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Maritime industry processes in the Baltic Sea Region

/ Synthesis of eco-inefficiencies and the potential of digital technologies for solving them

ECOPRODIGI

ECOPRODIGI
RESEARCH REPORT 2020

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EXECUTIVE SUMMARY

ECOPRODIGI (2017-2020) is an Interreg Baltic Sea Region flagship project, which links research organisations, enterprises, associations and business support organisations. Altogether, 21 partners jointly investigate the most critical eco-inefficiencies in maritime processes in the Baltic Sea Region as well as develop and pilot digital solutions for improving the eco-efficiency by focusing on three specific cases:

1) digital performance monitoring of vessels,
2) cargo stowage optimisation at ports and
3) process optimisation at shipyards.

Furthermore, looking towards the future, the project partners, on one hand, create a digitalisation roadmap and training modules for future decision makers in the maritime industry but also reach out to policymakers to engage them in discussion regarding how they can support the digital change.

This report provides an overview of the project and main findings achieved to date, describes the main eco-inefficiencies identified and presents the potential of digital technologies and new concepts for improving them. Also, as the current digital transformation relates to the way how changes are managed in organisations, this report presents the main challenges and requirements identified in the process of moving towards more digitalised business operations. Finally, the last section looks at the maritime sector from a broader perspective and provides some ideas about the most likely future developments.

The main findings of the project so far indicate that major improvements in eco-efficiency can be carried out in the maritime industry. They can be summarised as follows:

1) In the first case, 'digital performance monitoring', the project partners estimate, for instance, that fuel consumption and emissions can potentially be reduced by 2-20% based on data and analysis from distinct ship segments, routes and their baseline situations. The reductions are possible to achieve by taking such actions as capitalising on the latest digital technologies, utilising and analysing real-time operational data and vessel performance, anticipating operating conditions and maintenance of the ship and its components, changing working methods and improving practices as well as placing a focus on the training of personnel.

2) In the second case, 'cargo stowage optimisation' the project partners identified a set of eco-efficiency bottlenecks in the cargo stowage processes at ports that can be subject to improvement. The use of advanced digital technologies can contribute to more efficient utilisation of vessels and terminal operations. The port stays can be reduced, and, thereby, vessels can sail more slowly and reduce fuel consumption and emissions. Moreover, when stability calculations improve due to further digitalisation of cargo unit data, the ship can be loaded more optimally and the amount of ballast water can potentially be decreased without compromising safety, which again reduces fuel consumption on the sea leg. It is estimated that fuel consumption and emissions can potentially be reduced by 2-10% per route and ship and that additional benefits can be gained on the landside due to future digital decision support tools applied for the end-to-end stowage process. In addition, improved cargo unit pick up time estimates can be provided to customers waiting for the cargo to be handled at port, whereby the service improves.

3) In the third case, 'process optimisation at shipyards', improved situational awareness and process management, including the use of new technologies, such as 3D and solutions for managing the complex supply chain, have potential for improving the shipyard processes aimed at increased eco-efficiency. For example, in block building phase 3D technology reduces lead-time and potentially saves hundreds of man-hours in rework due to the fact that more efficient processes and proactive actions are enabled.

1. INTRODUCTION

Shipping remains the dominant transportation mode as 80-90% of international trade in goods is carried on sea. It is relatively cheap and efficient compared to other transport modes, and its significance is not expected to decrease. As 15% of the global cargo traffic is handled in the Baltic Sea, it is one of the busiest intersections of marine traffic in the world. There are some 2,000 ships operating in the Baltic Sea at the same time, and the maritime traffic, as well as the size of the ships, continues to grow. Considering the emissions per tonnes of cargo, shipping is a rather ecological mode of transport, but the maritime sector is responsible for a significant amount of total emissions globally. As a result of fuel consumption, ships generate sulphur oxides, nitrogen oxides, particulate matter and carbon dioxide. The maritime industry also has other negative ecological impacts, notably the transfer of aquatic species through ballast water, the discharge of oil, garbage and sewage, anti-fouling pollution and vessel scrapping. As the transport volumes are expected to grow in the future, there is a clear need for reducing emissions (see e.g. Eyring et al. 2010; Madjidian et al. 2013; Schippl et al. 2013; Cogliolo 2015; Lister 2015; Shi et al. 2018).

The need to reduce emissions not only concerns the shipping companies and cargo transporters, but also the shipyards that build the vessels. The ships need to be designed and built in a manner that complies with environmental standards and contributes to reduced emissions when ready to sail on the sea; similarly, the shipbuilding process needs to be planned and carried out in a way that attains environmentally sustainable goals. Shipyards are large and complex operating environments with thousands of employees working on different manufacturing processes at the yard. Moreover, the number of companies operating at a shipyard is high since many subcontracted enterprises operate in the same environment. Therefore, the way in which the ships are built has a significant impact on the environment. In addition, the management of this large operational environment, including implementation of new ecologically sustainable and digital solutions, requires specific know-how.

ECOPRODIGI project

The Interreg Baltic Sea Region flagship project 'Eco-efficiency[1] to maritime industry processes in the Baltic Sea Region through digitalisation' (ECOPRODIGI) was initiated to respond to several arising challenges maritime enterprises currently face, as the project plan states. One of the challenges relates to the aforementioned state of the environment. Environmental requirements increasingly add pressure to organisations to find new solutions that contribute to reaching environmental targets. This is something that both regulators and end-customers call for. Additionally, global competition is fierce, and maritime organisations need to find efficient means in order to compete in productivity and at attractive price levels, simultaneously adding value to customers. Digitalisation offers enterprises novel solutions to improve the situation. The benefits of digitalisation have been widely discussed during recent years, and several industries are making great efforts to capitalise on them. Yet, for a long time, maritime industry enterprises were reputed to follow a slower pace in this development. More initiatives from the industry were called for, and this encouraged a group of Baltic Sea Region (BSR) organisations to initiate this new collaborative project, and take action in this respect. The implementation period for ECOPRODIGI is set for the years 2017-2020.

ECOPRODIGI seeks to increase eco-efficiency in the BSR maritime industry by creating and piloting digital solutions, as well as providing guidelines for future development. The effort is carried out through the intensive collaboration of industry end-users and research organisations, as well as associations and business support organisations. As defined in the project plan, ECOPRODIGI supports the BSR in becoming a forerunner in maritime industry digitalisation and clean shipping. Altogether, 21 project partners and six associated partners from around the BSR are involved in the project **(see Table 1).** ECOPRODIGI is a unique initiative in the sense that approximately half of the 21 project partners represent private companies operating in the maritime industry. The great number of industrial partners means that all the challenges identified and solutions created for solving the challenges derive from real industry needs.

