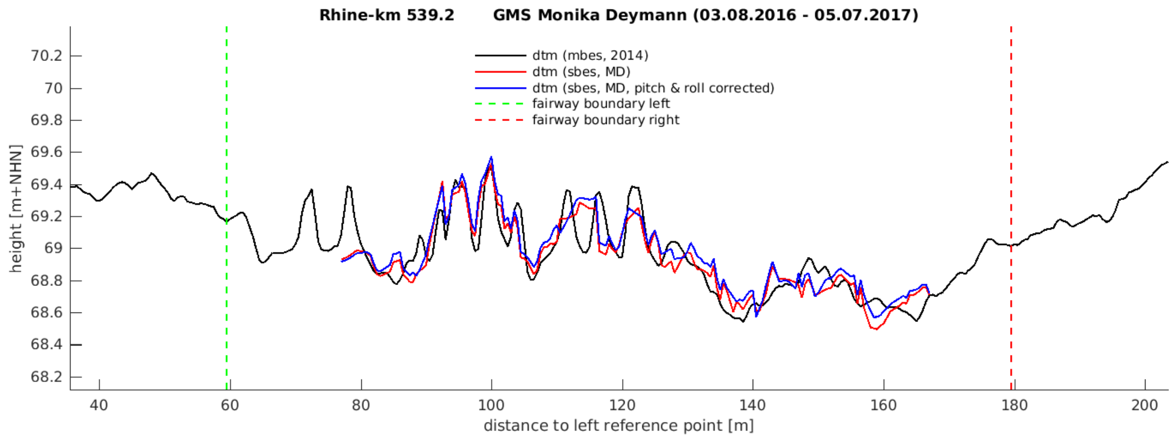


Figure 38: Comparison of a digital terrain model based on professional soundings (mbes) and the sbes results of the GMS Monika Deymann after eleven months of operation. Measurements at cross sections of the river Rhine at km 507.5 (gravel bed) and km 539.2 (bedrock). The dashed lines represent the fairway boundaries.

In a next step, the total coverage and the coverage ratio in the fairway were derived from the echo-sounding data depending on the number of trips of the GMS Monika Deymann. The total coverage in a cross section describes the width of the measured area within a cross section. The coverage ratio in the fairway is defined as the ratio between the area within the fairway covered by measurements to the overall fairway width in a cross section. A value of 100 % means that the entire fairway is covered by ship-based measurements. It is possible that a coverage greater than the fairway width is achieved while the coverage ratio is less than 100 % because sometimes vessels sail outside of the fairway especially at higher water levels. Both values are increasing with each trip of the vessel. Figure 39 shows the coverage ratio after 80 trips for a maximum lateral distance of two adjacent echo-sounder measurements of 5 m between Rhine-km 500 and 810. For most of the investigated area the ratio is in the range of 50 to 90 % tending to increase further downstream. Due to the greater fairway width the vessel has more space to navigate downstream than in the rather narrow cross sections of the mountain stretch further upstream.

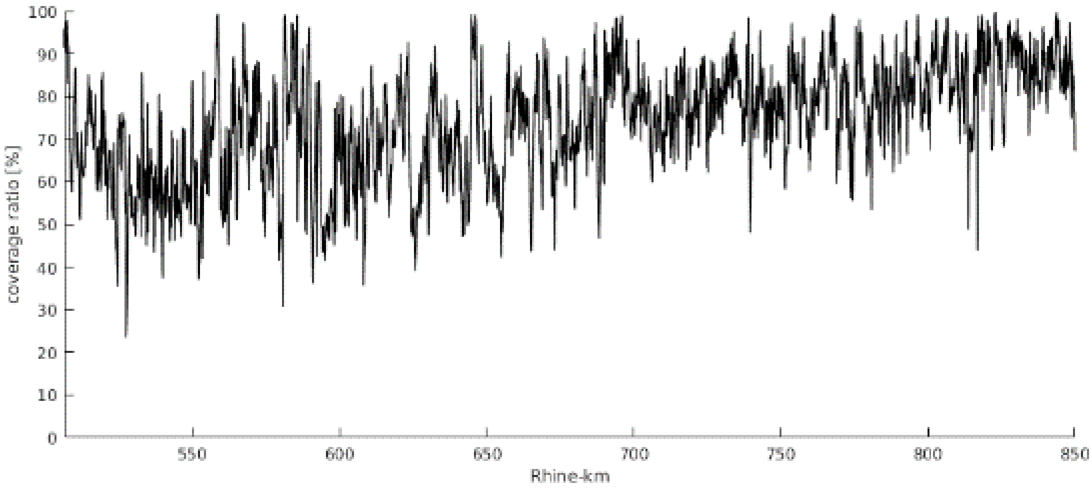


Figure 39: Coverage ratio [%] of river Rhine fairway (from km 500 to 810) after eleven months of operation of GMS Monika Deymann.

Like the flow velocities of the FGS Symphonie, the flow velocities obtained by the 1D ADCP installed in the bow thruster channel of the GMS Monika Deymann were compared to equivalent results from the numerical model TELEMAC 2D. Flow velocities are, generally, underestimated (Figure 40: grey shaded area) when the vessel navigates a bend or sails at an angle to the main flow direction. The 1D measurement values cover only the longitudinal flow component in relation to the ship's axis. Therefore, in a next step, the flow velocities will only be calculated and transmitted if the vessel is moving straight ahead, which assures the measured flow component to be the main flow velocity. This can be achieved, for example, by comparing the course of the vessel (COG, derived from GPS signal) to the ship's heading (HDT, derived from GPS compass).

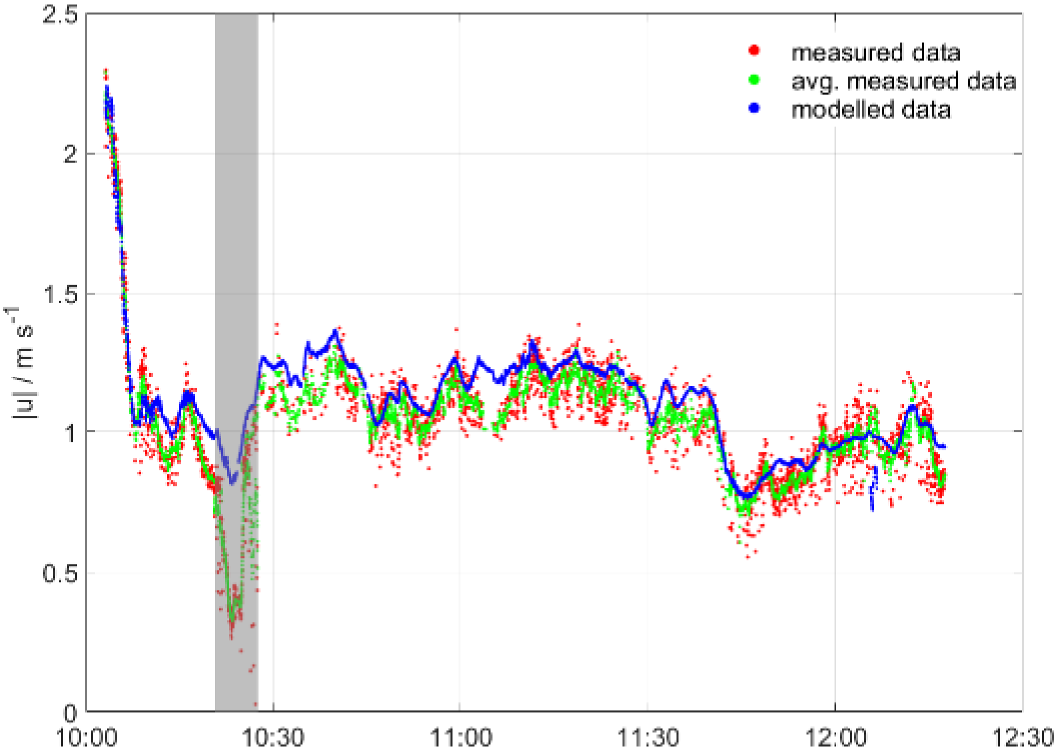


Figure 40: Comparison between measured longitudinal velocity (red), averaged (green) and modelled velocity data (blue). Measurements obtained via the GMS Monika Deymann while sailing upstream on 8 August 2016.

The following Figures 41 and 42 show the comparison of post-processed measured flow velocity data (red) to the flow velocity from the 2D-HN-model (blue) for the equivalent low water level (GLW) and the mean water level (MW).

The results at MW in November 2016 are shown in Figure 41. All measurement cells deliver reliable results for the magnitude of current velocity. Exemplary, the results measured at a distance of 17.5 m in front of the bow of GMS Monika Deymann are shown. The 1D results are in good agreement with the 2D-HN-model. The maximum deviation from converting the flow velocities from the 2D-HN-model in the ship's path into a 1D component is estimated to be 0.1 m/s within the test stretch. Another error occurs from the fact that the flow velocities are underestimated especially in bends when using a 1D-measuring device.

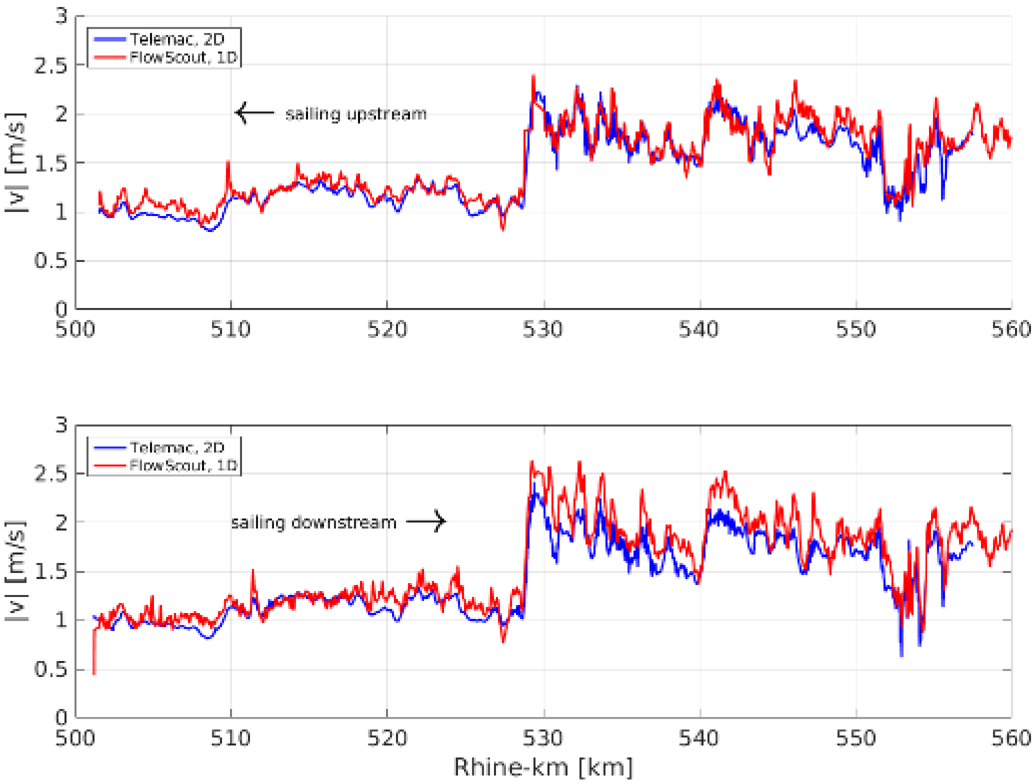


Figure 41: Comparison of 1D flow velocities measured 17.5 m in front of the bow (red) and 2D modelled flow velocities (blue) at MW (Level Kaub: 224 cm). Top panel: GMS Monika Deymann sailing upstream at November 21st 2016 (Level Kaub: 224 cm); Bottom panel: GMS Monika Deymann sailing downstream at November 22nd 2016 (Level Kaub: 232 cm).

Figure 42 shows the flow velocities at GlW in October 2016. The draught of GMS Monika Deymann was around 1.60 m due to the small water depths. Therefore, small under keel clearances occurred together with a small immersion depth of the 1D-ADCP. Under these conditions, most measurement cells do not deliver reliable results for the magnitude of the current velocities if the vessel is sailing upstream, see Figure 42. The analysis of the measurement data suggested that the quality of the velocity data is mainly determined by the ratio between water depth and the immersion depth of the 1D-ADCP. If the vessel's draught and, consequently, the immersion depth of the 1D-ADCP, which is situated 0.9 m above the keel, was small and the return current velocity is increasing, which happens in case of small water depth when sailing upstream, measuring the flow velocity was not possible in some parts of the test stretch. For the chosen mounting position of the 1D-ADCP an immersion depth of more than 1 m and an under keel clearance of the vessel of more than 1.5 m have proved to be ideal. This corresponds to a draught of about 2 m and a mean water level within the test stretch. Other potential sources for the poor quality of the measured data are the fluctuating and non-steady bow wave system as well as the higher flow velocities around the bow introducing air. Air bubbles can cause incorrect measurements or a poor data quality at the flowmeter and also the echo sounders at the bow.

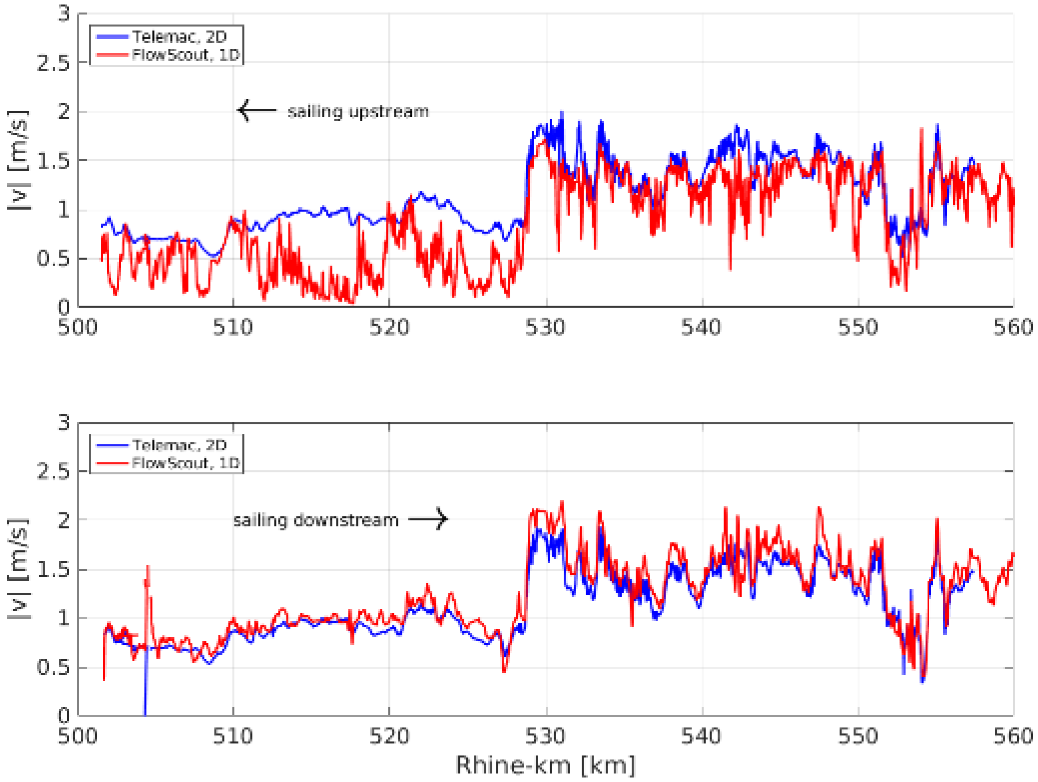


Figure 42: Comparison of 1D current velocities measured 17.5 m in front of the bow (red) and 2D modelled flow velocities (blue) at GlW (Level Kaub: 78 cm).Top panel: GMS Monika Deymann sailing upstream at October 10th 2016 (Level Kaub: 82 cm); Bottom panel: GMS Monika Deymann sailing downstream at October 11th 2016 (Level Kaub: 82 cm).

The mounting position of the 1D-ADCP at the bow of the vessel has a huge influence on the device's security and its maintenance effort. Within the first 10 months of operation of the 2D-ADCP on FGS Symphonie, the device was damaged by flotsam once. Until now, there was no damage of the flowmeter on GMS Monika Deymann. Due to the chosen location in the bow thruster channel, it is possible to access the sensor without a diver in case the vessel is empty.

Discussion of results

The feasible update rate of the DAQ system is much smaller than it is required of hydrographic surveying. Therefore, the boatmasters can use the measured and transmitted bottom heights as additional information for navigation or route planning. Due to their spatial resolution the measurements cannot replace professional echo soundings with a multibeam-system. In areas where professional echo soundings are not available or the time between echo soundings is too long, vessel-based measurements can significantly improve the data basis. The same applies to areas with high morphological activity.

On-board FGS Symphonie the echo sounder is located at the bow. While navigating a bend, it is, however, the vessel's stern that passes the outer side of the bend. Therefore, there is no recording of the river's bottom heights in this area when the echo sounder is installed at the bow. Thus, it is recommended to install at least two echo sounders at bow and stern.

Results of the H-ADCP measurements revealed reliable values for the flow velocity within the vessel's path. However, at low water levels, also unreliable results were derived, demanding further actions in order to improve the quality of the information provided. The measurements should be performed at least one ship breadth in front of the bow. Generally, it seems not necessary to record data with a high spatial resolution. 2D H-ADCP measurements would only improve the data density and accuracy in bends.