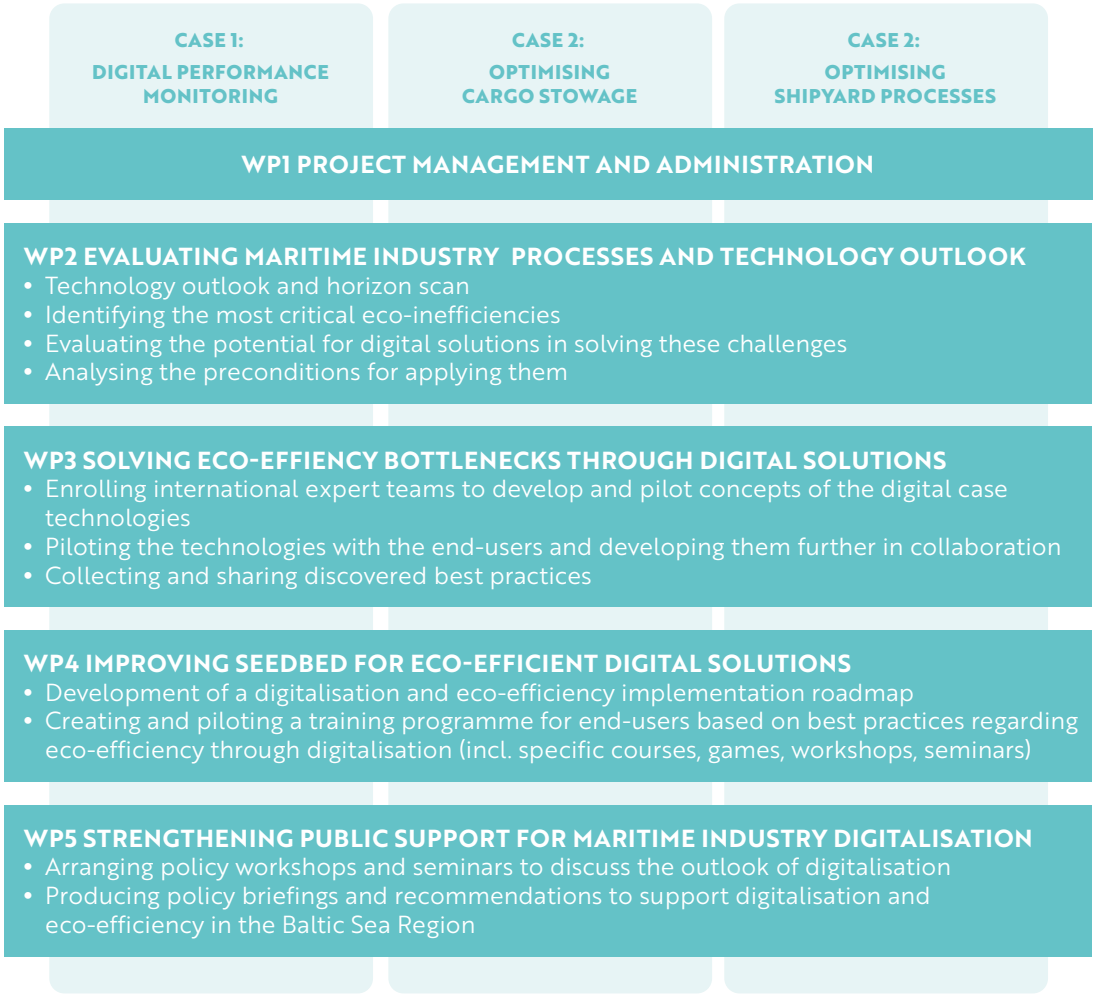
As drafted at the application phase, the project encompasses several work packages (WP) and technology application cases **(see Figure 1).** In sum, the project maps out the most critical eco-inefficiencies in the maritime industry, and based on the work, develops and pilots eco-efficient digital solutions and concepts to respond to the identified needs. The eco-inefficiencies are identified and solutions and concepts are developed within three different technology application cases taking into account almost the whole life cycle of the vessel with a special focus on 1) digital performance monitoring, 2) cargo stowage optimisation and 3) process optimisation at shipyards. Moreover, based on the work carried out in the technology cases, the project will look into the future in several ways. First, the project produces a digitalisation roadmap for the maritime industry so that maritime actors can compare their actions with it and further develop their work in a pragmatic manner towards a more eco-efficient direction. Second, the project creates and pilots training modules in order to support the learning of future maritime industry leaders and employees. Third, the project involves policymakers by promoting discussion with them and by producing policy briefings and recommendations for how to support the digital transformation that ultimately leads the BSR towards improved eco-efficiency.

[1]Eco-efficiency can be described as a combination of economic and environmental efficiency, or simply the process of creating more value with less ecological impact (see e.g. Lehni 2000).

TABLE 1. PROJECT PARTNERS

PROJECT PARTNER	COUNTRY
University of Turku (UTU), Lead Partner	Finland
Aalborg University (AAU)	Denmark
Chalmers University of Technology	Sweden
University of South-Eastern Norway (HSU)	Norway
University of Southern Denmark (SDU)	Denmark
Carina Solutions Oy (Carinafour)	Finland
Centrum Balticum Foundation	Finland
Danish Maritime	Denmark
DFDS A/S	Denmark
Island Ferry Secretariat	Denmark
Klaipeda Science and Technology Park	Lithuania
Machine Technology Center Turku Ltd	Finland
Meyer Turku Ltd	Finland
OSK-ShipTech A/S	Denmark
Kockum Sonics AB	Sweden
Logimatic Solutions A/S	Denmark
Sininen Polku Oy	Finland
RISE Research Institutes of Sweden	Sweden
JSC "Western Baltic Engineering"	Lithuania
Vessel Performance Solutions Aps	Denmark
J. Lauritzen	Denmark
ASSOCIATED PARTNER	**COUNTRY**
ATS AB	Sweden
Svendborg International Maritime Academy (SIMAC)	Denmark
Polish Maritime Cluster	Poland
Seismo-Shelf LTD	Russia
AS Tallink Group	Estonia
Tallinn University of Technology	Estonia

FIGURE 1. STRUCTURE OF THE PROJECT



Aim and content of the synthesis

This synthesis was developed under Work Package 2 'Evaluating maritime industry processes and technology outlook' (See Figure 1) of the ECOPRODIGI project, and it represents the first publicly distributed report of the project and serves as a working document for further project activities. This synthesis offers an overview of the results achieved so far in the aforementioned three technology cases. The report summarises the eco-inefficiencies identified in the processes of the involved end-users, and it introduces the digital technologies that are currently in use and the most promising digital technologies and concepts for improving eco-efficiency. The report also addresses challenges and requirements that the implementation of new technologies and concepts involves. On that basis, the report provides an outlook for the future in regard to capitalising the benefits of digitalisation. The focus is on the BSR, but the scope is global, as the solutions may be utilised anywhere.

The work in the three technology cases was carried out as a joint effort of different research institutions, enterprises and business support organisations. More information on the collaboration and activities can be found under the description of each specific case in the following sections. The description of the project outcomes was mainly produced by the following authors based on contributions from the participating project partners:

- **Introduction: Elisa Aro and Teemu Itälinna, Pan-European Institute, University of Turku**
- **Sections 2 and 3: Niels Gorm Malý Rytter, Aalborg University**
- **Section 4: Elisa Aro, Pan-European Institute, University of Turku**
- **Section 5: Teemu Itälinna, Pan-European Institute, University of Turku**
- **Conclusions: all three authors contributed to the content.**

2. MONITORING DIGITAL PERFORMANCE OF VESSELS

2.1. CASE ISLAND FERRIES

Description of the case and methods

The first technology case of ECOPRODIGI concerns the digital performance monitoring of different types of vessels. Two different industry end-users are involved in this specific technology case. The first one is the Island Ferry Secretariat/Association, which is formed by 18 municipalities owning and operating approximately 25 ferries to small Danish Islands.

The Island Ferries connect the Danish mainland to small islands of strategic importance, and their operations are supported financially by municipalities and government in contrast to other Danish ferry companies, which are mainly privately owned and operated on a commercial basis (with government incentive), such as, Mols Linien, Ærø ferry, and Scandlines. The project involves four out of the 25 ferries. An overview of the routes and ships in focus is presented in **Figure 2.**

The Island Ferry routes for the four sample ferries are generally short in duration, for example, from 25 to 65 minutes, which means that the ferries spend a significant amount of their time in ports even though port operations are executed quickly.

From the summer of 2018 to the spring of 2019, a team of researchers and students from Aalborg University (AAU), University of Southern Denmark (SDU) and experts from Danish Maritime, completed visits and case studies of the four ferry routes to investigate the current state of operational modes, processes, systems and eco-efficiency performance and to estimate the improvement potential from implementing digital performance solutions for the ferries.

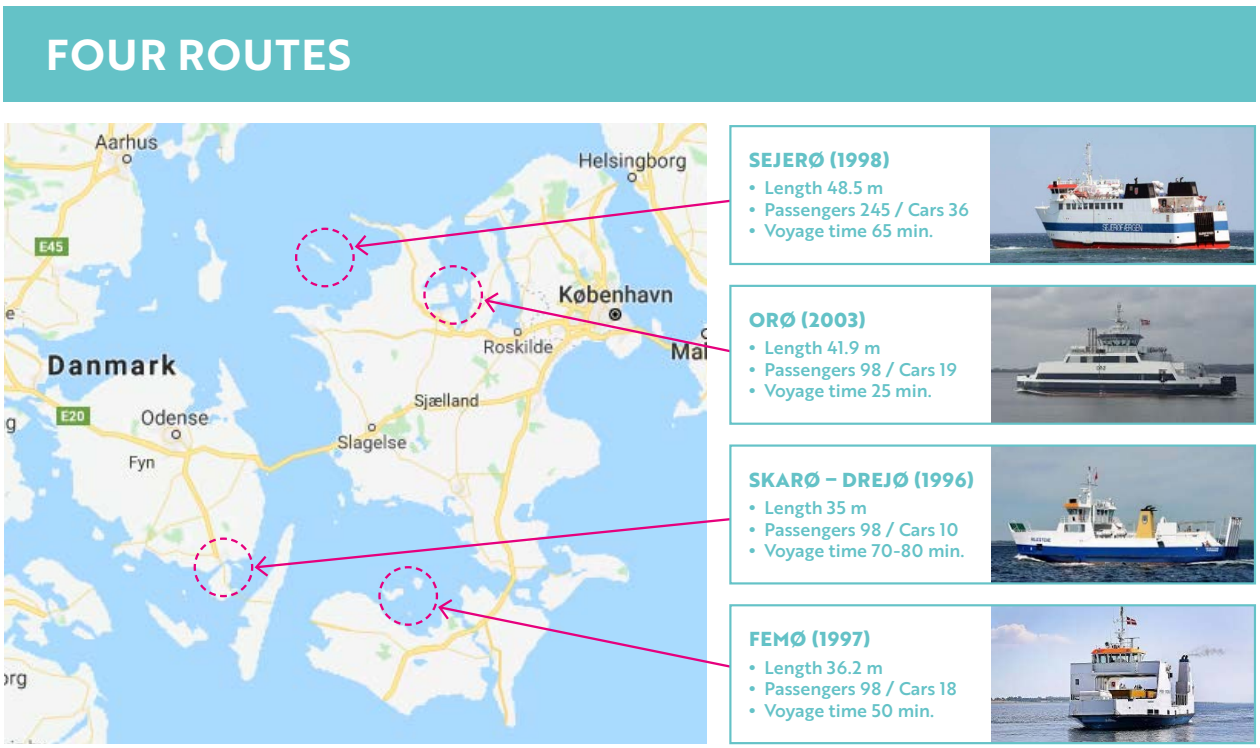
The visits immediately revealed that none of the ferries in 2018 had a set-up for permanent logging, storage or analysis of voyage performance data, which could support daily and operational or tactical/strategic decisions either onboard or onshore. Initially, this hampered the team of researchers, students and experts in gathering larger sets of baseline data for vessel performance as a basis for evaluating the current eco-efficiency potential of the ferries. It was therefore decided to set up some intermediate solution logging data for a limited set of days, voyages and operational parameters for the four routes where this was possible. Based on data gathered from these sample voyages, the researchers were able to obtain a rough indication of the following:

- **Typical routes, operational modes and profile of vessel operations for voyages sailed**
- **Time (min) and energy (kWh) spent across different modes of operations (harbour, manoeuvring, sea passage)**
- **Energy production and consumption for each specific operational characteristic, such as machinery, equipment and sailing/service purposes.**

The gathering of additional data from sample voyages was guided by a methodological framework originally developed by a team of researchers and included the following elements:

- **Definition of operational modes of the ferry**
- **Identification of machinery for energy provision/production on the ferry**

FIGURE 2. FERRIES AND ROUTES IN THE PROJECT



- Identification of machinery and equipment for energy consumption
- Estimation of time and energy consumption and production per operational mode. Type, amount and load of machinery and energy consuming equipment in use.

See Figures 3-5 for a further introduction to the methodology.

Current state and the most critical eco-inefficiencies

The Island Ferry Association decided to join this project as different municipal ferry companies have made little investment in technologies and processes for digital performance monitoring over the recent years, but they increasingly aim to operate their ferries in a more modern and eco-efficient manner with less CO2 emissions. The investigations of researchers revealed that the current state of digitalisation and eco-efficiency varies from route to route, but generally there is significant potential for further reducing fuel consumption and emissions across all routes.

The four ferries which were included in the study are between 15 and 22 years of age and are either single- or double-ended ferries with diesel engines running mainly on marine gas oil (MGO) due to Sulphur Emission Control Area's (SECA) regulation for sulphur content of fuel (most of the ferries also have auxiliary engines; however, one ferry had a shaft generator instead). The ferries operate with limited vehicle and passenger carrying capacity (the largest ferry can carry up to 136 tons, 245 passengers or 36 cars). The ferries generally have instruments and monitors at the bridge and/or in the engine room, enabling the crew to operate the ferry safely in line with regulations. The monitors/instruments on the bridge allow the navigators to have a real-time overview of critical operational parameters, such as:

- Vessel position (global positioning system, GPS)
- Speed over ground (SOG), (GPS)
- Main engine revolutions per minute (rpm), power (not always similar for auxiliary engines) and other measures
- Fuel consumption of the main engine (three out of the four ferries also had flowmeters installed); however, the crew did not trust current readings due to lack of calibration of measurement equipment (Femø, Orø), and for the last route, there was no flowmeter installed (Skarø/Drejø)
- Water depth (Electronic Chart Display and Information System, ECDIS)
- Wind direction and speed
- Depth/under keel clearance (Eco-sounder, not present on all ferries).