The described procedure for measuring and transmitting the data is promising. Further technical issues to be considered relate to automatic plausibility checks and processing of the collected data, as well as provision of it in a suitable manner to the boatmaster or shipping company, allowing the proper use of it, as well as raising the awareness and knowledge of the relevant benefits. In particular, when a greater number of vessels will be involved in the measurement programme, the automated handling of big data volumes becomes important.

ii. Danube vessels

The tasks assigned to NAVROM in PROMINENT relate to the purchase and installation of equipment to convey information to the project partners (in particular TNO) on hydrologic parameters (water depth and speed of the water flow), as well as mechanic parameters (rotational speed, engine load and fuel consumption of propulsion engines).

For this purpose, a technical solution was developed to meet the project requirements set. It was sent to various manufacturers in order to find competent partners being able to manufacture and assemble the system components. The winner of the tender procedure became RO SHIPPING SRL, a representative of ALPHATRON from Rotterdam – The Netherlands.

After starting the design and execution procedure, several problems were faced relating to the procedure of hydrologic parameters measurement and their transmission from different measurement points on the vessel and around the convoy. However, these problems were solved.

Description of systems implemented

Ten vessels of the NAVROM fleet were involved in the pilots to be realised in WP5. The vessels selected belong to the pusher types described in the following.

- **MERCUR 200 series (205, 206)**

L=34.66 m, B=10.09 m, T=1.70 m, H=8.70 m, ∇=389 m^3
2 main engines of type CAT 3512 B, P_B=955 kW (each engine)

Figure 43: Pusher, MERCUR 200 series, MERCUR 205.

- **MERCUR 200 series (207)**

$L=34.60$ m, $B=11.04$ m, $T=2.00$ m, $H=8.70$ m, $\nabla=507$ m^3
2 main engines of type CAT 3512 B, $P_B=955$ kW (each engine)

Figure 44: Pusher, MERCUR 200 series, MERCUR 207.

- **MERCUR 300 series (301, 303, 304,305, 306)**

$L=34.60$ m, $B=11.04$ m, $T=2.04$ m, $H=8.70$ m, $\nabla=508$ m^3
2 main engines of type CAT 3512 B-HD, $P_B=1249$ kW (each engine)

Figure 45: Pusher, MERCUR 300 series, MERCUR 303.

- **River pusher (ANINA, ROVINARI 8)**

$L=20.72$ m, $B=7.78$ m, $T=1.50$ m, $\nabla=152$ m^3
2 main engines of type VOLVO PENTA D 12D-C, $P_B=300$ kW (each engine)

Figure 46: River pusher, ANINA.

Contrary to the initial proposal for mounting the measuring equipment, a slightly different solution was chosen in order to minimise unfavourable effects caused by the flow disturbances of the lighters on the measurements. The solution chosen comprises a robust device, simply and easily to be installed on the sides of the lighters of the respective convoy. The speed and depth sensors are dipped into the water in the fore part of the convoy or in any other convenient part, supported by a specially constructed bracket (Figures 47 and 48). The technical specifications of the sensors used are given in Appendix B. The transmitter unit is a terminal box located close to the sensors. The receiver unit and GPRS transmitting unit are installed in the wheelhouse. The data transmission between them is realised by a wi-fi connection.

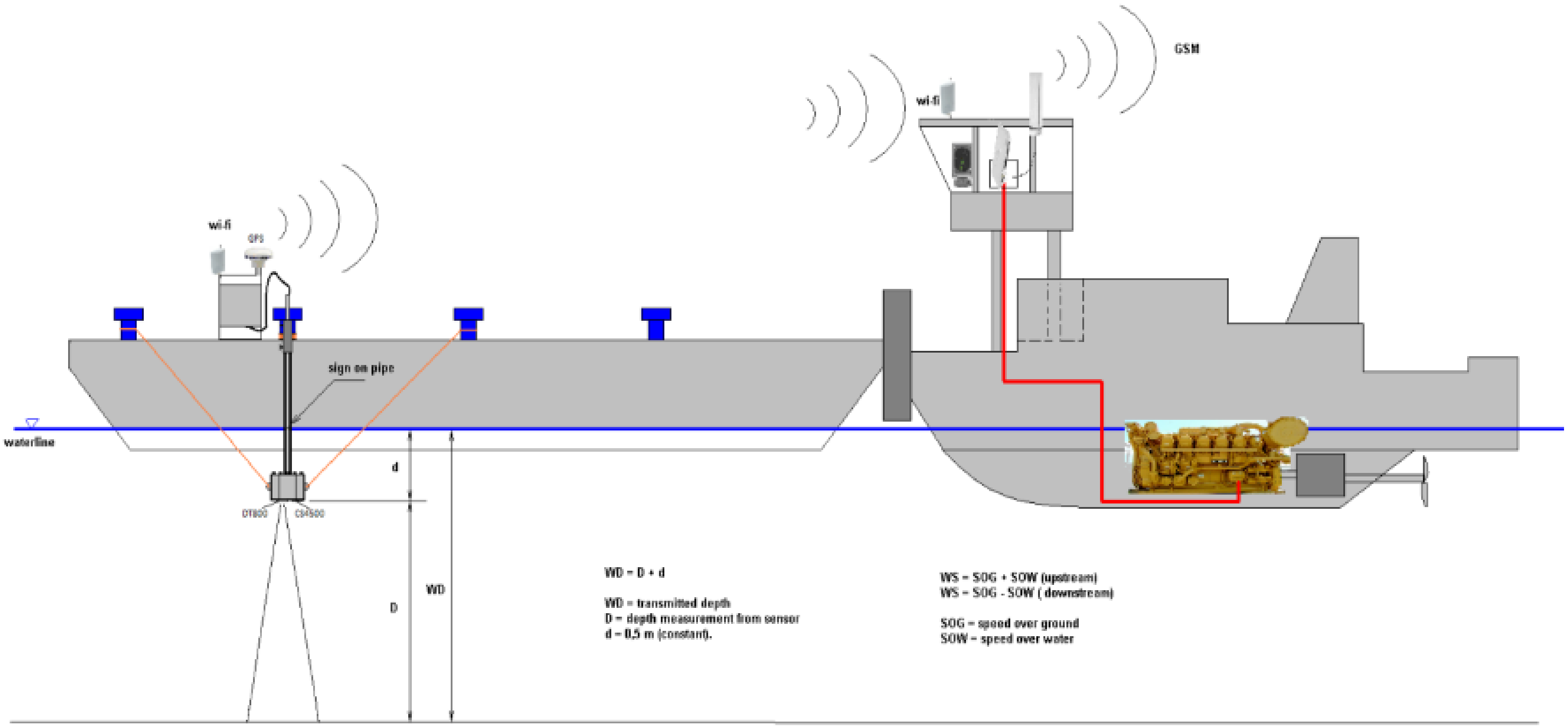


Figure 47: Arrangement of the measuring device (sensors), the transmitter unit, the receiver unit and the GPRS transmitting unit.

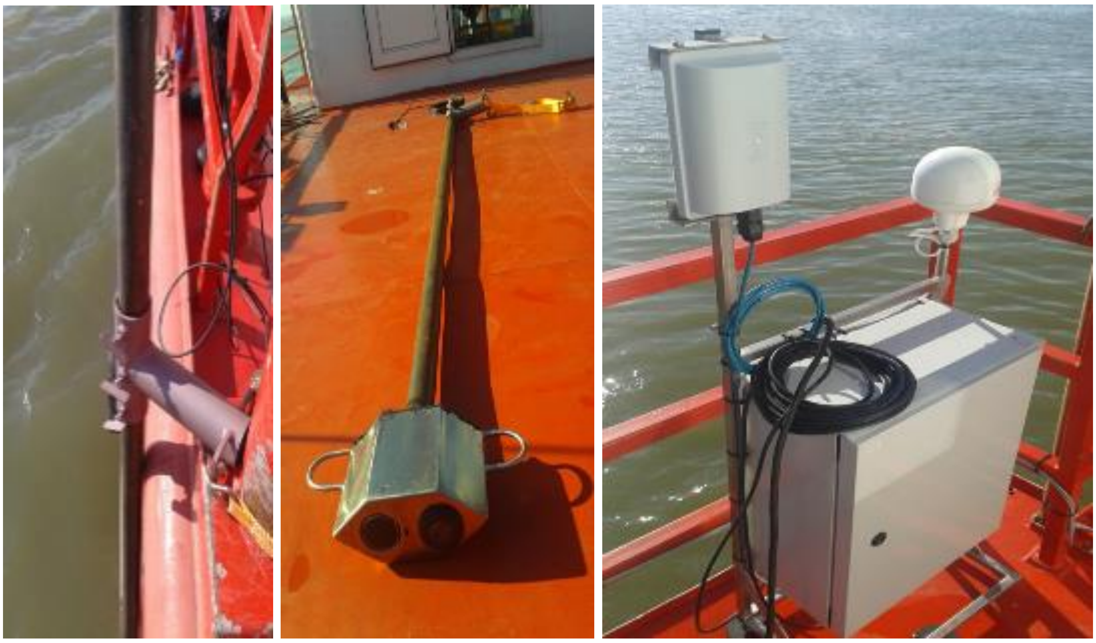


Figure 48: Sensor bracket mounted on the side of a lighter (left). Bracket with sensors for depth and velocity measurements (middle). Terminal box for hydrographic sensors, wi-fi and DGPS antennas installed close to each other (right).

The communication to the server is realised by a GSM. All measured parameters are displayed through the server in normal view for every NAVROM vessel participating in the project. For all partners of PROMINENT involved, access to the data was granted based on ID and password. The database language is English. The support platform is a Tresco platform, http://www.tresco.eu/index.php/gb/tresco-fleet.

Figure 49: Tresco server with display.

With respect to the acquisition, implementation and operation of the system, the following costs had to be covered by NAVROM:

Table 8: Acquisition, installation and operating costs of water depth and flow velocity measurement devices given for one vessel of the Romanian Shipping company NAVROM.

Sensors:	28 863	EUR per vessel
Software:	440	EUR per vessel
Maintenance:	100	EUR per vessel and month
Handling of mobile equipment:	200	EUR per vessel and month
Transmission of data:	120	EUR per vessel per month

In addition, within the task relating to the monitoring of exhaust gas emissions and operational profiles, the software was upgraded in order to include an additional monitoring parameter: the exhaust gas temperature, relevant for the evaluation of the applicability of an SCR after-treatment system. The respective costs amounted to approximately 10 000 EUR. The latter costs are not related to energy-efficient navigation.

Floating and submerged objects constitute the most significant operational barrier to using the speed and depth measurement equipment. E.g. logs, drift wood, ice, etc. can have a noticeable negative impact on the sensors, considering a ship speed of approximately 18 km/h or higher. The sensors may become out of order and have to be repaired. The associated costs may amount to 2 500 EUR per repair activity. Therefore, e.g. in winter time with floating ice, the speed and depth measurement equipment has to be put out of the water, and measurement can be realised only for limited time periods and circumstances (e.g. when no harmful objects are present in the waterway).

Results

For all of the ten NAVROM vessels, useful results could be obtained. They are presented on Tresco Fleet (Figure 49), as well as stored for further processing on a server. The measured values are given every minute. They comprise information relating to the location and engine parameters of the vessel, as well as hydrologic framework conditions. In the example presented below (2.11.2016, 15:32), the speed over ground (SOG) = 5.7 km/h, the flow velocity = 0.5 m/s, and the water depth (not corrected for sinkage and trim) = 6 m. The measured values can be compared with survey results for validation purposes. For the test stretch close to the reference gauge Corabia at Danube rkm 630, possibilities for provision and usage of waterway information (water depth) derived from the on-board measurements of the NAVROM vessels and referred to the gauge readings were created, presented below more in detail.

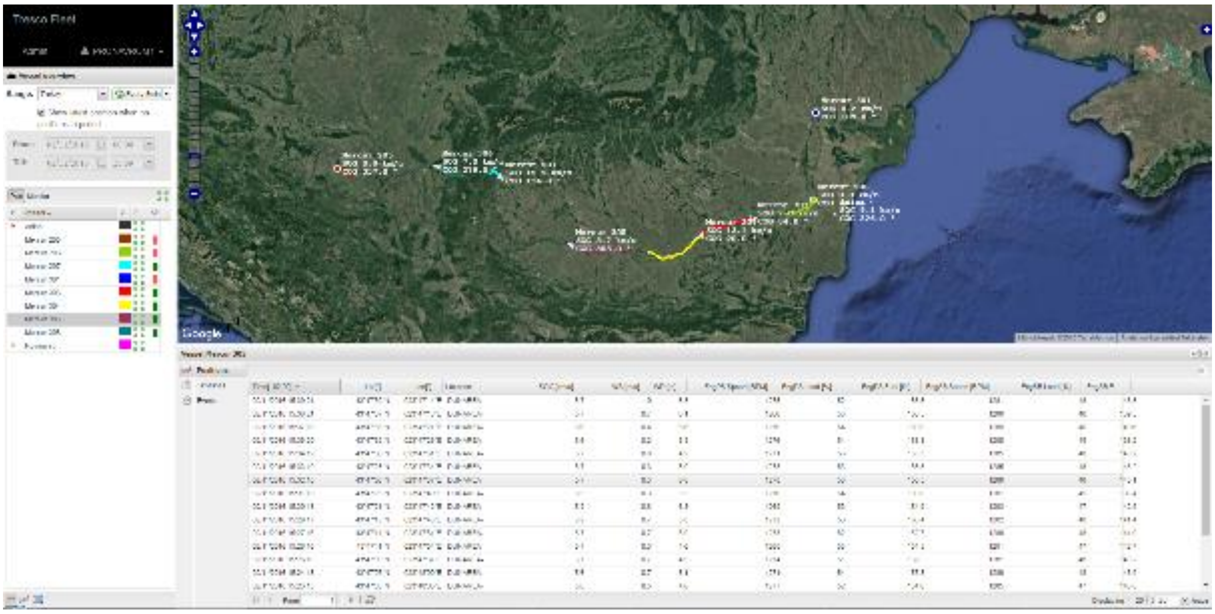


Figure 50: Screen shot of Tresco Fleet used by NAVROM with measured values of the pusher MERCUR 305 sailing on the Lower Danube obtained on November 2nd, 2016.

The results delivered and stored in the webserver can be downloaded online or offline as .xls form. In addition, the project partners (e.g. TNO) can make use of the opportunity to download them as .csv files.

Webinterface for water-depth monitoring at Corabia

The goal of the monitoring tool is to provide a day-to-day estimation of the navigation conditions at the Danube bottleneck at Corabia. Currently, only depth information is provided, giving an idea of the topography of the fairway. The webinterface presented below utilises the correlation between the changes of the water depth in the fairway and the ones of the water level recorded by the gauge. The profile reveals shallowest parts of the river and gives more detailed information about the exact locations of the critical points. For every 100 meters of the test section, the current water depth is presented.

The tool works as follows (Figure 51): The actual water depth profile is found by visiting the website www.iwtnavigator.eu. This website hosts the “Danube water levels tool”. With each visit, a request is made to the TNO server to check for updates on the depth estimation. This server, then, combines the current water level obtained from the gauge with the pre-calculated profile of the riverbed to determine the present water depth at Corabia. The updated results for the water depth are sent back to the iwtnavigator.eu and shown on the website as displayed in Figure 52.

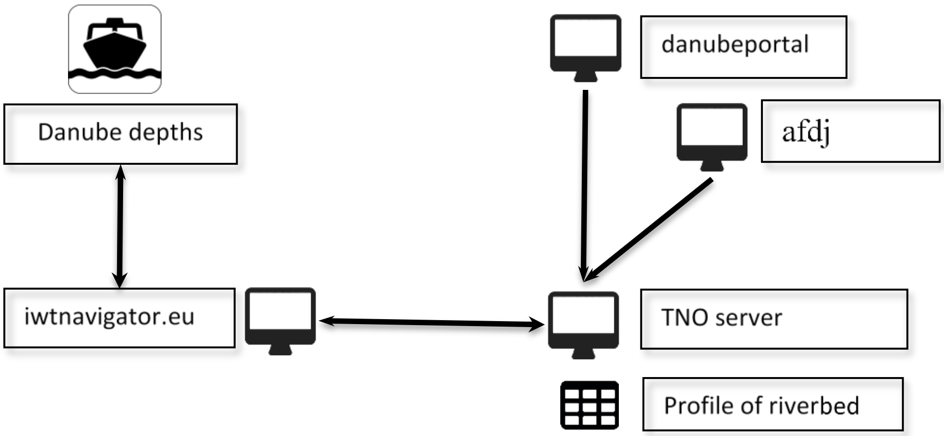


Figure 51: Graphical representation of the dependencies in the “Danube water levels tool”.

The map displays the city of Corabia and the part of the Danube situated near this city. The border between Romania and Bulgaria is indicated as well. The red line represents the average route that the vessels use to pass this section, which corresponds to the fairway. Since the depth profile is defined in a high (100m) resolution, numerical depth values can be obtained by tapping/clicking on the map or graph, which will activate a popup screen. The lowest graph is used to keep overview of the whole section when the user zooms in, which is especially useful when accessing the website with mobile devices. It allows for scrolling and zooming out.