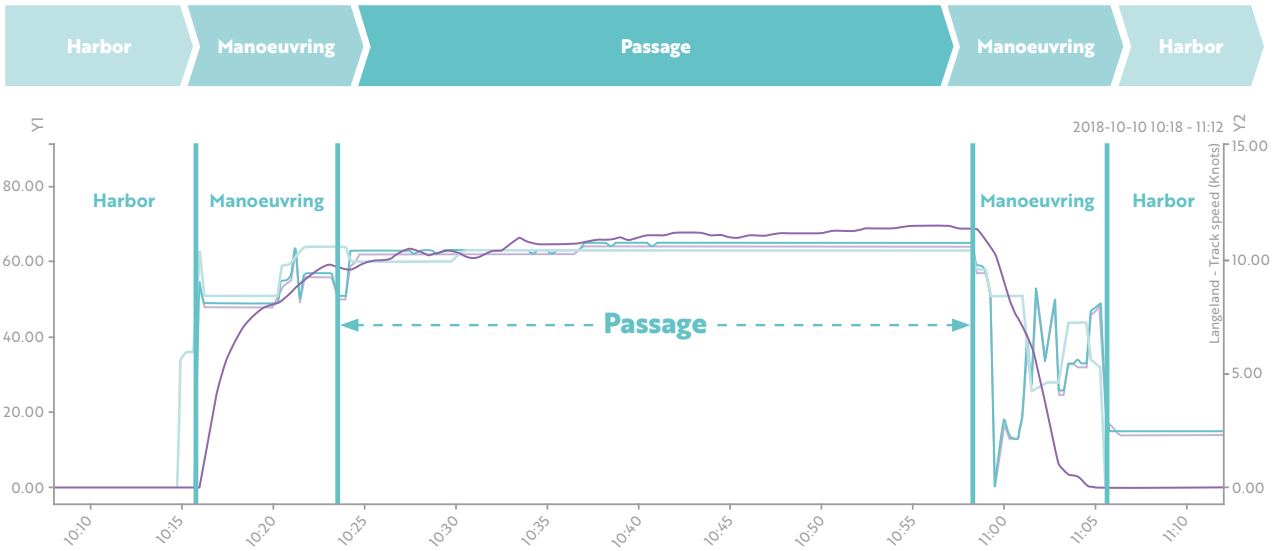
However, few or none of the ferries were able to display a real-time picture of other parameters, such as speed through water (STW), trim, auxiliary engine/shaft generator rpm and power, shore power, accommodation consumption, exhaust gas temperature and engine room temperature, among others. Bunker fuel consumption is typically monitored through manual tank readings or by summing up bills from weekly bunker purchases forming basis for calculating the ratio of fuel consumed to nautical miles sailed, for example, per week and month.

Based on sample voyages, particularly those of the Sejerø, Orø and Femø ferries, and applying the before mentioned model/framework on the gathered data, the following was observed/concluded with the study:

- A typical picture is that the operational modes of manoeuvring and sea passage account for the largest share of the energy consumption. Harbour mode consumption will depend on the length of the harbour stay or overnight consumption, which in many cases will be a shore power connection (where crew sometimes sleep on the ferry).[2]
- During sea passage, the main engine produces the energy, which is consumed as vessel propulsion. The auxiliary engine typically generates power for consumers as bow thrusters, other equipment (for example, pumps) onboard and the accommodation (hotel load). On one ferry, an oil-fired boiler was also used for other purposes, such as, heating the accommodations and ventilating the kitchen. On one of the ferries, a shaft generator was applied instead of auxiliary engines for these purposes.
- Main engine revolutions per minute (rpm), power (not always similar for auxiliary engines) and other measures
- During harbour stays, most of the energy for machinery and onboard systems, inclusive of, for example, heating and lightning, is provided by the auxiliary engine (sometimes the main engine might also remain running) but if duration of the port stay is, for example, more than 15 minutes, as it is for overnight, then shore or no power is used and the auxiliary engine is shut down.
- Several ferries appear over-dimensioned in capacity, but also machinery and equipment size compared to the needs for most of the year or during voyages in general (for example, oversized auxiliary engines), and by commissioning smaller and newer ferries to the routes in the future, there might be a significant potential for saving energy on some of the routes.

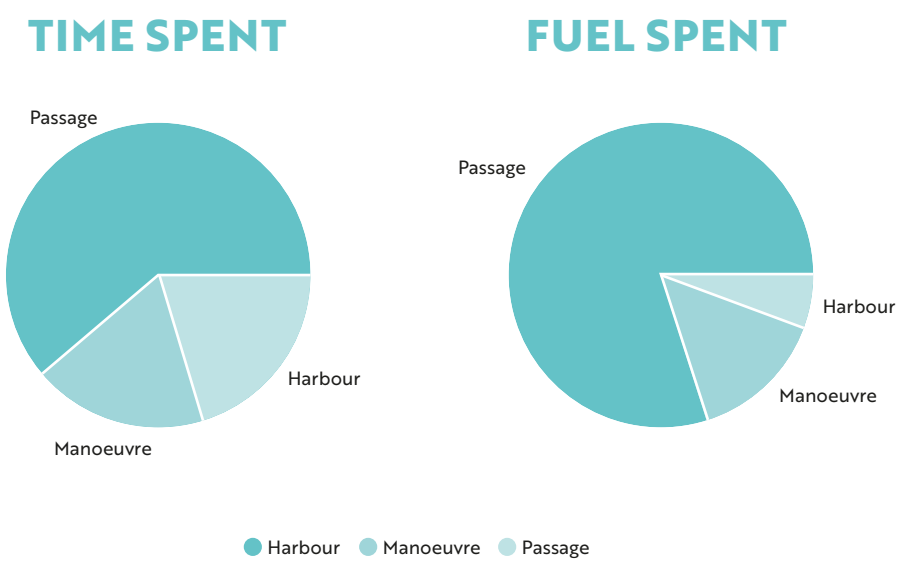
[2]As an example, for the Sejerø ferry, energy consumption was approx. 100 L MGO for the sea passage and 3-5 L for port manoeuvring, and for the port stay, it was approx. 10-40 L MGO (depending on if shore power was connected or if the auxiliary engine was running). The distribution/pattern across the operational modes is, however, very route dependent, and it is different for some of the other routes.