The date of the last profile update is shown on the top left. This is important since the values on the website might not be accurate when the gauge value is not up-to-date. Furthermore, at the top of the website the shallowest depths are displayed to warn about the most critical points of the Corabia section. These values are defined such that only 5 % of the observations would lie below these values, and they can be considered to be the lowest values to be expected, though shallower water may be encountered with a 5 % likelihood.

The red bar will only be replaced with a link to sources with more information about the shallow water conditions when water levels are low during a period[10].

[10] For example http://www.danubeportal.com

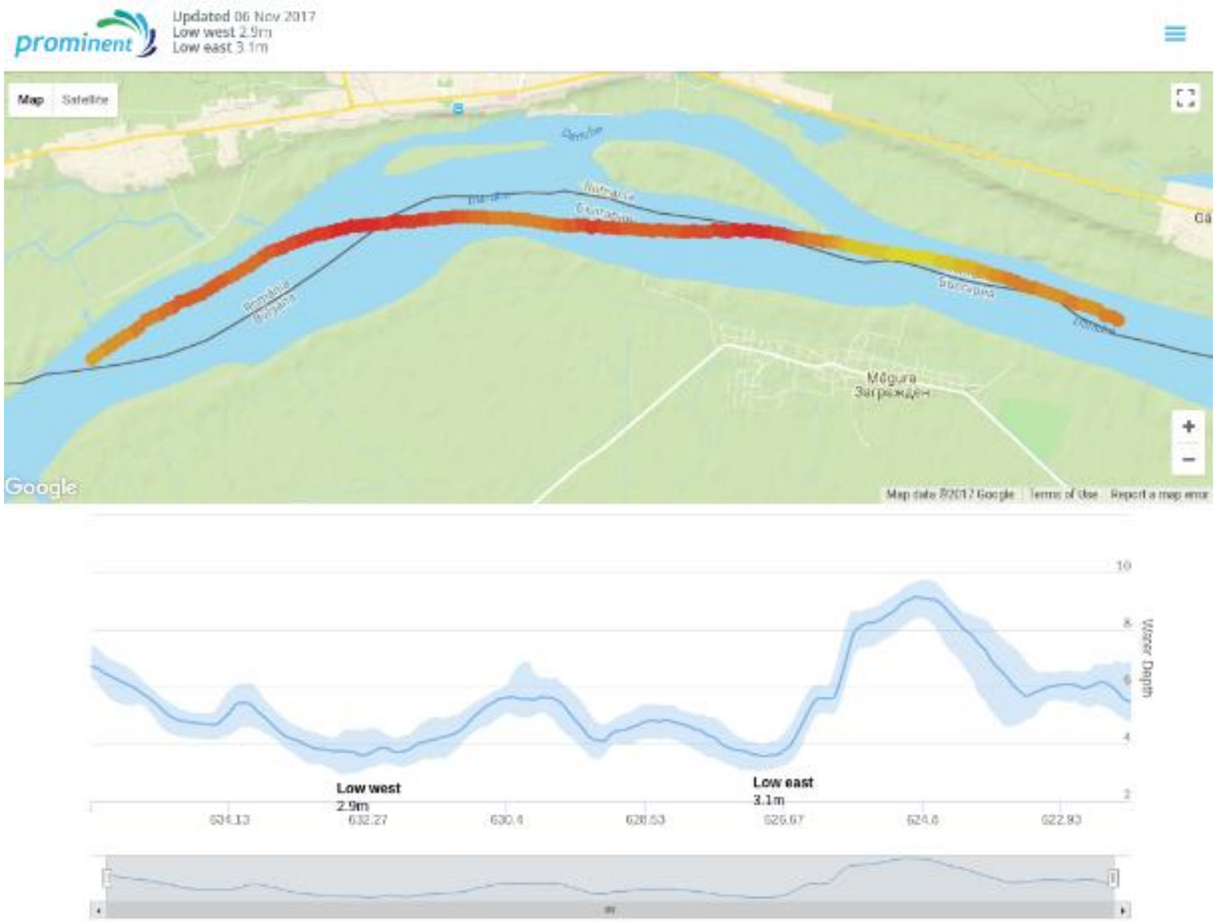


Figure 52: Screenshot of the “Danube water levels tool”. The upper figure shows the average route, the vessels were sailing. In the lower figure, the horizontal axis displays the river kilometres, and the vertical axis displays the latest water depths derived from the on-board measurements performed. The average water depth is presented by the solid line in the graph. The shaded area represents the bandwidths of the water depths in the fairway at the considered river kilometres.

Plausibility check of the results obtained by the on-board measurements

The results of the on-board measurements (06.11.2017) were compared with surveying results (single beam) derived by the Romanian waterway authority AFDJ (06.07.2017 and 31.08.2017). The comparison was performed for minimum, maximum and average values of the water depth, *Schweighofer et al. (2017).*

The minimum values of the water depth derived by the on-board measurements deviate from the surveying results by 0.2 m up to 0.8 m.

The maximum values of the water depth derived by the on-board measurements deviate from the surveying results by 0.0 m up to 1.0 m.

The average values of the water depth derived by the on-board measurements deviate from the surveying results by 0.1 m up to 0.6 m.

In general, the on-board measurements give plausible results. The agreement with the surveying results is good at several points, although at some points maximum deviations of up to 1 m occur.

The deviations may be explained by the following circumstances:

- The on-board measurements were not corrected for sinkage and trim, leading most likely to smaller values of the water depth estimated;
- The on-board measurements cover laterally a greater part of the fairway, while the surveying results are given only for three points in the cross section of the fairway (left, centre, right), resulting in different local minima and maxima;
- The on-board measurements cover a time period of more than one year, resulting in consideration of morphological changes over the time period considered, while the surveying results are given for a single moment, describing an instantaneous topography of the river bed.

In order to be able to perform a proper validation of the on-board results obtained, a comparison of the on-board results with surveying results is recommended to be carried out, covering identical measurement points and minimal time differences between the measurement campaigns. Currently, it may be concluded that the on-board measurements give plausible results, and the accuracy seems to be sufficient for provision of a good qualitative description of the longitudinal river-bed profile, showing where potential critical spots are located to be undertaken a closer examination by the responsible waterway authority.

Usage by the ship-owner NAVROM

According to NAVROM, the equipment installed on the vessels involved in the PROMINENT project provides a great number of useful data which is successfully used. More in detail:

- The information transmitted by the water-depth and the water-speed sensors is transmitted to the vessel's wheelhouse where the boatmaster can see the data in real time. It is important that the measured depth is the one at the bow of the convoy;
- The Ships' Monitoring Department of NAVROM, using the Tresco webserver, makes also use of the data. Especially the one related to the depth of the water in difficult navigation areas of the Danube is of great interest. This information can also be accessed by members of the vessel by logging in to the webserver. Each vessel participating in the measurement campaign becomes a provider of information to the database (webserver);
- Very important information provided by the equipment are the real-time geographic location of the vessel's position (LOG, LAT), the vessel's speed over ground (SOG) and the navigation history;
- In addition, the data transmitted from the propulsion engines of the vessels are used to assess fuel consumption and the percentage of use of engine power in difficult areas of navigation. The boatmaster can be alerted whenever a speed overrun on the propeller shaft is observed, knowing that fuel consumption increases exponentially over a certain rotational speed (over 1400 rpm);
- Taking into account the navigation parameters on the Danube in the lower sectors, it is important to know the direction and the value of the water currents, especially, when the vessels are operated in a convoy comprising many lighters. The respective information is taken from the water-speed sensor.

5. Pilot on liquefied natural gas (LNG)

a. Introduction

In order to verify the methane reduction achieved by the installation of upgraded dual fuel engine control software, SGS Nederland BV, Environmental Service and Wartsila Netherlands BV carried out emission measurement at W6L20DF engine on board of the RPG Stuttgart.

i. Location

All measurements were performed sailing at the Haringvliet in the south of the Netherlands with sufficient (>6 meters to avoid interaction effects) water depth. The measurements were performed before and after the software upgrade on 9 April and 17 April 2018. The gaseous emissions O_2, CO, CO_2, NO_X and THC (total hydrocarbons) were measured, together with engine operational parameters. The results were calculated by the carbon balance method.

Figure 53: Location of measurement.

Figure 54: Depth map of the measurement location, note depth numbers are above 10, indicating sufficiently deep water for consistent measurements.

ii. Engines, baseline and comparisons

Before the original Factory Acceptance Test of the exact engine for the RPG Stuttgart (engine A) an emission measurement was performed at Wärtsilä Vaasa test facility, on 26-06-2016. This measurement was done with exactly the same software package and performance settings as used on board before the modifications.

Also before the modifications, an emission measurement was performed at Wärtsilä Vaasa test facility with another engine from the same series and equal to the RPG Stuttgart engine (engine B).

The new software package with performance settings developed on engine B in Vaasa was used for both a second round of measurements in Vaasa as those on board of RPG Stuttgart on 17-4-2018 using engine A.

Both measurements were used for comparison and validation of the on-board results.
The emission characteristic has a good repeatability due to the controlled combustion; charge air pressure, temperatures and many other parameters governing the combustion are electronically controlled by the engine management system. Engine A and engine B showed good correlation.

During the modification days an air leakage was found on the engine A air receiver aboard RPG Stuttgart. This resulted in a loss of combustion air and disturbed NOx/THC emissions (increased NOx, decreased THC) and increased sensitivity for knocking behaviour during engine loading. The air leakage was fixed.

Due to the air leakage the measurement of 9 April is not usable for a correct comparison of emissions. Wärtsilä has decided to use the base line measurement of 26 June 2016 instead for comparison to the on-board measurement after modification of 17 April 2018 in order to make a correct comparison. For clarity: both sets of measurement were done using engine A.

iii. The test vessel: RPG Stuttgart

Figure 55: RPG Stuttgart, the test vessel.

The RPG Stuttgart sails under Swiss flag. The innovative 110 by 11.45-meter barge is part of a series of vessels designed for improved safety and environmental performance and optimum payload. The vessel is owned by Intership AG in Zug, Switzerland and crewed by Rederij Plouvier in Antwerp, Belgium. Together with its sister company Intertrans in Birsfelden (Switzerland), Plouvier Transport operates barges that are equipped to transport mineral oils and its components over the European inland waterways. The RPG Stuttgart has been time chartered to Shell Trading Rotterdam. The RPG Stuttgart is running on Liquefied Natural Gas (LNG). She is used to transport refined oil products in the ARA (Amsterdam-Rotterdam-Antwerp) and Rhinetrack (Germany/Switzerland) regions. The main characteristics are shown in Table 9.

Table 9: RPG Stuttgart main characteristics.

RPG Stuttgart	
ENI number	2337160
Year of construction	2017
Yard	Centromost Stocznia Rzeczna, Plock, Poland & Veka, Werkendam, Netherlands
Operator	Intertrans
Owner	Intership AG in Zug
Flag	Switzerland
Tank volume	3040 m3
Tonnage	2653 ton
Length	11000 cm
Width	1145 cm
Draft	320 cm
Propulsion	Wärtsilä 6L20DF, 990kW

b) Description of used methods and equipment

i. Determination of the concentrations of O_2, CO_2, CO , NO_X and CxHy

The following measurement principles and equipment were used:

oxygen	O_2	paramagnetic (NEN-EN 14789)
carbon dioxide	CO_2	infrared absorption (NEN-ISO 12039)
carbon monoxide	CO	infrared absorption (NEN-EN 15058)
nitrogen oxides	NO_X	chemiluminescence (NEN-EN 14792)
hydrocarbons	CxHy	heated flame ionisation detection (NEN-EN 12619)
temperature	° C	Chromel alumel Thermocouple type K

See also Figure 56.

The sample point for the Horiba PG-350 exhaust analyser and corresponding pump were placed ca. 5 metres upstream of the end of the exhaust piping. From there on, the sampled flue gases were transferred via a temperature-controlled Teflon pipe (160 °C) to a flue gas cooler where the water vapor was removed. Thereafter the dried and filtered flue gases were led to the measuring instruments.

The concentrations of O_2, CO_2, CO and NO in the filtrated and dried flue gas sample flow are analysed using monitors. Note that in converter (C) the NO_2 in the sample flow is converted to NO.

The concentrations of CxHy in the filtrated and dried flue gas sample flow were analysed using the FID monitor. The exhaust gas of the engine was continuously sampled from the exhaust pipe.
The sample flow was transported through a heated Teflon tube to a Ratfisch flame ionisation detector.

Prior to the measurements, a leak test of the complete system was carried out. The exhaust analyser was calibrated with zero and certified span gas before and after the test run. The flue gas temperature was determined using a thermocouple type K and recording device.

ii. Emission measurement setup

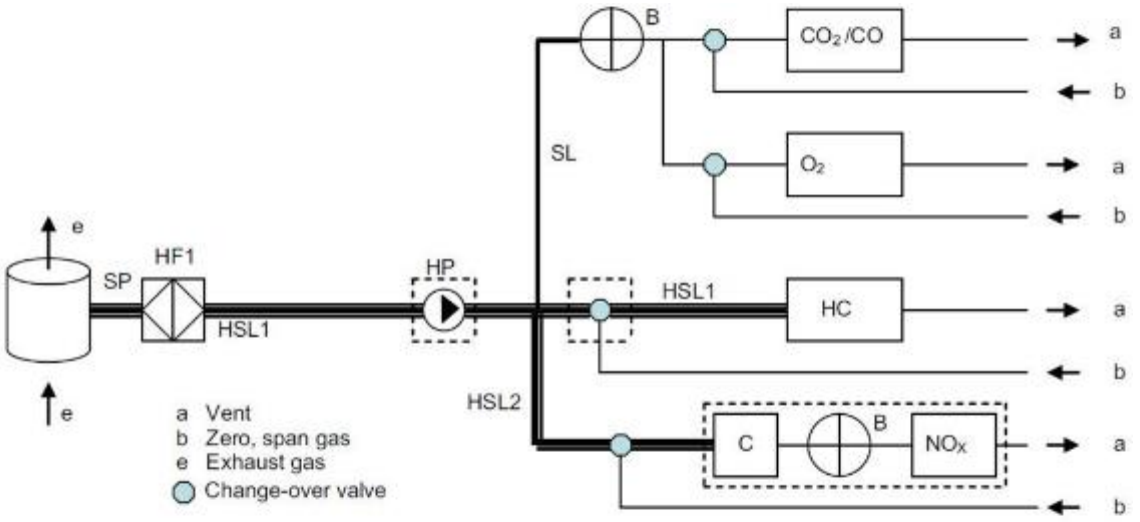


Figure 56: Schematic measurement setup.

iii. Impression of the measurement setup aboard RPG Stuttgart

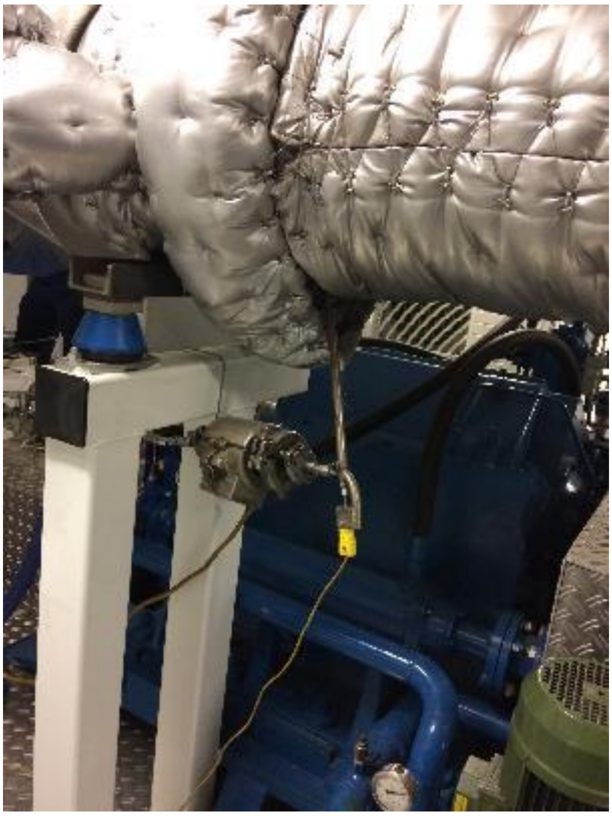


Figure 57: Prop with heated filter and thermocouple.

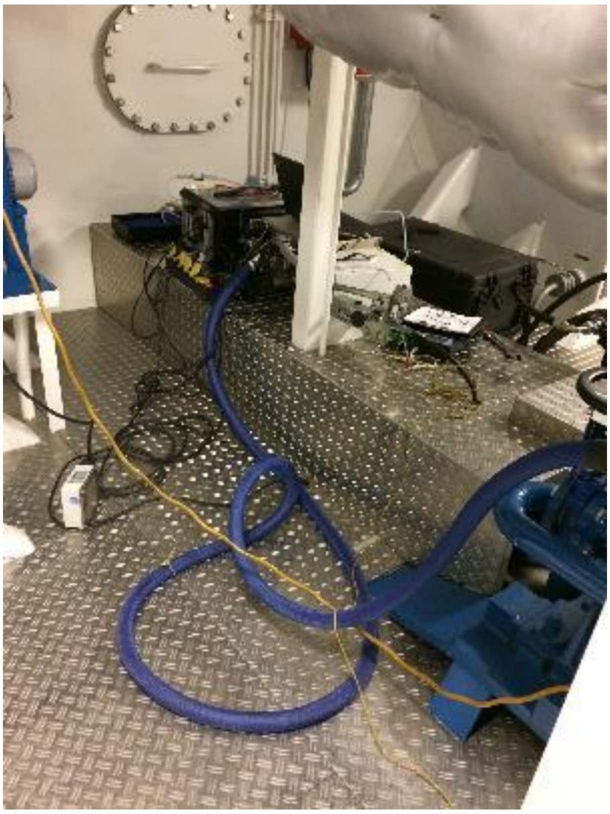


Figure 58: Temperature-controlled Teflon pipe.

Figure 59: Pump with cooler, Ratfisch and Horriba monitor.

iv. Fuel consumption measurements

The gas fuel consumption was measured by an on-board available Coriolis-type mass flowmeter. The gas flowmeter was installed in the gas supply line inside the enclosure of the Gas Valve Unit. The gas fuel consumption was logged and averaged over the measurements period per load point. The composition of the used LNG can be found in *Bleuanus and Portman (2018)* and the annex.

The pilot fuel consumption was not measurable on-board due to the pilot system pressure demands and on-board system layout. The pilot fuel consumption was very small in relation to the gas consumption. The used pilot amount was not significantly changed by the new software, so the Gas Energy Ratio as defined in the Stage-V regulation was not affected by this upgrade. In the emission calculation the pilot consumption as determined during the original FAT of Engine A was used. The fuel used was of standard EN590 fuel composition.

Figure 60: Gas flow meter reading.

v. Engine load

The engine load was derived from engine speed and torque measurement. The engine speed was measured by a pickup mounted on the flywheel. This installation was equipped with a fixed torque flange between flywheel and gearbox. This torque flange was also used during these measurements to determine the engine torque. Both the engine speed and torque were logged by the engine control system and averaged over measurement periods.

vi. Engine details

Specifications of the engine used (engine A) were as follows:

Table 10: Engine specifications.

Engine type	Wärtsilä 6L20DF
Engine SN#	PAAE301449
Nominal speed	Variable 450 -1200rpm
Engine load	Variable FPP (max 1110 kW)
Cylinders	6
Fuel	Main: LNG – Pilot: EN590
Lubricating oil	Shell MYSELLA S5
Bore	200mm
Stroke	280mm
Receiver temp.	Variable
Rotation direction	Clockwise
Automation	UNIC C3
Turbocharger	KBB ST4 with air filter at driving end

vii. Measurement programme and periods

Measurement programme

The test cycle type E3 propeller-law heavy-duty engine for ship propulsion was used. The engine speed was set and the engine load was a result of vessel and ship’s condition. The ship’s conditions were kept as equal as possible.

Measurement periods and speed-load curves

Table 11: Measurement periods and speed-load curves 09/04/18.

Test	Load	100%	75%	50%	25%
Date		09/04/18	09/04/18	09/04/18	09/04/18
Start	(hh:mm)	14:01	14:28	15:08	15:52
End	(hh:mm)	14:11	14:38	15:18	16:02
Speed		100%	91%	80%	63%
Power		100%	75%	50%	25%

Note: During the modification days an air leakage was found on the engine A air receiver aboard RPG Stuttgart. In further post processing, the corresponding measurements of the original FAT for engine A were used as baseline, but we include here also the power/speed relation found on 8-4-2018 to show the vessel condition was very similar in the measurements on 8-4 and 17-4

Table 12: Measurement periods and speed-load curves 17/04/18.

Test	Load	100%	75%	50%	25%
Date		17/04/18	17/04/18	17/04/18	17/04/18
Start	(hh:mm)	08:41	09:36	10:23	11:33
End	(hh:mm)	08:51	09:46	10:33	11:43
Speed		100%	91%	80%	63%
Power		100%	75%	50%	25%

c) Results

This chapter contains an overview of the main measurement results. The calculated emissions are based on the carbon balance method, calculated with gas and pilot consumption and engine load.

It is important to note that besides the measured improvements in THC emission, also as a side effect of the engine upgrade, the engine loading response was improved which leads to more stable gas operation. In practice, this means that the vessel will trip less often to diesel operation. As emissions are much lower when the vessel is running on gas, this means that the actual real-world emissions are lower also because of this.

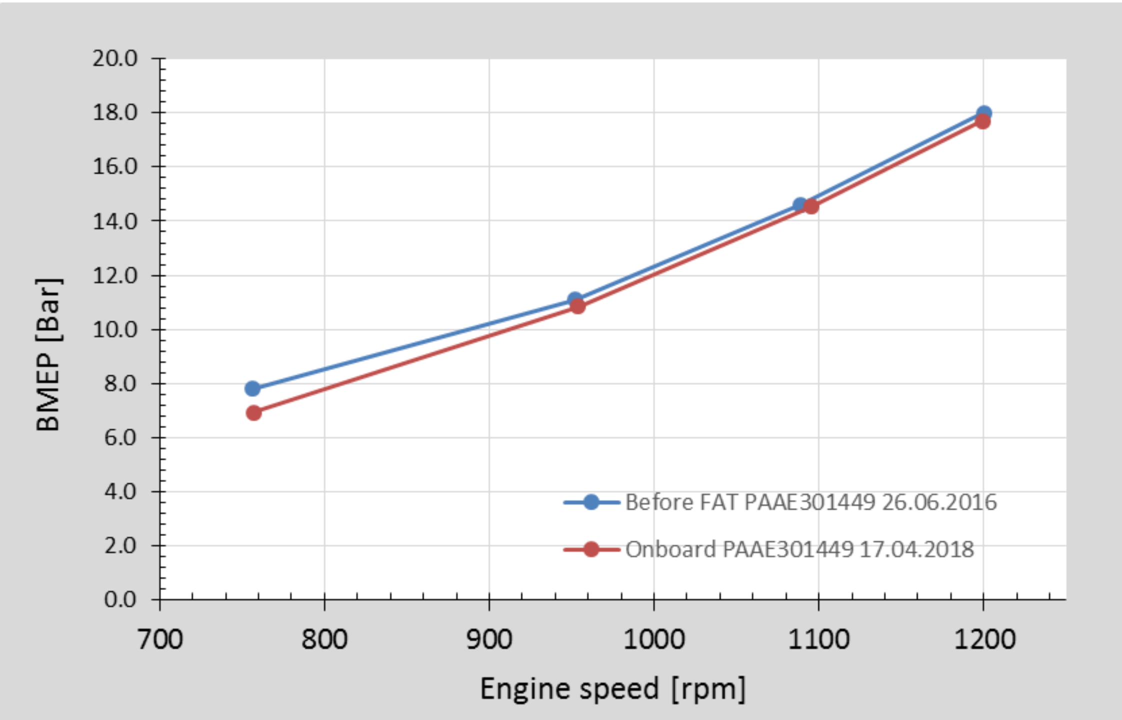


Figure 61: Load curves of the baseline (pre FAT) and post-modification measurements.

Both load-speed curves are very comparable. As all results were expressed as a function of load as they were expressed in g/kWh, the small difference between both curves was automatically corrected for.

Conclusion: **The baseline and post-modification measurements were valid for use in comparisons.**

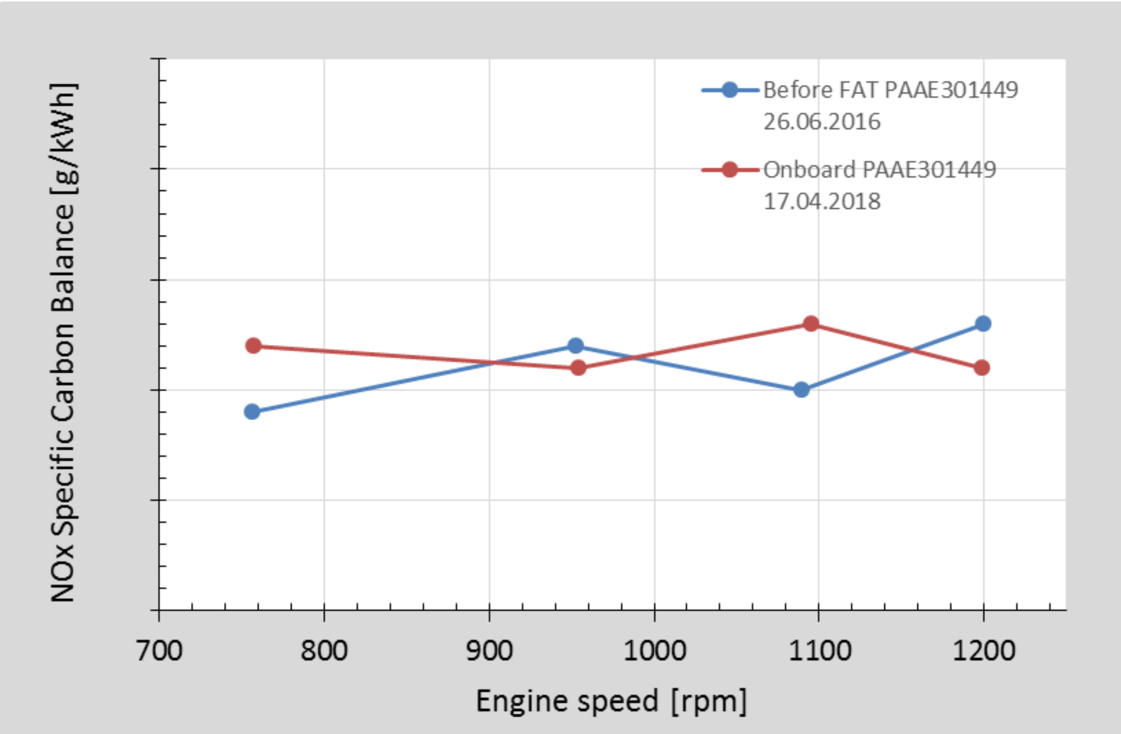


Figure 62: NOx emission in baseline and post-modification measurements.

The NO_X emissions are on equal level, showing only a slight increase of 0.1 g/kWh when weighted over the E3 cycle. This is a negligible increase which is well within the expected measurement accuracy.

Conclusion: **The upgrade has no adverse impact on NO_X emissions.**

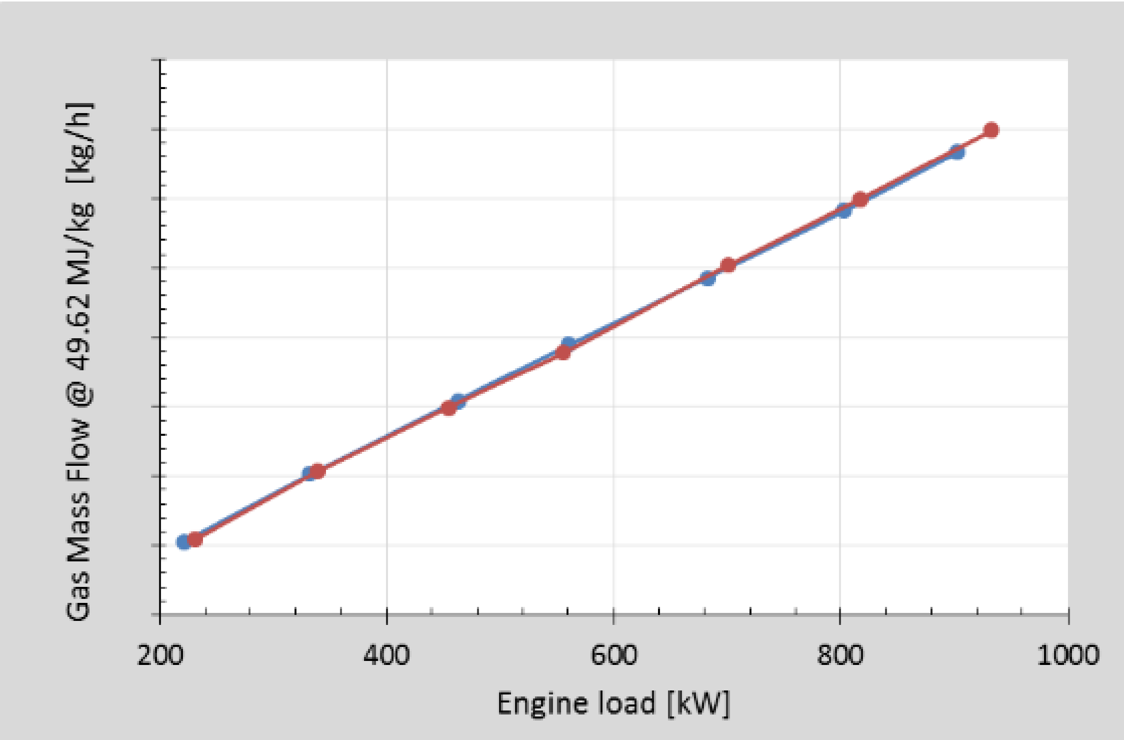


Figure 63: Gas consumption in baseline and post-modification measurements.

Gas mass flow is almost equal on all load points and any differences in mass flow are within measurement tolerances.

Conclusion: The upgrade has no adverse impact on fuel consumption.

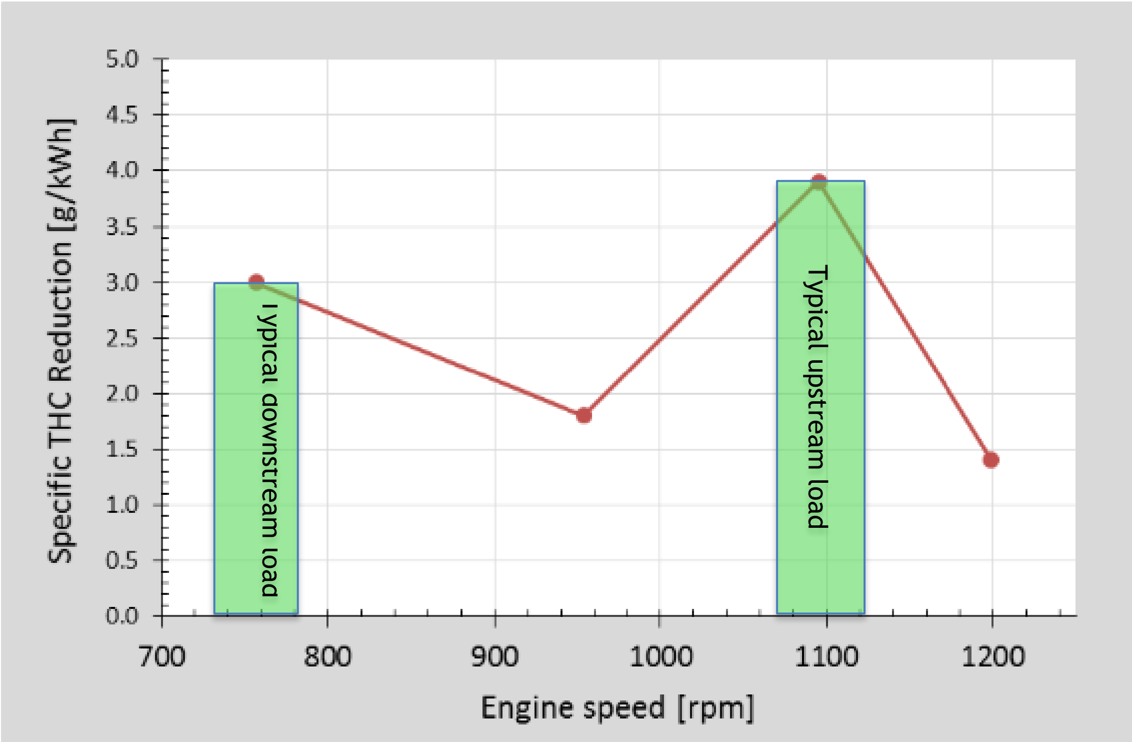


Figure 64: Difference in THC emission between baseline and post-modification measurements.

The THC emissions are reduced by 2.9 g/kWh when weighted over the E3 cycle. More interesting is that the vessels main operation points of operation are at 1100 rpm when sailing upstream and at 750 rpm during downstream operation. On these operation points, there THC reduction is even more significant, with a 3 g/kWh reduction achieved during downstream operation and a 3.9 g/kWh reduction during upstream operation. From an absolute emissions viewpoint, it is important to note that most energy is used during upstream sailing (both in time and load).

Conclusion: The upgrade has a big positive impact on THC emissions, with a 2.9 g/kWh reduction over the E3 cycle and a 3.9g/kWh reduction at the most important load point in the real operation of the vessel.

i. Indicative yearly greenhouse gas reduction

To show the significance of the achieved THC emission reduction, we have calculated the total expected greenhouse gas emission reduction in CO_2 equivalent tons. We used a simplified operational profile that consist of 54% (by time) upstream operation at 1100 rpm and 46% downstream operation at 750 rpm.

Utilizing the data in the following table, we arrive at the conclusion that this upgrade reduces greenhouse gas emissions by 151.6 + 32.8 = 184.4 tons per year per vessel. Using the 2016 fleet average for new cars sold in the Netherlands of 118g CO_2/km, this is equivalent to 1.5 million kilometres driven by a passenger car. The average mileage per year in the Netherlands according to the CBS is 13.200 km per year, so the upgrade of one vessel has the same effect as taking 132 cars off the road. At a conservatively estimated useful life of 20 years, this means a total reduction of 3688 tons.

Conclusion: The upgrade of one single vessel has an impact similar to taking 132 cars off the road.

Table 13: Indicative GHG reduction per year.