FIGURES 3–4. NORMAL FERRY OPERATION AND THE VOYAGE SEPARATED INTO MODES 'HARBOUR, MANOEUVRE AND PASSAGE', BASED ON OPERATIONAL DATA



Y1: Lever thrusters (100%)
Y2: Tracked speed (knots)

FIGURE 5. TIME AND FUEL SPENT IN DIFFERENT MODES – IN PERCENTAGE OF TOTAL VOYAGE TIME AND TOTAL FUEL CONSUMPTION



Potential of digital technologies for solving the eco-inefficiencies

There appears to be a visible potential for saving fuel by operating the ferries differently. As an example, the following tactics/practices can be applied:

- Replan sailing routes to avoid shallow waters
- Adjust vessel speed depending on water depth during routes
- Equivalently adjust vessel speed depending on wind and wave direction and speed
- Eliminate permanent (over)use of ballast water and operate with more optimal draft/trim without compromising passenger comfort
- Make smoother turns with vessels during sea passage and port manoeuvring
- Execute port manoeuvring without the use of bow thrusters but still not compromising safety/ collision avoidance
- Shut down of equipment not in use
- Optimal distribution of workload between fore and aft propeller for double-ender ferries
- Data-driven hull/propeller cleaning
- Adjusting temperatures in engine room to increase ventilation for turbo charger
- Redesign sailing schedules and transit time to be more eco-efficient without compromising service frequency, or quality for citizens/clients
- Increase use of shore power in port to reduce emissions and noise onboard for the crew and for people living or working in the port zone.

Two examples of the potential of the above-listed tactics/practices are explained further:

- A sea trial for one of the routes under study revealed that main engine fuel consumption, for example, can be reduced by 5% by simply planning and executing a slightly longer route on deeper waters, even with increased speed, so desired transit time still can be met.
- Several sea trials for a double-ender ferry revealed that fuel consumption can be reduced by up to 15% by operating with an optimal push/pull distribution of workload for the aft/fore thrusters compared with the less optimal settings for the ferry (current daily operations are however not that far from optimal distribution of propeller workload).

Based on the data collection and subsequent analysis of sea trial results from three of the four ferry routes, the research team estimated that there might be a significant potential for reducing fuel consumption and emissions of Island Ferries in Denmark by up to 10-20% per route compared with the 2018/2019 baseline totals. Such results can be obtained in a relatively short time based on further implementation of digital technologies for vessel performance monitoring, change of work and continuous improvement practices. Digital solutions will enable ferry operators and land-based staff to make future operational, tactical and strategic decisions, and to adjust, for instance, operational work practices based on robust evidence/data going forward compared with what they are able to do at present. Without robust data sets and artificial intelligence (AI) models providing decision support, which is the case today, it is difficult for ferry operators and leaders to know the precise eco-efficiency impact of alternative work and sailing schedule practices, as well as the efforts needed to retrofit and upgrade ships, machinery and equipment for the ferry routes.

The ferry routes of the Island Ferry Association are owned and operated by local municipalities. The ferry routes do not operate in competitive markets per se; instead, they receive both municipal and government support to remain economically and financially sustainable non-profit entities. As a guiding principle, the ferry routes generate a third of the revenue from tickets sales, another third from municipality support and the last

third from government funding. The ferries' main objective is politically determined: to deliver regular transportation services to islanders situated on small islands around Denmark, which would likely be uninhabited if such services were not provided. For the Island Ferry routes, the main goal of the digitalisation efforts is to achieve a more green and sustainable ferry operation, which is part of the national and local government sustainability and decarbonising strategy, before trying to realise cost savings from more fuel efficient operations which is considered as an added benefit.

For the Island Ferries, the ECOPRODIGI project is an opportunity to raise digitalisation and eco-efficiency to higher levels in close collaboration with academic partners (for example, AAU and SDU), Danish Maritime and vendors; additionally, the improved branding value for local politicians of operating a state-of-the-art eco-efficient fleet should not be underestimated. With the ECOPRODIGI project, the Island Ferry Association aims at achieving a long-term vision for digitalising and decarbonising vessel operations. This implies getting a real-time high-frequency end-to-end solution for digital performance monitoring and decision support tested and demonstrated for the ferry routes. Additional investments in new ships and emission-free propulsion technologies are likely to happen in the longer term to reap significant eco-efficiency benefits for the fleet and remain on the politicians' agendas for the future.

It was found that a digital end-to-end solution must perform for smaller ferries operating in coastal zones where it should enable high-frequency digital performance monitoring of ships, engines and systems. The solution concept should allow auto logging of up to 50-100 channels of data with high-frequency onboard sensors, as well as local storage, connectivity, onshore cloud-based storage and subsequent data cleaning, modelling and analysis via state-of-the-art AI models/scripts. Finally, results and decision support recommendations should ideally be visualised and user-friendly at the same level as the most advanced engines, equipment and vessel performance monitoring platforms typically applied for equivalent ships at the moment (see, for example, **www.blueflow.se**). The following elements of the solution have been selected for further development and testing within the scope of ECOPRODIGI:

- **High-frequency, low-cost, scalable, flexible and technically robust end-to-end digital Internet of Things (IOT) solutions for logging of bridge and engine/systems data, local storage, connectivity via 4G network in coastal zones and onshore cloud-based storage of data in a data warehouse. Use of complementary national Automatic Identification System (AIS), ocean and weather data sources to cross-validate data quality when possible.**

- Display/visualisations of vessel and engine performance under various navigational and operational conditions based on high-frequency data which can support crew onboard and technical managers in executing their daily vessel operations in a more eco-efficient manner, as well as enable condition-based, predictive maintenance of hull, propeller, machinery and equipment.
- AI models providing decision support for operational/tactical/strategic decisions to be made by crew onboard and land-based staff and service personnel.
- Dashboard/visual reports which quickly and intuitively provide updated (real-time) feedback to vessels and crew on sensor data quality and vessel performance for selected metrics/key performance indicators (KPIs) and enable staff to make ongoing improvements in energy efficiency.
- All of the above elements integrated into an existing open source software solution developed by one of the academic partners, SDU.
- Training modules, as for example E-learning applications, which can train crew onboard in 'theoretical and/or methodological' aspects of operational data gathering and digital performance monitoring, as well as ensure that they acquire continuous improvement, i.e.'kaizen', skills to work with ongoing energy efficiency improvements as part of their daily work. Development and testing of such modules might however become part of future work to be done in the project.

Regarding the benefit case for the listed initiatives, a business case and set of visionary/stretch targets have been set for ships, engines and crew/staff within test scope during the project's implementation period:

- Reduction in fuel consumption and emissions for vessels by 10-20% across ferry routes compared with the 2017/2018 baseline due to improved models for vessel operations and hull, propeller and engine performance, as well as excess fuel consumption.
- Prevention of rare but business- and safety-critical and expensive engine breakdowns, seriously impacting service levels for islanders and generating additional costs for replacement ferries (+2,000 EUR/day).

After testing and implementing new digital solutions and work processes, a formal evaluation is planned of how the initiatives meet the targets set for fuel consumption, emissions and cost savings/return of investment. As a follow-up to the results, a range of smaller and medium-size Danish ferry operators, representing both public and private businesses, will receive a questionnaire from the research team with the purpose of creating a broader overview of the current state and progress regarding the application of digital performance monitoring solutions and eco-efficient work practices for vessel operations.

2.2. CASE J. LAURITZEN

Description of the case

The second industry end-user in the technology case, 'digital performance monitoring', is the shipping company J. Lauritzen (from now on Lauritzen), which operates a modern, diversified fleet of bulk carriers and gas carriers. The company is owned by the Lauritzen Foundation, a commercial foundation with the objective of supporting shipping, culture, social humanitarian work and education. The company employs a staff of approximately 1,000 employees of many different nationalities both at sea and onshore. The headquarters are in Copenhagen, and there are also offices in the Philippines, Singapore and the USA. At the end of year 2018, the company operated/controlled 109 vessels and employed 167 employees onshore and 638 seafarers onboard either on their own or bareboat chartered vessels. Revenue was 565 million USD, but came out with a loss of –24 million USD.

The project focuses on the gas carrier business, which per yearend 2018 consisted of 34 vessels of which 14 were the company's own vessels. The particular focus is on six ethylene (E-class) gas carriers and options for digitalising data capture, performance monitoring and decision support for these ships.

Current state and the most critical eco-inefficiencies

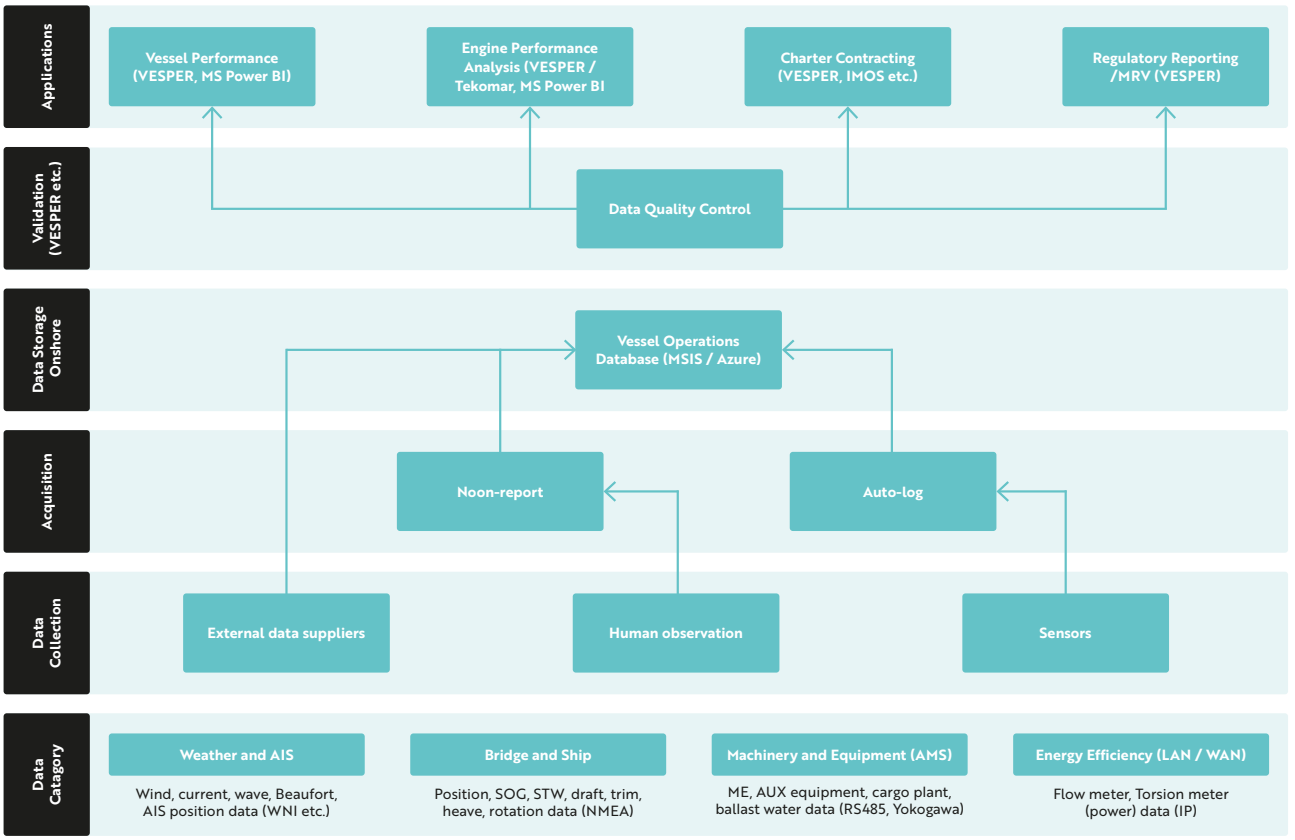
Over the last years, Lauritzen has invested significantly in digital performance monitoring for their fleet with the objective of achieving operational excellence and improving on KPIs for safety, operational costs and customer service. They embarked on their journey of digitalising their vessel operations and performance monitoring almost a decade ago in order to become more fuel-efficient and increase reliability of operations. Today, performance monitoring of the fleet is enabled via two complementary digital solutions: (1) noon report-based[3] performance monitoring using the Vesper platform (Vessel Performance Solutions™, Lyngby, Denmark) and (2) autolog-based performance monitoring which is Lauritzen's own developed solution **(see Figure 6).**

An additional input into the Vesper platform tested as part of the ECOPRODIGI project are datasets from sources such as AIS and weather forecast/hindcast providers which enable cross-validation of noon report data and improved reliability/validity of performance models and results.

In the first digital solution, instruments, for example, flow meter values are read on a daily basis, and a dataset is entered into a HTML form and submitted as mail files to onshore staff via satellite connection where the data are stored in Lauritzen's proprietary MS SQL Server database. From the data warehouse, data are then uploaded as XML files into the Vessel Performance Solutions™ Vesper (cloud-based) platform, where performance monitoring and analysis are enabled. The Vesper software platform consists of a set of modules enabling users to track individual ship or fleet performance for KPIs, such as hull and propeller (fouling) performance, specific fuel oil consumption (SFOC) of engine, base load consumption, charter party, boiler performance, bunkering and excess fuel consumption. The platform also allows users to conduct ad hoc extensive analysis of operational data quality from the vessels, and produce updated fuel tables, extract charter party statistics for commercial purposes, consolidate monitoring, reporting and verification (MRV) reports for the authorities and perform other necessary actions. The performance department, as well as the technical managers, are the main users of the platform on a daily basis, and they are able to track vessel performance and take required actions to improve energy and fuel efficiency in collaboration with crew onboard the vessels. The core part of the Vesper platform consists of a number of physical, mathematical and statistical models called the 'Vessel Performance Analysis engine' (VPAe) which convert input data into a robust overview of the energy efficiency of the ships catering/normalising for factors such as wind, weather and the operational profile (for example, cargo, draft and trim) of the vessels. The VPAe also provides a set of recommendations for how to further reduce excess fuel consumption.

[3]Noon reports are completed either when the sea state is changed (sea, port manoeuvring, port state) or approximately once per day (at noon).