Operational points	rpm		1100	750
THC reduction	g/kWh		3.9	3
THC reduction	kg/h		2.7	0.7
Running hours gas	h	4080 total hours	0.54	0.46
Running hours gas	h/year		2203	1877
Annual THC reduction	ton		6.0	1.3
Annual CH4 reduction	ton	90% of THC is CH4	5.4	1.2
Annual CO2 equivalent reduction	ton	GWP of CH4 is 28	151.6	32.8
Annual CO2 equivalent car	km	118 g/km average for road cars	1284072	277456
Annual Total car km	km	1.561.528		

ii. Discussion of measurement uncertainty

When carrying out a measurement one always needs to be aware that there will be errors in the final results. This is not only true for the measurements, errors may also occur in calculations. See the annex for the discussion of errors on emission measurement by SGS.

6. Pilot on logistics education

a. Pilot simulations

E-learning is, nowadays, highly attractive in the educational sector. Applications range from augmented learning elements in presence courses to stand alone-lectures, from basic education to advanced training. The advantages compared to conventional education are manifold. First of all, education can become independent of the student's location. Further, the student can proceed at his own pace and repeat difficult parts. Not only the learning pace can be set individually, but also the total time spent on the whole module and the distribution of time among different topics. E-learning courses can be prepared thoroughly in advance and reviewed by different teachers, thus, the quality is not directly depending on the competence of a single teacher.

Extensive pictorial, as well as audio and video material makes both conventional lectures and e-learning courses appealing. However, especially interactive applications are only available in e-learning courses and contribute highly to the learning outcome.

The educational situation for inland navigation staff is quite difficult, conventional onshore learning classes are hard to organise, due to the usually long stays of students on the vessel. Therefore, online e-learning modules are a great possibility to improve the education. As mentioned above, e-learning modules are ideal for learning on the go and can, therefore, support the learning process during the student's absence.

Within the project three e-learning modules were developed, dealing with:

1. energy and cost-efficient navigation;
2. vessel stability;
   and
3. handling of dangerous goods.

They are produced in simple English and complemented with many graphics, pictures, animations and videos. Highlights of the modules are the interactive applications. Each course is further divided into subtopics with a small quiz/exam at the end. One module is meant not to last longer than approximately 45 min and can be interrupted at any time, but preferably after every subtopic. Therefore, the modules can easily be used to learn in short or unknown time windows and are not too time consuming.

The competence plans for the modules have been developed considering the curricula of STC and Schiffer-Berufskolleg RHEIN (SBK) with further input from IMST and EICB. Based on that, a didactical concept has been developed and according to that, the content and pictorial material was gathered from all partners, or it was newly created and adjusted. The commercial software Adobe Captivate 9.0 was used for the authoring of the final module conforming to the SCORM standard.

The modules have been reviewed and revised iteratively by the partners involved in the sub-work package SWP 4.1 and associated experts. Within the reviews, the content was adapted, extended or removed to create a better consistency. The graphical design and layout have been arranged to match the corporate design of the PROMINENT project and to achieve a well-structured appearance. Voice-over explanations were recorded and a linguistic revision was performed. To facilitate the use of the modules in day-to-day education, they were translated to German and Dutch.

The e-learning modules are available with open access on the INes-Danube (ILIAS) platform within the web/based community of practice established in SWP 4.3.

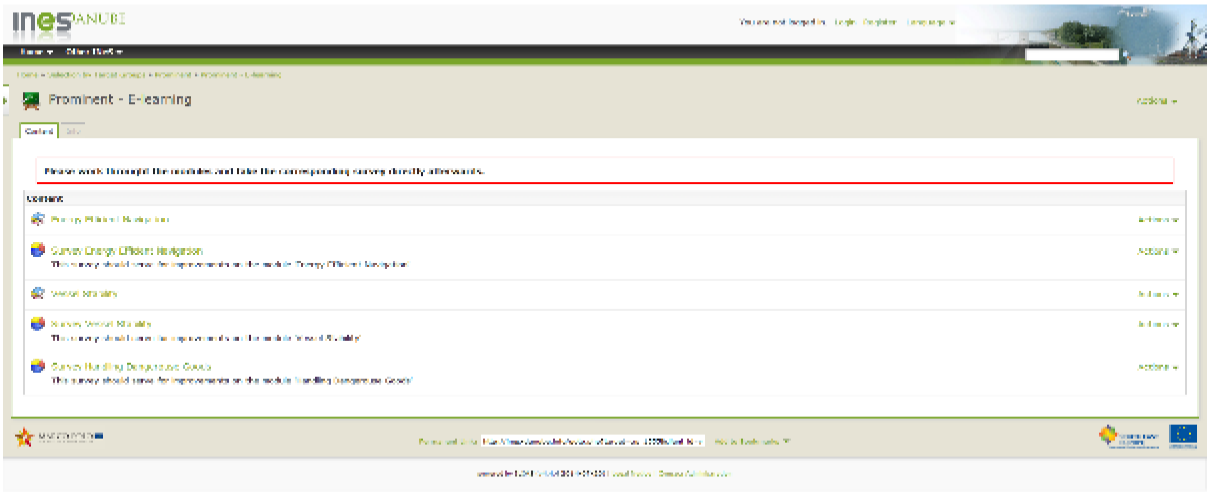


Figure 65: E-learning module and questionnaire integrated in the INes Danube LMS.

The testing and assessment of the e-learning prototypes under real conditions is very important.

The most important information collected using questionare can be categorised into five parts, which can be further specified by the following questions:

1) General
    a. How long does it take to work through the whole module?
    b. How long does it take to work through the different parts of one module?
    c. Does everything work properly?
    d. Is the language understandable?
    e. Is the voice over helpful?
    f. Are the closed captions helpful?
2) Content
    a. Is the content compatible with the content learned in a conventional class? Is it supplementing the content from class?
    b. Is the content understandable?
    c. Is the content too difficult or too easy?
    d. Is the exam compatible with the content?
3) Appeal/attractiveness
    a. Is the design appealing?
    b. Is the quality of images and videos ok?
    c. Are the slides clearly structured?
    d. Are the slides overcrowded or too empty?
4) Handling
    a. Is the handling of the module self-explaining?
    b. Is the navigation through the slides comfortable?
    c. Does the navigation work properly?
5) Additional value over conventional learning
    a. Does the module contribute to a better understanding of the content?
    b. Are the animations and interactive elements helpful?

Based on the outcome of the pilots at STC and SBK, the modules were revised once more and finalised.

In the following sections, an overview of the modules and highlights are given.

i. Energy and cost-efficient navigation

The aim of the “energy and cost-efficient navigation” module is to provide basic and advanced information on the influence of water depth, current and sailing speed on the resulting fuel consumption.

The module starts with an introductive part, where the need for energy and cost-efficient navigation is explained and the influencing factors are listed. Further, the Efficient Navigation Tool (ENAT) is introduced, which is linked to the work performed in SWP 5.4. In the second part some physical basics are explained. In the third part, the different influencing factors are introduced in more detail. They are divided into vessel specific and waterway specific factors. After each part, there are a few questions covering the previous content. These questions are only a learning control and do not count for the rating. In the end of the entire module, there is a final exam with ten questions, covering the whole content. This final exam will be rated, and at least six out of the ten questions must be correct to pass the test.

The whole module extends over about 52 slides and contains graphics, images and videos, as well as interactive elements. Besides the bullet points and small texts on the slide, the content is read out and explained in more detail (voice over). The voice over content can be displayed as closed captions.

In Figure 66, the influence of the water depth on the fuel consumption is explained with an interactive application. By clicking on the plus or minus sign, the water depth can be changed and the corresponding propulsion curve occurs in the diagram. The difference is immediately visible and curves can easily be compared. Figure 67 shows a slide with a video visualising the wave pattern of a vessel.

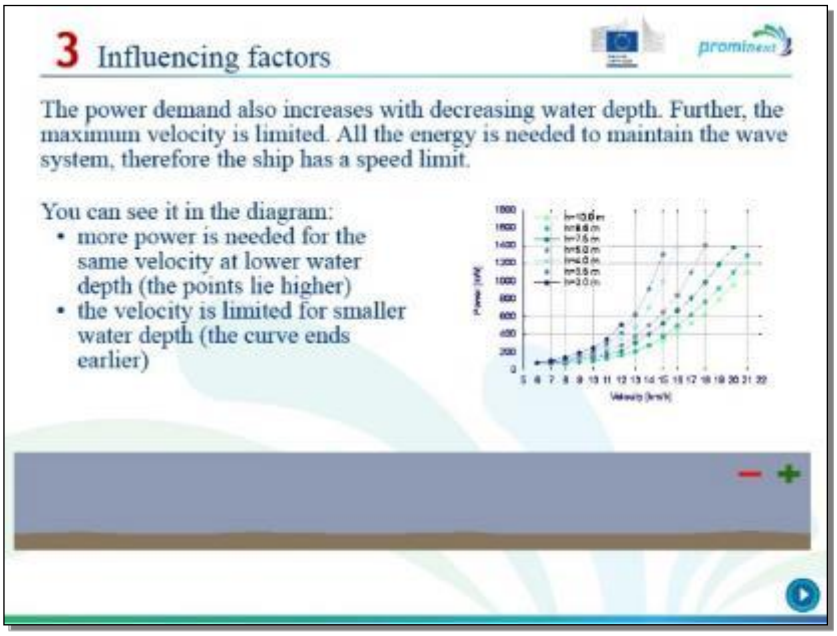


Figure 66: Interactive element for the explanation of the influence of the water depth on the fuel consumption.

Figure 67: Video to visualise and explain the wave pattern of a vessel in deep water.

ii. Vessel stability

The aim of the “vessel stability” module is to provide basic and advanced calculation schemes for the stability of inland vessels with focus on container and liquid bulk cargo vessels. It is to create awareness and sensitivity for vessel stability.

The module is divided into four parts. The first part deals with basic stability and covers some general terms and definitions. In the second part, the calculation of the centre of gravity is addressed and examples are given. The third part deals with the calculation of stability and gives calculation examples. In the last part, the influences of external factors on vessel stability are stated. After each part, there are a few questions about the previous content. These questions are only a learning control and do not count for the rating. In the end of the whole module, there is a final exam with ten questions, covering the whole content. This final exam will be rated, and at least six out of the ten questions must be correct to pass the test.

The whole module extends over about 104 slides and contains graphics, images and videos, as well as interactive elements. Besides the bullet points and small texts on the slide, the content is read out and explained in more detail (voice over). The voice over content can be displayed as closed captions.

Figure 68 shows an exemplary slide with an interactive application allowing to add the coloured cargo to the vessel and to simultaneously watch the change of the height of the centre of gravity. On the slide in Figure 69, the student is asked to calculate the height of the centre of gravity with the given values. After entering the calculated value, the student will receive a feedback, weather his answer was correct or not and he can continue with the course.

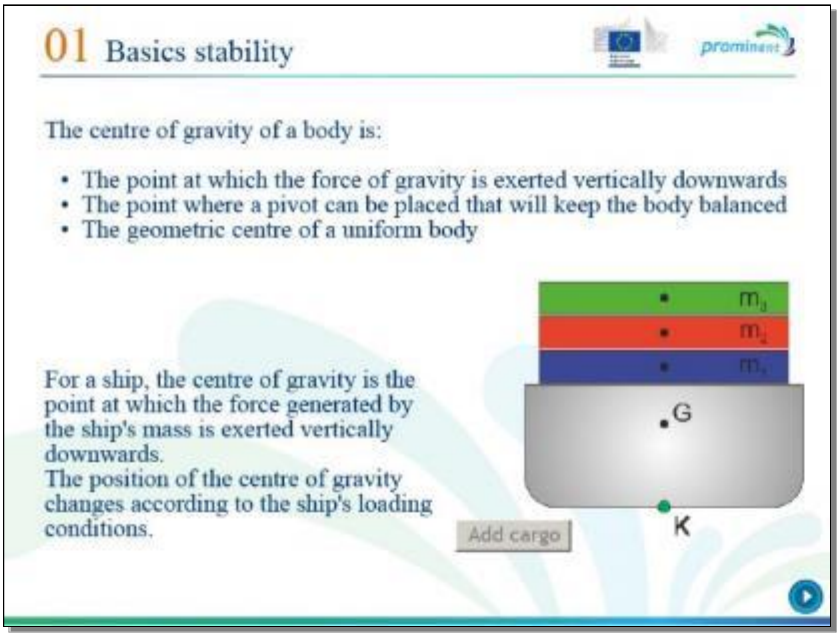


Figure 68: Interactive tool to show the changes in the centre of gravity due to additional cargo.

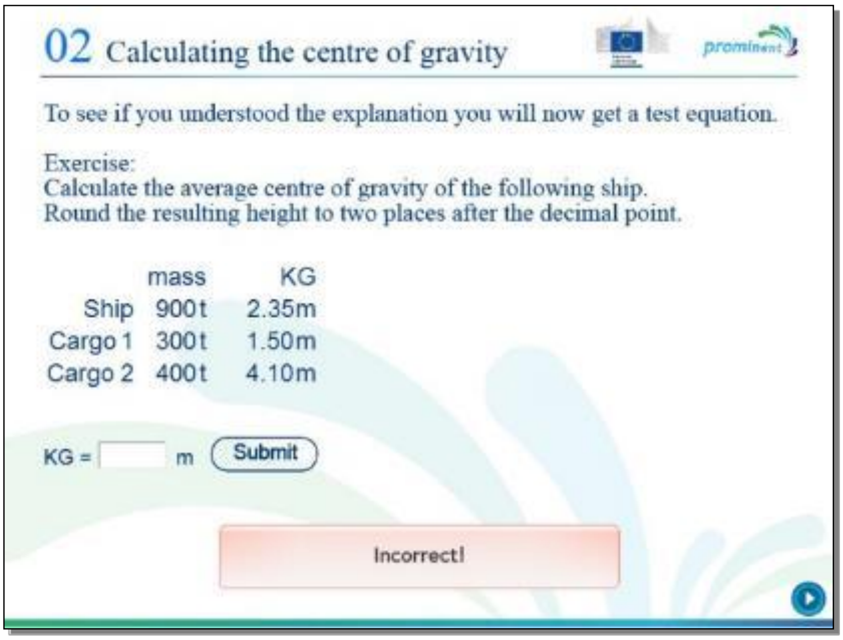


Figure 69: Calculation of the centre of gravity.

iii. Handling of dangerous goods

Handling of dangerous goods is a popular topic, especially in the context of alternative fuels, such as LNG or hydrogen. To avoid repetition and overlap with existing e-learning courses on this topic, a thorough enquiry was necessary. Based on that, the following content was chosen. The module is divided into three parts. The first part is an ADN module for a crew not having an ADN certificate, and a vessel which is not an ADN one. The members of the crew learn how to deal with ADN vessels during encounters in daily traffic. This addresses for example keeping the right distance and so on. The second part of the module addresses a crew sailing on board of an ADN vessel, but the members not having an ADN certificate themselves. The third part is an ADN module for the ADN-certified crew with a special focus on LNG as a cargo. The module concentrates on cargo handling, loading and discharging LNG.

b. Pilot e-SRB and e-Logbook

Within PROMINENT sub-work package 4.2 (SWP4.2), a prototype of a European E-Service Record Book and e-Logbook was developed. The results of SWP4.2 and the detailed characteristics of the prototype are described in deliverable *“D4.2 – European e-Service Record Book and e-Logbook”, Jongkind (2018)*. In close cooperation with the Joint Research Centre (JRC) of the European Commission, the project team selected four so called use-cases, based on the JRC report *“Electronic tool for Inland Waterways Transport D.3 Requirements - Final Report”, Andritsos (2016)*.

The four use cases are:

- voyage initialization & end (UC3);
- crew embarking & disembarking (UC4);
- control / inspection by the competent authorities (UC5);
- working time registration (UC9).

By means of these functions, the vessel unit is used for checking and recording the qualifications of the crew, the sailing time, the working time and the operation of the vessel. Using the Vessel unit leads to less administration, reduction of fraud (level playing field) and efficient inspection.

The development of the prototype is based on the relevant actors, current procedures and possible eIWT assisted procedures. The prototype is based on proven technology, which means that most of the required functions are already used in other industries and services. Besides, existing techniques and data-sources are used, such as GSM, GPRS, GPS and RIS (River Information Services).

i. e-SRB

For the e-Service book, a modern smartcard was used. Smartcards offer many advantages. A visible inspection is possible by printing cardholders photo, there is a possibility for internal storage, of data and the cards are durable and easy to produce.

Figure 70: E-SRB (Crew card).

Basically, there are two types of smartcards: equipped with contact or with contactless chips. Both have specific usages and advantages. Mostly, a trade-off between ease of use (RFID) and storage capacity (Contact). The e-SRB will be equipped with a Mifare desfire EV1 RFID chip with up to 8Kb of internal memory.

ii. Electronic Inland Vessel Unit (e-IVU)

The prototype is a linux-based mini PC, with the flexibility to add components as needed. The current prototype acts as an embedded device, which means all other applications are hidden or removed. It was designed with a 100 % availability and supplied with its own memory-card. The vessel unit has its own GPS locator and Sim-Card (GSM) for communication purposes. The unit fits in any wheelhouse of any vessel on inland waterways. Besides, it is a well-designed user-interface, including a touch screen.

Figure 71: Vessel Unit prototype.

The Raspberry PI computer was selected as it offers a well-established record for prototype projects. Also a great number of hardware add-ons and sensors are available for the Raspberry PI. The casing which holds the 7”touch monitor was custom designed for the project.

Figure 72: Screenshot prototype.

iii. Execution of the pilot

During the pilot on board different inland waterway vessels in the Rhine and Danube area, the prototype as described in the report “D4.2 European e-Service Record Book and e-Logbook” was tested. This report contains an overview of how the prototype covers all the requirements described in the Joint Research Centre report “Electronic tool for Inland Waterways Transport D.3 Requirements”. The main objective of this pilot was to show and test how the prototype works during daily practice on board inland waterway vessels. The focus was on the user-friendliness of the prototype, the comparison with the paper version of the SRB and Logbook and on the necessary improvements of the prototype developed. The evaluation is based on the four use-cases mentioned in chapter 1. Where relevant also other related experiences and suggestions mentioned during the pilot will be described.

The pilot period started in November 2017 till April 2018. Firstly, the prototype was installed on different Inland vessels in the Rhine region (Rotterdam area). Installing prototypes on board vessels in a relatively short distance from the developer gave the opportunity to troubleshoot and even improve the prototype in a very efficient way. This made the pilot on board the first couple of vessels an interactive and iterative process of testing, learning and improving based on experiences and sometimes unforeseen circumstances. Due to very helpful crew on board and ashore, already during the first couple of weeks improvements of the prototype were implemented. An overview of the improvements is given in the next section. After installing prototypes in the Rhine Region, the installation on board vessels in the Danube region was done. Testing the prototype on board vessels in two of the main European waterways gives the most relevant information of experiences of the stakeholders involved.

The prototype was installed on ten different vessels in the Rhine and Danube region. During the pilot a variety of vessels was used; Push-boats and Tanker vessels from large inland shipping companies as well as privately-owned companies. Also the prototype was installed on training vessels, which gave students the opportunity to get familiar with the innovations of their future job on board. Table 14 gives an overview of all vessels taking part in the pilot, and Figures 73 up to 77 illustrate the different types of vessels involved.

Table 14: Overview of vessels taking part in the pilot.

Name	ENI	Company	Sailing area	Flag	Vessel type	Last operating under
Prinses Christina	00020059	STC-Group	Rotterdam	Netherlands	Hotel ship/ training vessel	A1
Prinses Beatrix	02005698	STC-Group	Rotterdam	Netherlands	Hotel ship/ training vessel	A1
Mercur 101	08601698	Navrom	Germany-Austria-Slovakia	Romania	Push-boat, long distance	B
Mercur 104	33001366	Navrom	Germany-Austria-Slovakia	Romania	Push-boat, long distance	A2
Tender 16	02334978	De Tenders Rotterdam BV	Rotterdam	Netherlands	Passenger vessel	A1/A2
Hanna	02327503	Bugro BV	Netherlands-Belgium	Netherlands	Motortanker	A2
Erasmus	04811600	Interstream Barging	Netherlands-Belgium	Germany	Motortanker	B
Faraday	02321090	Interstream Barging	Netherlands-Belgium	Netherlands	Motortanker	B
Bizon	02317080	ThyssenKrupp Veerhaven BV	Port of Rotterdam	Netherlands	Push-boat, port operations	A1
Veerhaven X	02329273	ThyssenKrupp Veerhaven BV	Netherlands-Germany	Netherlands	Push-boat, long distance	B

Figure 73: Faraday.

Figure 74: Hanna.

Figure 75: Veerhaven X.

Figure 76: Mercur 104.

Figure 77: Prinses Beatrix and Prinses Christina.

iv. User experiences and recommendations

During the pilot on board the Inland Vessels the crew on board and ashore, inspection, water police, developers, project team members and members of the Advisory board tested the system and shared their experiences during project meetings and by means of a questionnaire. In this chapter, general, as well as use-case specific user experiences will be described.

General user experiences

The prototype works intuitive and has suitable measures to be used in the wheelhouse. Furthermore the experience regarding connections and availability of GPS and GSM network are positive. In the Rhine region as well as on the Danube all data was well uploaded on the database. In case of a weak GSM signal or even a disconnected prototype, the local storage was working well and when the vessel sailed into an area with GSM coverage the system started updating the data onto the remote database. Regarding the size of the touch screen, most users requested for a larger screen, in order to have larger buttons and more text and data visible. Also some requests regarding the language used were received.

Timing of registration and adjustments

In the current concept there is a registration of actions on a certain moment. During the pilot it appeared that the timing of registration and the possibility to input data in advance or to make adjustments afterwards is very important. Three practical situations can illustrate how the timing of the input should be considered. Firstly when a crewmember is set to “on board/resting” he cannot change back to “on board/active” for the next eight hours. This is very unpractical. If a mistake is made, someone has to start work after less than 8 hours of rest or when a short break is taken, the crewmember cannot change his status back to “on board/active”. Because the used terms in the drop down menu are very alike, a mistake is easily made. Particularly on a moving vessel. Currently a solution (by-pass) is that the crewmember is disembarked and directly re-embarked in the system. This is of course not the desirable way. Secondly in case the crew operating on board a vessel is already known for a certain period in advance, it would be helpful to input these data in advance or at least give a possibility to copy data in order to make the handling in the system more efficient. Secondly the possibility to make adjustments afterwards is important.

Crew cards and qualifications

A crucial element in this system is a good use of crew cards. During the pilot it happened that not all crew cards were up-to-date, due to wrong entry of data or due to crew not requesting an update of their card in time. Within the vessel unit concept a wrong card leads automatically to problems when starting a new voyage. When implementing the use of crew cards as a substitution of the current service record book, the crew must be very aware of their own responsibility of an updated crew card.

Regarding the names of qualifications on board it must be well communicated which names of qualifications in different languages are used. During the pilot sometimes the crew was not familiar with the names used for the different qualifications, f.e. Boatmaster. Although the qualifications used were common used in different kind of information and communication sources in Europe, such as European commission, CCNR, etc.

Specific user experiences during control/inspection (UC5)

From an inspection point of view it is important that the system takes over all the registration tasks from the crew. The regulations are leading and the way the registration system works should be based on the regulations. The applicable regulations are a complicating factor, due to different exploitation modes, special provisions, exceptional arrangements and individual exemptions. The prototype is used as a digital time recording device, but in this situation this leads only partly to a reduction of the administrative burden. The possibility to login with the inspection card and to connect a laptop to access the recorded data, is felt as a benefit.

Improvements of prototype during the pilot

During the pilot period the project team took the opportunity to already improve the vessel unit based on user experiences. This paragraph gives an overview of the most important improvements carried out during the pilot

Bad GPS signal

Inside the eIVU we built a GPS unit with internal antenna. During initial testing this worked fine but during trials the signal was often not good. An extra module was added which uses GSM localisation. This is a technique which uses a database of known GSM antenna's. This gave the vessel unit a very fast and reliable location update. For future development an external antenna on the unit might be needed.

Software updates

Already during the pilot the unit needed regular updates. This is partly because the units are connected to the internet and need security updates. Also some bugs in the software needed to be fixed. The units will need to have some sort of automatic software update mechanism. During the pilot the vessels were visited frequently. But in the future this is not the most efficient solution.

Unit alive

During the pilot it was sometimes difficult to know if the unit was still active or a problem occurred. For this reason every six hours the unit will generate a log which is sent back to the control server. This log includes a position, which makes it possible to check if the unit is still operational.

Multiple boat masters

Some vessels have more than one boat master on board, working in shifts. This caused a problem when initialising a new voyage. For this reason a selection box at voyage initialisation was created, which makes it possible to select a boat master by choice.

Planned formations

During voyage initialisation, the boat master has to define the exploitation and formation of the voyage. In reality this scheme is very complicated with lots of (local) exemptions, which makes it difficult to check. A new option was added but not 100% satisfactory. Needs to be addressed in future development.

Vessels with multiple shifts

In case of a vessel having multiple shifts of crew which is not resting on-board, the procedure is not clear. The system gives two possibilities: (1) embark the complete crew and use resting time registration or (2) embark – disembark for every new shift. In the vessel unit the number of crew that can be embarked at any moment has been increased. This gives the boat master the decision which option will be used.

Recommendations and considerations

Based on the user experiences gained during this pilot recommendations and considerations can be drawn for the further development of the vessel unit. First the considerations regarding the four use-cases will be described. Secondly the recommendations from end-users regarding the future development of the whole vessel unit concept will be described.

Considerations regarding the current 4 use-cases

Considerations to be made when working out the general concept of the vessel unit in more detail are:

- The possibility to modify the data afterwards, within certain limits. In the current system, an error late entry cannot be corrected (UC3, UC4, UC9);
- The possibility to program a fixed schedule in the prototype when a vessel is operating in Exploitation Mode B for a longer period;
- The sailing time is not visible in the screen. But this is necessary to check the applicable regulations (UC3, UC4, UC5);
- If an error occurs, will there be a registration (UC5)?;
- Is it possible to change crew when an inspector has logged in with his card and an inspection is ongoing (UC3, UC5)?;
- Will all inspectors have a card or will there be a possibility to print the data from the prototype (UC5)?;
- A larger screen gives the opportunity to add more data or to create larger buttons. Although this may also lead to a larger vessel unit in the wheelhouse (all use-cases);
- For the use during night hours, it would be very helpful if the screen could be dimmed manually (all use-cases);
- The software should ideally be in the native language of the particular crew. The use of English is not that widespread in inland navigation (all use-cases).

Additional user recommendations for future developments

During the pilot recommendations from end-users were noted regarding possible future functionalities of a vessel unit on board. Although these functionalities were outside the scope of the project, it is relevant for future developments of the vessel unit concept to take in consideration.

- Transferring the data from the prototype to the computer in the office gives opportunities for the organisation ashore;
- Currently a biometric identification is not applicable. This increases the fraud possibilities, as there is not a check whether the crew of the corresponding crew-card is on board;
- A valuable addition would be to have more or all certificates that are commonly used in the inland navigation, linked to the crew card. For example: Radar, VHF license, ADN certificate. Then a crew member only needs to carry one card instead of the all different cards currently in use;
- It would be considered useful if the system would give a pop up notification on checking in or out with the card, when the crewmember's license is about to expire;
- For future use, it would be helpful if there was a mobile app that the crew could use to see if they are properly signed on or off and active on duty;
- Connection with ship's tachograph, gives the opportunity to avoid forgetting the start and end of a voyage;
- In order to avoid any complex installation situations for this short pilot, an internal GPS receiver was used in the vessel unit. For long term use in the future connecting to the existing GPS would give better results.

c. Pilot Community of Practice (CoP) logistics education

Task 5.5.3. "Pilot CoP Logistics education" includes Train-the-Trainer workshops and pilot courses to test the developed capstone course. Each partner involved in Task 5.5.3. (FHOO, STC and IMST) organised a first Train-the-Trainer workshop in their country and conducted a pilot course to test the developed content. Feedback was collected during the workshops and the pilot courses to facilitate an evaluation of the task. A questionnaire was developed for the pilot courses, which was handed out to participants before and after the pilot course to survey their attitude towards inland waterway transport and to collect feedback concerning the course. Within the workshops, discussions were used to gather feedback from the participants.

Since the pilot courses from FHOO and IMST took place at the same time, students from both universities were told to exchange information during the pilot course using a blog. The blog is integrated in the online Community of Practice (CoP) in addition to the developed learning materials and case studies (CoP: http://ines-danube.info/goto.php?target=crs_1244). Students provided updates on their elaborations on a regular basis (e.g. before presentations, after study visit, etc.), and it was possible to ask questions and to provide feedback during the pilot course. Furthermore, a Skype meeting between students from IMST and FHOO was organised at the beginning of the course to provide students the opportunity to exchange information concerning their tasks within the courses.

i. Pilot FHOO

On the 6th of October 2016, a Train-the-Trainer workshop was hosted at the port of Enns by FHOO. Teachers from vocational schools, a representative of the Niederrhein Chamber of Commerce and Industry (DE) and project partners attended the workshop. The PROMINENT project was presented as well as the provided materials, content and the online Community of Practice (CoP). Qualitative feedback was collected at the end of the workshop using discussions.

Figure 78: Train-the-Trainer workshop in the port of Enns (Austria).

The case study, developed by FHOO in collaboration with the Austrian agricultural machinery manufacturer Pöttinger, was integrated in the course “transport logistics and infrastructure” from the 3rd semester of the Master programme “Supply Chain Management” at the University of Applied Sciences Upper Austria. The course lasted for 3 months and in total 32 students participated.

Structure of Pilot Course FHOO

Preparatory phase
Students worked together in groups consisting of 5 to 6 students (students stayed in these groups throughout the whole course) and were assigned to different transport modes (rail, road, air and waterway). The groups had to prepare a presentation including information such as strengths and weaknesses about the different transport modes until the first lecture.

First lecture – 19th and 20th October 2016
The course concept (grading, tasks, etc.) was presented to the students. Afterwards the presentations from the preparatory phase were presented (approx. 10 minutes/group). In addition, a lecture about ‘intermodal transport’ (30 minutes) was included. Afterwards, the Case Studies including instructions were handed out to the groups and shortly described. In total, six different case studies were handed out (including PROMINENT case study). On the next day, the students had time to ask questions concerning the tasks of the case studies and afterwards they were told to work on their own until the afternoon and to start elaborating a transport strategy as described in the task.

Exchange of information with Romanian students – 2nd November 2016
The students had a Skype meeting with their colleagues from IMST, where they exchanged ideas and information related to the case studies.

Second lecture – 10th and 11th November 2016
At the beginning of the lecture, the groups had to present their transport strategies in front of the plenum including a discussion of their solutions. Afterwards each case study was handed over to another group. Thus, each group had to rely on the work done by the first group for their further elaborations. In addition, the groups were peer evaluated by each other in order to evaluate the work done by the previous group. During the second lecture, a presentation on the topic of air and ocean transport by a representative of the industry was included. Afterwards students had time to prepare a final transport solution based on the proposed transport strategy by the previous group.

Third lecture – 1st and 2nd December 2016
At the beginning of the third lecture, the final transport solutions were presented by each group. A representative of the PROMINENT case company Pöttinger was also present at the final presentations. In addition, another representative of the industry was also present. Results were discussed in the plenum. At the end, the students provided general feedback on the course. The final test – including questions elaborated within the learning materials of Task 4.3.1. – of the course (multiple choice test) took place on the 16th December 2016.

Feedback from students at the end of the last lecture suggested that they enjoyed working on a real life case study and to be able to apply their theoretical knowledge on a real issue from industry. They also enjoyed the discussions with lecturers and the representatives of the industry.

ii. Pilot IMST

During the last quarter of 2016, IMST also hosted a train-the-trainer workshop at the University of Craiova. Professors attended the workshop at which the PROMINENT project, the elaborated Community of Practice (CoP) as well as the pilot course concept was presented. Feedback was collected using a discussion.

The case study, developed by IMST, in collaboration with the tyre manufacturer Eurotire Manufacturing, was integrated in the course “industrial logistics” from the first semester of the master programme “Management of Logistics Systems” at the University of Craiova. The course lasted for 4 months (7th October 2016 – 11th January 2017), and in total 12 students participated.

Figure 79: Technical visit of Eurotire Manufacturing in Drobeta Turnu Severin by pilot course students.

Structure of Pilot Course IMST

Preparatory phase
Students were divided in three groups consisting of four students (students stayed in these groups throughout the whole course) and worked together to fulfil their tasks.

First technical visit and lecture – 26th and 27th October 2016
The technical visit was made at the company Eurotire Manufacturing in Drobeta Turnu Severin. The visit was hosted by the commercial director of the company and the responsible for logistics issues. They presented the manufacture activities and some general data regarding the transport and logistic issues. During the first lecture (after the technical visit), students received three case studies for the transport of different types of tires in different locations. The next day, the students were given questionnaires that they filled out, and then they were asked a number of specific questions relating to each study case.

Self-study
The students had to develop their case study in order to provide the best technical solution for transportation of the products in specific locations. They started to prepare a SWOT analysis of different transport modes focused on the technical specs of the tires.

Second lecture – 26th and 27th October 2016
The students visited the Romanian Naval Authority and the Port of Drobeta. They met with representatives of the two institutions who presented elements on river transport and water

transport possibilities using existing port capacities. They were asked if they intend to use inland waterway transport as a transport solution for their products.

Exchange information with Austrian students – 2nd November 2016
The students had a Skype meeting with their colleagues from FHOO where they exchanged ideas and information related to the case studies.

Self-study
The students had to continue developing a transport solution for the case study under consideration, and they prepared a power point presentation for the next lecture.

Third lecture – 11th January 2017
The third lecture included a presentation of the results obtained by each group of students. Since the case studies had been handed out by Eurotire Manufacturing, a representative of the company was also present for the final presentation. A question and answer session was conducted in order to determine the involvement of students in developing the transport strategies. After that, the students filled out the second questionnaire. The final test of the course (multiple choice test) took place on the 25th January 2017.

According to the feedback from the students, they enjoyed the opportunity to visit a company such as Eurotire Manufacturing. They also mentioned that they would like to have more company visits within lectures in the future. In addition, the students prefer to have more interactive exchange with other students such as Skype meetings rather than using a blog.

iii. Pilot STC

Mid October 2016, the STC-Group hosted the kick-off of a train-the-trainer programme for lecturers of Dutch bachelor educations in logistics and transport. Eight universities of applied sciences were invited of which three attended the programme, namely Emmen, Rotterdam and Venlo.