FIGURE 6. ILLUSTRATION OF LAURITZEN DATA VALUE CHAINS AND VESSEL PERFORMANCE MONITORING SYSTEMS



Lauritzen and another shipping company, Torm, recently reported that the development and implementation of the Vesper platform to match their needs, which was part of a Danish government-supported research and innovation project called BlueInnoship, over a four year period (2015-2019), saved the companies 4-7% in fuel consumption (see Vpoglobal 2019).

In the second solution, more than 10 of Lauritzen's ships have had data loggers (MW100 acquisition unit loggers [Yokogawa, Tokyo, Japan]) installed onboard to enable high-frequency, two-minute interval logging from bridge systems and engine equipment. Data sources include power meters (energy production), flowmeters (fuel consumption) and torsion meters (power), as well as parameters such as position (GPS), speed, wind direction, and under keel clearance which are typically displayed at the bridge (via NMEA [National Marine Electronics Association] standards). The data loggers are currently being used in combination for logging average (or accumulated) values from more than 200 sensors/data channels onboard the vessels every 2 minutes, and size and scale of the data sets captured are very different to noon report data (approx. 720 logs vs 1 per day). Results from data loggers are written into a binary file with time stamps (time series data), and every 24 hours the file is closed, and an email is sent via mail gateway and 3G/4G or satellite connection onshore with the result. In the office, data are imported into Lauritzen's MS SQL Server (a sort of data warehouse), and deployed and analysed on a more ad hoc basis using MS SQL Server Reporting Services (SSRS), MS SQL Server Analysis Services (SSAS) (data are structured into cubes for fast access) and MS Power BI functionalities.

Lauritzen has developed several modules and scripts which support a more 'refined/detailed' monitoring and analysis of sensor data quality, vessel operations and performance based on the autologged data sets. However, at the current stage, these modules and scripts have not progressed to the extent and quality of the Vesper platform. **See Figure 7** for further information about the current autolog performance monitoring set-up of Lauritzen.

Potential of digital technologies for solving the eco-inefficiencies

For Lauritzen, there is a continuing effort to enhance their digital set-up for digital performance monitoring as an essential element in making their fleet more cost competitive, green and fuel efficient in the future. The company's fleet operates in very competitive markets for either dry bulk cargo or LPG/ethylene products where freight and vessel charter rates are generally on a low level and are more volatile compared with what they were a decade ago (see e.g. Danish Ship Finance 2018).

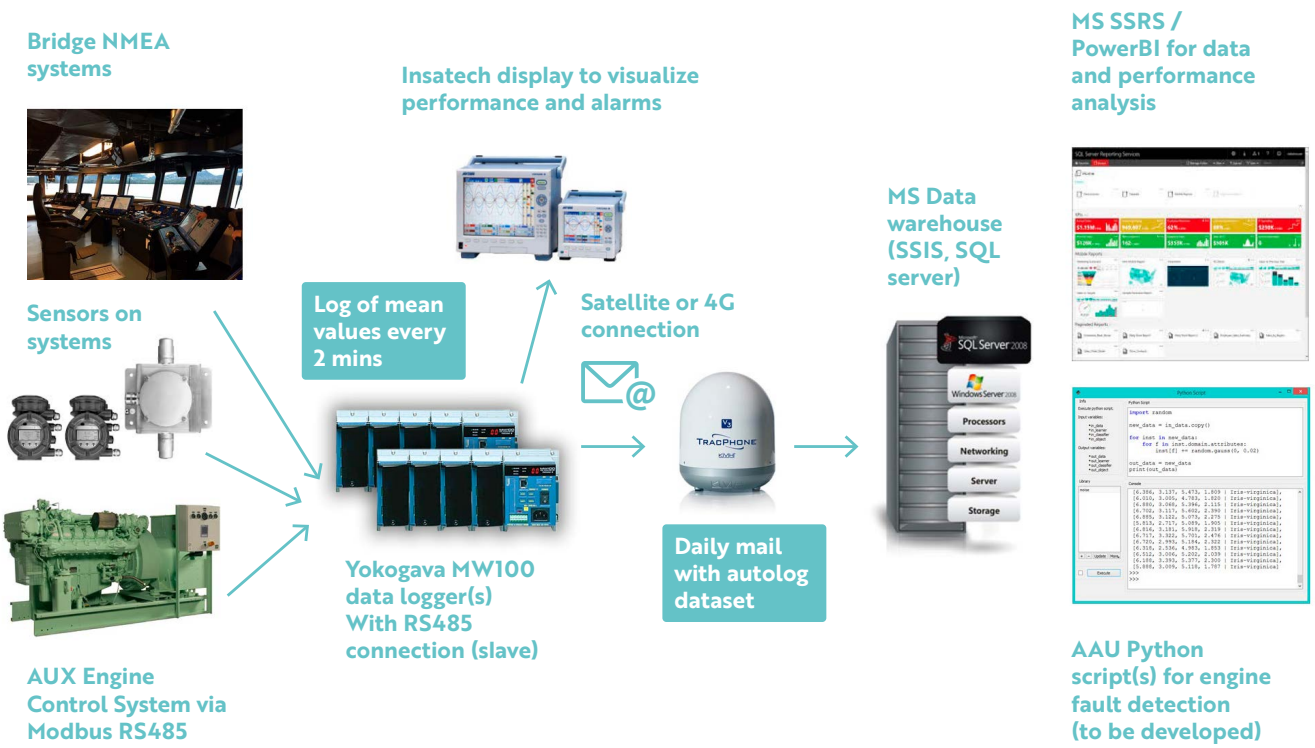
In addition, bunker prices have over the last decade been high and volatile, and they are likely to increase in the near future, particularly for MGO and VLSFO, which in the future will be used by all Lauritzen vessels (of smaller size), and competitor fleets which are unlikely to get scrubbers installed in the attempt to comply with the International Maritime Organization (IMO) 2020 sulphur cap regulation.

To remain competitive and profitable, it is thus critical for Lauritzen to improve its fuel efficiency and reduce its operational expenses (OPEX) on an ongoing basis. For Lauritzen, the ECOPRODIGI project is an opportunity to raise digitalisation to higher levels in close collaboration with academic partners (for example, AAU and SDU) and vendors (Vesper and other enterprises), and reap additional eco-efficiency benefits from years of investment and successful implementations. With the ECOPRODIGI project, Lauritzen particularly aims at achieving their long-term vision for digitalising and decarbonising vessel operations, which implies getting a real-time high-frequency (1 Hz) end-to-end solution for digital performance monitoring up running for the whole fleet in the coming years.