In preparation, the STC-Group developed an IWT educational programme with the help of PTC, a Dutch cooperation of independent entrepreneurs in inland navigation. A case study emerged around the commercial opportunity to write a quotation with underlying proposal for the eco-friendly transport of a completely new hospital somewhere in the Netherlands. Students are provided with a lot of information, including a database with transport orders per construction phase and a generally accepted table with emissions per means of transport. Transport criteria are emissions, number of shipments, distances and costs. From a logistics standpoint, the proposal should elaborate on a smart concept for discharging and loading of materials and goods near the construction site (temporary quay or port with lifting equipment) and multimodal transport planning (combining transport orders with the right construction phase, bundling goods, JIT delivery, etc.). Getting and keeping the overview in the case study and project cooperation between the students are real challenges.

Figure 80: Kick-off of the Train-the-Trainer programme for lectures at the STC-Group.

Last winter, especially Emmen (four project groups) and Rotterdam (two project groups) applied for the case study pilot. The outcomes were satisfying, yet with room for improvement.

Positive aspects and observations were:

- getting the interest of young people for eco-friendly transport and the role of IWT in that respect;
- a challenging case study that really asks for cooperation, role taking, dividing the tasks and striving for the same result (consensus);
- understanding the otherwise underestimated role of geography and in geophysical conditions of making complex transport combinations possible (organisation, communication, planning);
- the case study has a broad scope which might trigger students with different backgrounds and interests: transport and logistics, business economics and finance, construction management or sustainability management.

The STC-Group sees room for improvement in:

- fine-tuning the case study (educational materials, expected output) on specific target groups (experienced and motivated students);
- selecting a proper mix of learning objectives, related to skills, competencies and knowledge;
- setting the scene more clearly in the role taking (working for the commercial department of PTC);

- combining the case study better with the other, online learning modules (one package).

Next school year, the case study will be offered again to all Dutch universities of applied science with a logistics department. Confidence is there that the complete PROMINENT learning package will land in Dutch bachelor educational programs.

iv. Joint case study

In the course of the final event, six students from the University of Applied Sciences, University of Craiova and STC worked together on the Pöttinger Case Study. The task was to elaborate a sustainable transport strategy for the Ukrainian market of the company. From March to April 2018, students communicated via Skype and WhatsApp and used the Community of Practice (CoP) to share their elaborations (e.g. SWOT Analysis). During the final event – from the 15th – 17th of April 2018– students again had time to work on the case study in Vienna. The solution was presented to the participants of the final event.

Figure 81: Joint case study presented at the final event of PROMINENT in April 2018.

The students enjoyed sharing their knowledge concerning inland waterway transport in their countries. In addition, they liked working on a case study which was drawn from a real-life setting rather than working on a theoretical case.

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Indexes

a. Figures

b. Tables

c. Abbreviations

AC	alternating current
ADCP	acoustic Doppler current profiler
ADN	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
AIS	Automatic Identification System
AR	Antwerp – Rotterdam
ARA	Antwerp – Rotterdam - Amsterdam
B	width, breadth
be	specific fuel consumption
BfG	Bundesanstalt für Gewässerkunde, Federal Institute of Hydrology
C	Celsius
CAN	Controller Area Network
CCNR	Central Commission for the Navigation of the Rhine

CFD	computational fluid dynamics
COG	centre of gravity
CoP	Community of Practice
csv	comma-separated values
CO	carbon monoxide
CO_2	carbon dioxide
DAQ	data acquisition system
DC	direct current
dGPS, DGPS	differential Global Positioning System
DOC	diesel oxidation catalyst
DPF	diesel particulate matter filter
DWT	deadweight tonnage
EAT	exhaust after-treatment
EC	European Commission
e-IVU	Electronic Inland Vessel Unit
ENAT	Efficient NAvigation Tool
EPA	Environmental Protection Agency
EPM	Environmental Performance Monitoring
EU	European Union
EUR	euro
FGS	Fahrgastschiff
Fr_h	Froude number based on the water depth
FTP	file transfer protocol
GHG	greenhouse gas
GL	Germanischer Lloyd
GlW	equivalent water level, gleichwertiger Wasserstand
GMS	Großes Motorgüterschiff
GSM	Global System for Mobile Communications
GPS	Global Positioning System
GPRS	General Packet Radio Service
h	hour
H	height
HC	hydrocarbon
HDT	Heading, True
HSPA	High Speed Packet Access
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
Hz	hertz
H2020	Horizon 2020
ID	identification
ISC	In Service Conformity
IWA	inland waterway auxiliary engine (NRMM Directive)
IWP	inland waterway propulsion engine (NRMM Directive)
IWT	inland waterway transport
JRC	Joint Research Centre
kHz	kilohertz
kN	kilonewton

km	kilometre
kW	kilowatt
l	litre
L	length
m	metre
MW	mean water level
NCD	NO_X Control Diagnostics
NHN	Normalhöhennull, standard geographical height system used in Germany
NRMM	non-road mobile machinery
NTE	not-to-exceed value
NTRIP	Networked Transport of RTCM via Internet Protocol
OBD	On-Board Diagnostics
OBM	On-Board Monitoring
OCE	Off-Cycle Emissions
OEM	Original Equipment Manufacturer
P_B	brake power
PC	personal computer
PD	delivered power
PEMS	portable emission measurement system
PLC	programmable logic controller
PM	particulate matter
PN	particulate number
PROMINENT	Promoting Innovation in the Inland Waterways Transport Sector
RDE	Real Driving Emissions
REC	Retrofit Emissions Control device
rkm	river kilometre
rpm, RPM	revolutions per minute
RSE	Real Sailing Emissions
R_{TS}	total resistance of ship
u	velocity
s	second
SAPOS HEPS	highly precise positioning service
SCR	selective catalytic reduction
SoG, SOG	speed over ground
SRB	service record book
SRM	standard reference material
StW, STW	speed through water
SWP	Sub-Work Package
t	tonne
T	draught, draft
V	volt
V_S	ship speed
wi-fi	local area wireless computer networking technology
WP	Work Package
xls	Microsoft Excel file format
1D	one-dimensional
2D	two-dimensional

∇	ship displacement volume
Δt	time (step)

Annexes

Appendix A: Sailing environment: German Rhine

In order to provide a proper navigation advice, the sailing conditions have to be known as accurately as possible. Within PROMINENT, BAW provided modelled flow data of the German section of the Rhine. In particular, of the part from Maxau to the Dutch border near Emmerich, comprising the stretch from Rhine km 334 to km 865. To get an impression of the geography, the contours are given in Figure 82.

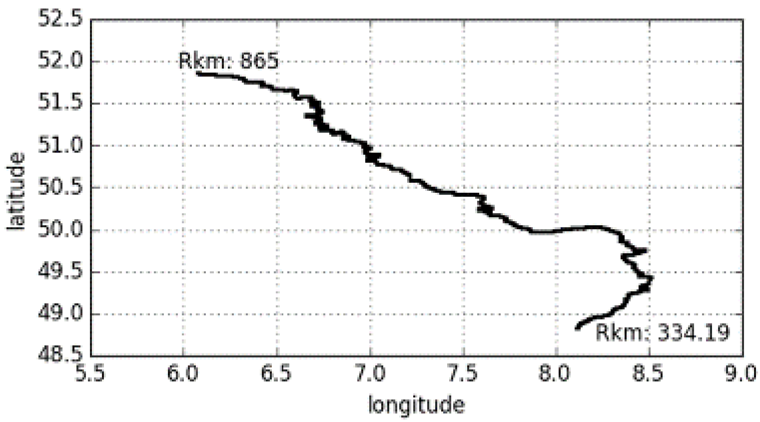


Figure 82: Rhine kms along the German Rhine section used in PROMINENT. Maxau is at approximately km 334, Emmerich near 865. The latitude and the longitude are given in degrees.

The discharge data is given for 6 different discharge conditions. For efficient navigation, the flow velocities and water depths have to be taken into account. To give an idea of the extent of the flow velocities that can be found on the Rhine, all flow velocities listed in the database are shown in Figure 83, showing a range from 0.3 m/s to almost 3 m/s.

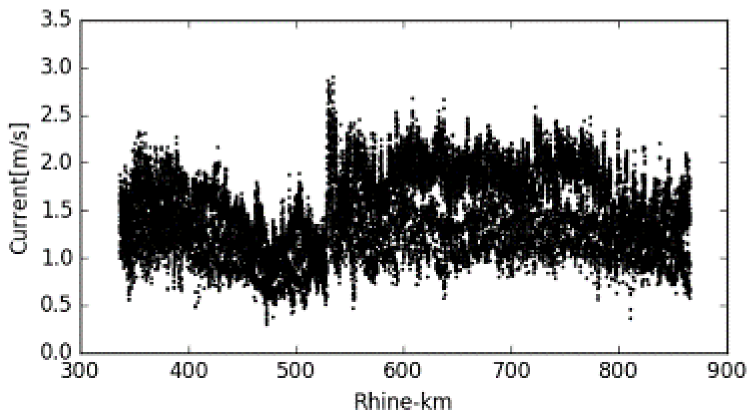


Figure 83: Flow velocities of the Rhine presented in m/s as function of the Rhine-river kilometre (Rhine-km).

Water depths are very variable along the river. Figure 84 shows the range in the average water depth that can be found along the stretch under consideration. The average water depth ranges from less than 2 metres in shallow-water sections up to over 10 metres in deep-water sections. The ENAT uses the average water depths as basis for the calculation of the advice to the skipper. Local bathymetry of the river has an influence on the local flow velocities and water depths, affecting the ship performance. However, consideration of the full set of navigation conditions changing in place and time is a task being too complex to be taken into account in the early version of the ENAT. Instead, average values for the water depth and flow velocity depending on the river kilometre and time are used for simplicity, assuming this approach to be sufficient for successful application of the ENAT.

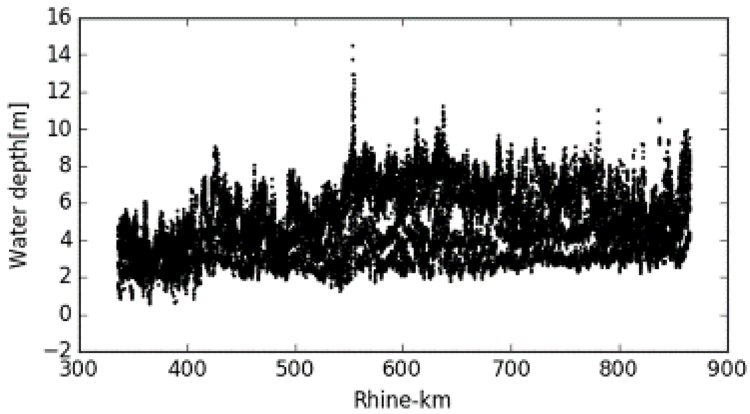
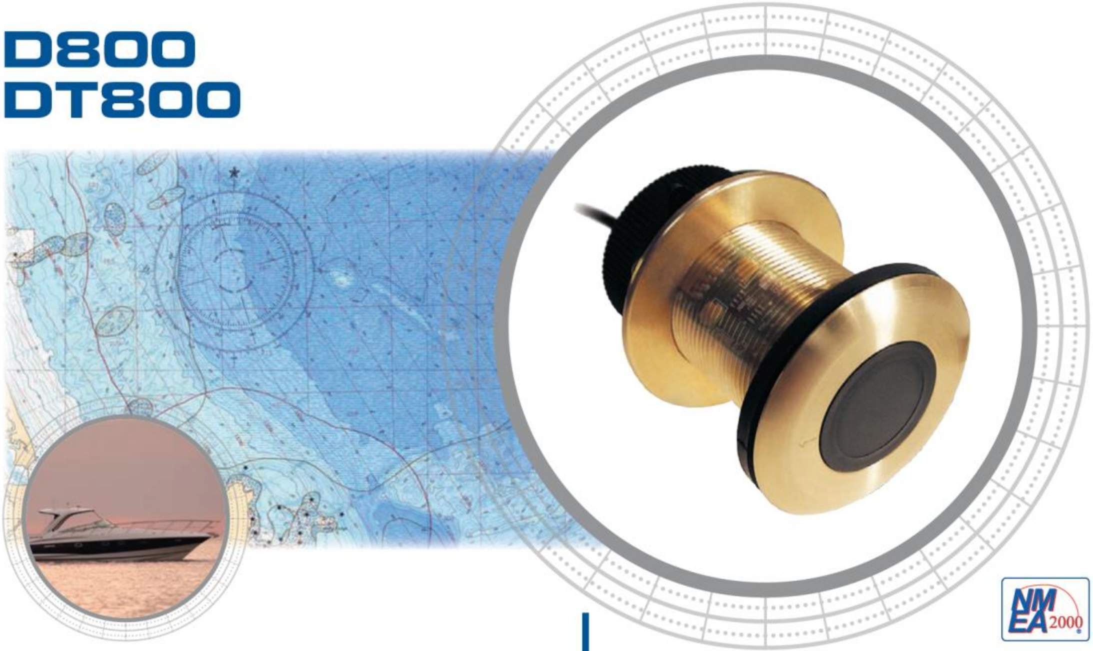


Figure 84: Water depths (averages) of the Rhine presented in m as function of the Rhine-river kilometre (Rhine-km).

Appendix B: Sensors used for depth and speed-through-water measurements on board the NAVROM vessels

D800
DT800



The Smart Alternative!

Airmar's D800 and DT800 Smart™ Sensors feature embedded micro-electronics. Depth and temperature signals are processed inside the sensor and can be displayed on any radar, chart plotter, or device that accepts NMEA 0183 or NMEA 2000® data. The 235 kHz frequency prevents mutual interference with other echosounders on the vessel.

Angle for Results

The DT800 Tilted Element Transducer's low-profile housing compensates for hull deadrise. The unique design tilts the ceramic element inside the transducer housing—giving all the advantages of a fairing block without a hull protrusion. Designed with Airmar's exclusive Broadband Ceramic Technology, the 235 kHz element improves resolution without sacrificing sensitivity. The higher power rating 100 W RMS provides spot-on depth readings in as little as 0.5 m (1.6′) of water and can reach depths up to 180 m (600′).

NMEA 2000

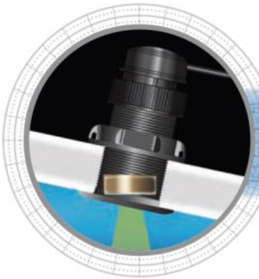
Tilted Element™ Thru-Hull Smart™ Sensors

Features

- Tilted-Element Broadband-Ceramic versions available in a 0° or 12° or 20° tilt
- Available in NMEA 0183 and NMEA 2000® versions
- 235 kHz frequency prevents mutual interference with other echosounders on the vessel
- Temperature sensor in DT800 models
- Cable lengths up to 100 m (330′) are possible with no loss of performance—NMEA 0183 only
- Plastic, bronze, or stainless steel housings available
- Retractable housing with water valve
- Available in low-profile, countersunk, or beveled-edge housings

AIRMAR®
TECHNOLOGY CORPORATION
Sensing Technology

www.airmar.com



D800, DT800

Technical Information

235 kHz Non-Broadband / Broadband		
Number of Elements and Configuration		
Beamwidth (@-3 dB)	12°	
RMS Power (W)	60 W	100 W

SPECIFICATIONS

Weight:
—0.9 kg (2 lb)—Plastic
—1.5 kg (3.4 lb)—Bronze
—1.6 kg (3.6 lb)—Stainless Steel
Acoustic Window: Urethane
Data Update Rate: 1 per second
Minimum Depth Range: 0.5 m (1.6')
Maximum Depth Range:
—Up to 100 m (330')—Non-Broadband
—Up to 180 m (590')—Broadband
Pressure Rating: 3 m (10')
Supply Voltage:
—10 VDC to 25 VDC—NMEA 0183
—9 VDC to 16 VDC—NMEA 2000
Supply Current:
— <40 mA—NMEA 0183
— <200 mA—NMEA 2000
Standard Cable Length:
—10 m (33')—NMEA 0183
—6 m (20') devicenet—NMEA 2000
Temperature Accuracy: ±0.5°C (±1.8°F)
Temperature Sensor Range: -10°C to 40°C (14°F to 104°F)
NMEA 2000® Load Equivalency Number (LEN): 4
CE Regulation: Complies to IERC60945

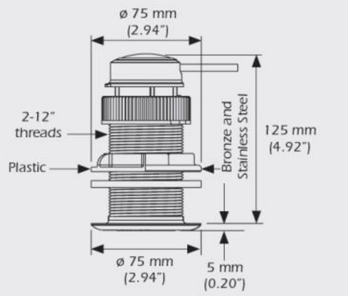
DATA OUTPUT PROTOCOL

NMEA 0183 Sentence Structure
$SDDBT, DDPT... Depth
$YXMTW........... Water Temperature

NMEA 2000® Supported PGNs
59392......... ISO Acknowledgement
600928....... ISO Address Claim
126208....... Acknowledge Group Function
126464....... Transmit PGN List Group Function
126464....... Received PGN List Group Function
126996....... Product Information
128267....... Water Depth (With Transducer Offset)
130310....... Environmental Parameters (Water Temperature)
130311....... Environmental Parameters (Water Temperature)
130312....... Environmental Parameters (Water Temperature)

DIMENSIONS

P617V Plastic, B617V Bronze, and SS617V Stainless Steel



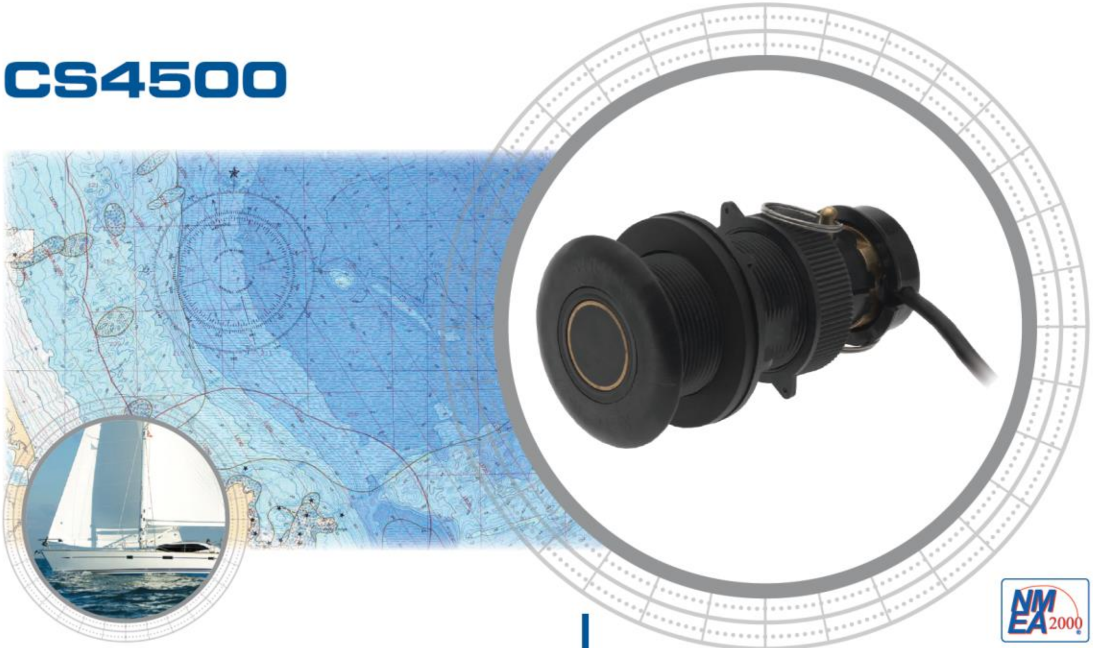
- **Also compatible with B17 and SS577 housings**

AIRMAR® TECHNOLOGY CORPORATION
Sensing Technology

ISO CERTIFIED CE

D800_DT800_rM 12/15/10

CS4500



High-Precision, Low Maintenance

Innovation at its finest! If one consistently demands the best, Airmar's CS4500 Ultrasonic Speed Sensor delivers.
Ultra-accuracy is foremost! With no moving parts, the ultrasonic sensor is capable of speed reading accuracy as low as 0.1 knots (0.1 MPH). By eliminating the traditional paddlewheel, there is no fouling, and drag is reduced to a minimum. Unlike paddlewheels, the CS4500 is engineered to measure water speed below the turbulent boundary layer of the hull, resulting in accurate clean-water readings.

Tried and True Technology

The innovation doesn't stop here. Ultrasonic sensing is a proven technology that has been used on ships for nearly 20 years. Building on this technology, Airmar developed an advanced design which operates at a higher-frequency, enabling reliable operation in both salt and fresh water. The state-of-the-art processor in the CS4500 calculates speed every half second, so it can respond to rapid changes in vessel speed. This translates into the most reliable and accurate ultrasonic speed sensor on the market—at a very competitive price.

Bronze housing—CS4500

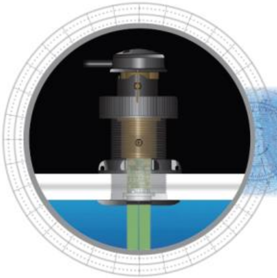
AIRMAR®
TECHNOLOGY CORPORATION
Sensing Technology

Ultrasonic
Speed Sensor

Features

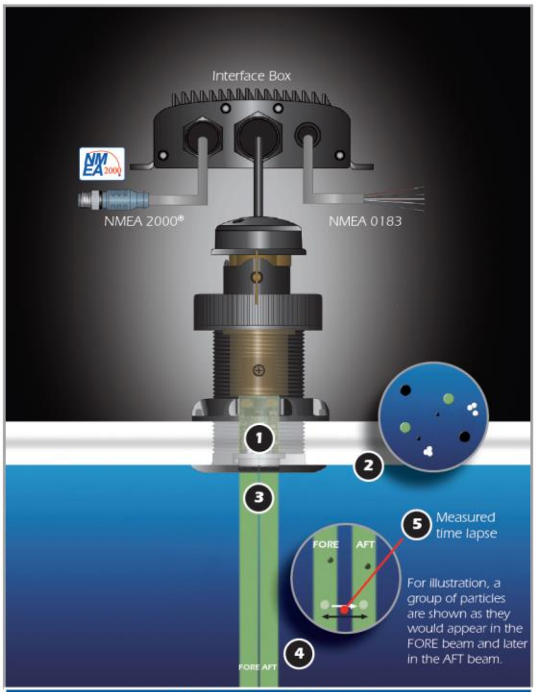
- Unparalleled accuracy as low as 0.1 knots (0.1 MPH)
- Designed for use with all types and sizes of sailboats and powerboats
- No moving parts
- Makes retrofitting a breeze—the retractable insert fits most Airmar 51 mm (2") housings
- Low-profile, plastic, or bronze housings available
- Built-in temperature sensor
- Optional Data Converter charges analog signal to NMEA 0183 data stream

www.airmar.com



CS4500

Technical Information



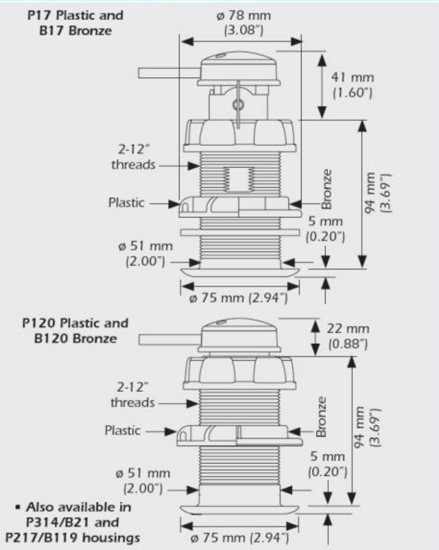
How the CS4500 Works

1	In the CS4500, two transducers are incorporated in a single housing.
2	Small particles present in the water pass through the beams.
3	The speed sensor uses ultrasonic pulses to collect echoes from the small particles in the water as they pass under two ceramics embedded in the sensor.
4	As the boat travels through the water, both ceramics "view" the same stream of particles. Because it takes time for particles to travel between the two ceramics, the aft ceramic detects the particles later than does the fore ceramic.
5	By measuring this time lapse, the instrument is able to calculate the boat speed.

SPECIFICATIONS

Transmit Frequency: 4.5 MHz
Pulse Repetition Frequency: 5.5 kHz
Sampling Distance Below The Sensor:
77 mm to 127 mm (3" to 5")—outside the boundary layer
Data Update Rate: 2 seconds
Signal Output: Airmar paddlewheel format
—5.6 Hz per knot
—20,000 pulses per nautical mile
Speed Range: 0.1 knot to 40 knots (0.1 MPH to 46 MPH)
Operating Temperature Range: 0°C to 40°C (32°F to 104°F)
Sensor Cable Type: Airmar C190
Sensor Cable Length: 10 m (33') standard
Instrument Cable Length: 3 m (10') standard, up to 30 m (10') possible
Supply Voltage: 10 VDC to 15 VDC
Supply Current: 155 mA at 12 VDC
Hole Diameter: 51 mm (2")
Sensor Insert Material: Bronze
Thru-Hull Housing Material: Plastic or bronze
Blanking Plug: Yes
Weight:
—1.4 kg (3 lb)—Plastic
—1.8 kg (4 lb)—Bronze
CE Compliant: Yes

DIMENSIONS



▪ Also available in P314/B21 and P217/B119 housings

AIRMAR® TECHNOLOGY CORPORATION
Sensing Technology

ISO CERTIFIED

 CS4500_rM 02/03/11

Appendix C: LNG composition

Gate terminal
Maasvlakteweg 993
Maasvlakte
Tel: +31 181 79 90 00

Slot start date-time: 2018-03-30 18:00:00

Slot end date-time: 2018-03-30 20:00:00

Slot ID nummer / Slot ID number: SNV_1005418

Weegbrug volgnummer / Weighbridge sequence number: 2017001472

LNG Leverancier klant / Customer's LNG Supplier:
Shell Western LNG B.V.
Carel van Bylandtlaan 30 2596 HR The Hague The Netherland
NL

Klant / Customer:
Shell Nederland Verkoopmaatschappij B.V.
Weena 70 3012 CM Rotterdam
NL

Kenteken Truck / License plate truck:
03-BDV-7

Kenteken Trailer / License plate trailer:
ON-80-PG

Container ID (if applicable, e.g. HOYU 434433 3):
Not Applicable

Afleveradres 1 / Delivery address 1:
RPG Stuttgart Seinehaven Rozenburg NL

Afleveradres 2 / Delivery address 2:

Afleveradres 3 / Delivery address 3:

Naam & handtekening Chauffeur / Driver name & signature:
Paul Deijkers

Naam & handtekening Operator / Operator name & signature:
J. van Beest

Product:
UN1972
Aardgas, Sterk Gekoeld, Vloeibaar, 2.1, (B/D)
Natural Gas, Refrigerated Liquid, 2.1, (B/D)

Ticket Datum / Ticket Date: 2018-03-30

Ticket Tijd / Ticket Time: 18:14:56

Compositie / Composition (Vol %):

Methane	90.394	Neo Pentane	0.004
Ethane	7.482	Iso Pentane	0.012
Propane	1.444	Hexane	0.000
Normal Butane	0.321	Carbon dioxide	0.000
Iso Butane	0.338	Nitrogen	0.001
Normal Pentane	0.004		

GHV (MJ/Kg):	LHV (MJ/kg):	Methane nr:	Temp. LNG (°C):
54.735	49.478	73.440 DIN EN 16726	-157.328
GHV (kWh/kg):	**WI (MJ/Nm3):**	**Dens. (kg/m3):**	**Dens. (kg/Nm3)**
15.204	55.526	450.210	0.796

Tot. energie geladen / Total energy loaded (MWh): 258.470

S (mg/Nm3): 0.000

Gewicht VOOR laden / Weight BEFORE loading:
21720 kg LB03 1220 2018-03-30 17:30

Gewicht NA laden / Weight AFTER loading:
38720 kg LB03 1221 2018-03-30 18:14

Netto gewicht geladen / Net weight loaded:
17000 kg

Cooldown service:
No

Commentaar / Comments:

Gate Terminal Truck Ticket - version TL 2/3 - 20170627 Printed on: 2018-03-30 18:15

Appendix D: SGS discussion of errors

9. DISCUSSION OF ERRORS

9.1 PURPOSE OF DISCUSSION OF ERRORS

When carrying out a measurement one always needs to be aware that there will be errors in the final results. This is not only true for the measurements, errors may also occur in the calculations.
An 'error' is defined as every deviation from the actual value. By carrying out an *evaluation of errors*, the influence of the error can be determined. This evaluation must be carried out both before and after the measurement. Before the measurement it is called an errors prognosis and after the measurement it is called an errors calculation. The errors discussion serves the following purposes:

9.1.1 Determination of the accuracy of a result

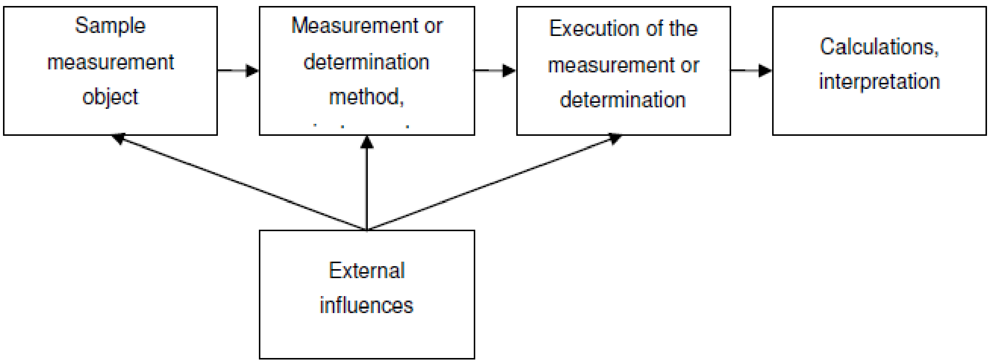
A measurement result for which the accuracy is unknown, is useless. If one wants to express the result of a test as an objective number, one will also want to express the accuracy as an objective number. By doing so, we will discover the boundaries within which the *true* value of the result.

9.1.2 Selection of the method and the instruments

Using the desired accuracy and the measurement method, the carrying out of an errors prognosis can determine whether the measurement meets the required accuracy. If the desired accuracy is not achieved, sources of error will need to be removed or a completely different measurement method will need to be found.
By ensuring that the experiments are carried out in an efficient manner, and by mainly focusing on the element that is the greatest source of inaccuracy, better results can be obtained and less time is wasted.

9.2 CLASSIFICATION OF ERRORS

The following figure gives a schematic overview of a number of steps in which errors may occur.



9.2.1 Errors related to measurement object

Sources of errors are often already present in the measurement object, for example:
- Lack of homogeneous composition of a gas.

- No long enough straight area for a volume measurement.
- A temperature measurement done on the 'shade side'.

9.2.2 Errors in the measurement or determination method

These so-called *method errors* often lead to wrong measurement or analysis results. It is hidden in the way the work is done. The measurement influences the value to be measured. e.g. when doing a velocity measurement in a small pipe, the pitot tube blocks a large part of the pipe so that a wrong velocity is measured.

9.2.3 Instrument errors

These mistakes hide in the instruments used. They can be the result of calibration errors or adjustment errors. It is also quite common for the *zero point* or *reference point* of a measuring device to not be constant.

9.2.4 Errors that are created during the execution of the measurement

This type of error is mainly created by the person carrying out the measurement and can be avoided through correct and careful carrying out of the measurement.

9.2.5 Errors resulting from external influences

This type of errors is created outside of the actual execution of the experiment, and yet influence the result, for example:

- magnetic fields around measuring equipment
- vibrations
- humidity
- weather conditions

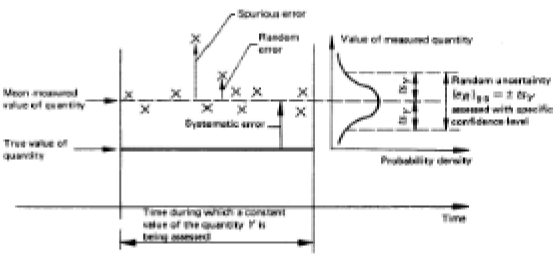
9.2.6 Errors in the interpretation of the errors

In this respect, one must ask oneself whether what one is measuring is actually what one thinks one is measuring. One must be certain that the method used is the correct one for what needs to be determined.

9.3 KINDS OF ERRORS THAT MAY OCCUR

The errors that may occur during a measurement can be subdivided into the following categories:

- *Systematic errors*
- *Chance errors*
- *Parasitic errors*



9.3.1 Systematic errors

Systematic errors are errors that influence a measurement in the same way every time. They always result in a value that is either too high or too low. The error is not reduced by repeating the measurement many times.
The systematic errors are mainly errors in the measuring equipment and are the result of the wrong calibration of an instrument or by a null setting that is incorrect.
The systematic errors can be subdivided into two large groups:

a) Constant systematic errors
These are normal for all measurements executed under the same circumstances and are constant over time but, depending on the nature of the error, they can vary with the value resulting from the measurement.

b) Variable systematic errors
These can be the result of not keeping the conditions under which the measurement is being executed constant. For instance, if the temperature rises near a measuring instrument that has been calibrated for a certain temperature.
A second type of variable systematic error can result from measuring with a digital instrument on a continually varying value.

9.3.2 Chance errors, replicability

Chance errors are defined as errors for which the magnitude and direction are completely dependent on chance and which can therefore be different for each and every measurement. If many measurements are conducted, the errors can partially compensate each other.
Another term that is often used in this context is *replicability*: the correspondence between several measurements of the same value with the same method. If something is replicable, it does not automatically mean that there is no systematic error. A systematic error can only be tracked down by carrying out the measurement with a different method.
It won't always be possible to put an error into one of these two groups because, on the one hand, subjective criteria are used to classify the error and, on the other hand, the errors that occur are often partially systematic and partially due to chance.

9.3.3 Parasitic errors

Parasitic errors are errors like human error or errors that result from the temporary failure of a measuring instrument. The observations that suffer from this kind of error should not be included in the averaging of the measurement values because they can produce large deviations in the results.

9.4 MEASUREMENT UNCERTAINTIES

Table 9-1 Overview of measurement uncertainties

	Sampling	Sample conditioning system	Analyser	Convertor effeciency	Reference gas	Total unc.
NO_x	2.0%	2.0%	7.4%	0.3%	2%	**8.1%**
O_2	2.0%	2.0%	4.1%	-	2%	**5.4%**
CO_2	2.0%	2.0%	4.3 %	-	2%	**5.5%**
CO	2.0%	2.0%	3.8 %	-	2%	**5.1%**
C_xH_y	2.0%	2.0%	7.4 %	-	2%	**8.1%**