Such a digital end-to-end solution must perform for ocean-going vessels operating and trading all over the world on a 24/7 basis, where it should enable high-frequency digital performance monitoring of ships, engines and systems. The solution concept should allow autologging of 200-500 channels of data with high-frequency onboard, as well as local storage, connectivity, onshore cloud-based storage and subsequent data cleaning, modelling, analysis via state-of-the-art AI models and scripts. Finally, results and decision support recommendations should be visualised and be user-friendly at the same level as the currently most advanced engine, equipment and vessel performance monitoring platforms (such as the interfaces in Vesper). The following elements of the solution are the focus of development and testing within the scope of ECOPRODIGI:

- **High-frequency, low-cost, scalable, flexible and technically robust end-to-end digital IOT solutions for logging of bridge and engine and systems data, local storage, connectivity via satellite/4G network, onshore cloud-based storage of data in data warehouses.**
- **AI model/script for prediction of engine performance problems and/or faults based on high-frequency data (1 Hz) which can support crew onboard and technical managers with condition-based and predictive maintenance, and thereby improving engine and equipment uptime (preventing breakdowns) and performance in due time, as well as reducing maintenance and repair costs, for example.**
- **AI models performing better (with less scatter, improved accuracy and confidence) than current VPAe models for estimating hull and propeller performance (added resistance) and excess fuel consumption of vessels due to such problems as fouling, hull and propeller wear. Enhanced models are developed not only relying on noon reports, but also hindcast weather and AIS position data and optionally high frequency autolog data.**

FIGURE 7. ILLUSTRATION OF LAURITZEN DATA VALUE CHAIN AND VESSEL PERFORMANCE MONITORING SET-UP FOR AUTOLOG DATA



- 'Vesper Performance Onboard Solution', which will be a visual report/dashboard based on Vesper which quickly and intuitively provides real-time feedback to vessels and crew on sensor/noon report data quality and vessel or engine performance for selected metrics and KPIs and enables staff to make ongoing improvements of energy efficiency.
- Training modules, for example E-learning applications which can be used for training crew onboard in 'theoretical/methodological' aspects of operational data gathering and digital performance monitoring, as well as ensure that they acquire kaizen skills to work with ongoing energy efficiency improvements as part of daily work. Development and testing of such modules might come later in the project.

Regarding the benefit case for the listed initiatives, a business case and set of visionary/stretch targets have been set for the following factors within test scope during the project's implementation period:

- Reduction in fuel consumption and emissions for vessels of 2-4% compared with the 2017/2018 baseline due to improved models for hull and propeller performance.
- Improvement of SFOC for main/auxiliary engines and emission reductions of 1-3% due to improved diagnosis of poor engine performance and fault detection and proactive and/or timely maintenance.
- Prevention of rare but business- and safety-wise critical engine breakdowns.

- It is also expected that 'Vesper on Board'/ Dashboards solutions and related training programmes on the topic of digital performance monitoring for the crew will contribute to additional reductions in fuel and energy consumption and vessel OPEX when implemented during/after the project period. These initiatives will enable crew to quickly detect and mitigate data quality issues (errors in sensor/noon report data) for the performance monitoring models. Also, they will provide valid and real-time information about energy performance for selected KPIs and provide decision support on how to close gaps to targets, thereby enabling crews to engage in kaizen and to operate vessels and engines in a more eco-efficient manner (in line with the Ship Energy Efficiency Management Plan [SEEMP] and MRV Scheme intentions).

In this case, as well, after testing and implementing new digital solutions and work processes, a formal evaluation is planned of to what degree the initiatives are either accomplished or are about to accomplish the visionary targets set for fuel consumption, emissions and cost savings/return of investment.

2.3. CHALLENGES AND REQUIREMENTS RELATED TO DIGITAL PERFORMANCE MONITORING

In order to be able to implement the new digital technologies successfully and achieve target eco-efficiency benefits several factors are required and challenges need to be solved. Several of the requirements and challenges are similar between the two cases, Island Ferries and Lauritzen, but also some differences appear.

Digitalisation and eco-efficiency must remain an essential part of the Danish national and local political agenda as well as part of the business and operations strategy of Lauritzen in the years to come if digital implementations are to proceed and eco-efficiency results achieved. In terms of the individual Island Ferry routes, they will thereby remain focused on digitalising the fleets and reducing fuel consumption, emissions and operational costs. Increased pressure to minimise public spending in rural areas might also put increased pressure on local municipality and ferry route budgets, which could further indirectly incentivise a reduction in fuel consumption, maintenance and repair costs, among other things. As regards Lauritzen and also most other shipping companies, including their competitors, the focus on digitalising the fleets and reducing fuel consumption, emissions and operational costs is likely to continue. This will also be further promoted by industry market and regulatory requirements currently being developed by the European Union (EU) and IMO. As reported in various studies, ownership structures and commercial models of the industry might however still act as a hindrance for further investments in digitalisation or might imply a slower adoption of eco-efficient execution of vessel operations for the industry (see the following publications: Poulsen & Johnson 2015; Poulsen & Sampson 2019).

With regard to both cases, from a technical perspective, the solutions being piloted for data capture, logging and data warehouse/cloud-based storage must meet requirements for performance (uptime, flexibility, scalability) and be sufficiently robust so they can provide high-frequency data of good quality on a daily basis and for reasonable costs to decision makers onboard and onshore both in coastal zones and independently of where vessels of the shipping company are trading in the world. It is relatively easy to acquire and purchase individual technology components from different vendors, but it is a much more resource-demanding and difficult challenge to integrate these components and ensure that they perform robustly in combination. Also, this is made even more complex when there is an overall lack of standards for, for example, operational data capture, storage and performance monitoring in the industry.

In both cases, domain expertise in shipping and engine operations combined with sufficient data availability and quality of high-frequency data is required for researchers and technology vendors to develop AI models which really can perform with high accuracy and quality. AI models of good quality can thus guide decision makers in practice when they have to optimise vessel and engine and/or equipment operations, maintenance and repair as well as deliver eco-efficiency benefits.

As far as both cases are concerned, researchers and industry professionals must succeed in building AI models and scripts, which perform well on set criteria for not only one or a few ferries or for sample vessels in a short sample period, but also for larger group of ferries and vessels, on voyages with variable data sets and for longer time periods.

Also, it is essential in the longer term that the Island Ferries and academic or industrial software/AI model vendors form a business partnership in order for vendors to maintain knowledge on data capture technologies, models and software visualisations on an ongoing basis. Similarly, shipping companies and software/AI model vendors need to enter into a business partnership enabling them to adjust and fine-tune their knowledge on data, models and software on a constant basis.

For the project to succeed in the Island Ferries case, it is essential to demonstrate that AI models can be integrated and converted into production-ready (tested) (open source) software, including visual tools, which are quick and user-friendly for both the crew on-board and the staff onshore to apply. The shipping companies and vendors, on the other hand, need to get AI models integrated to the production-ready software and develop visual tools, which should not only be quickly applied by

Photo: Tapio Karvonen

but should be more user-friendly for the staff and crew. As regards the case of Island Ferries onshore staff and crew are ultimately accountable for meeting eco-efficiency and budget targets set by the municipality and in the case of the shipping company, they are accountable for reaching business- and eco-efficiency targets set by the company for the short and long term. If data and recommendations are not transparent and trustworthy, staff in both cases are likely to rely more on their gut feeling and years of working experience when taking actions to solve problems.

As far as both cases are concerned, training users such as onshore staff and onboard crew in the discipline (theory/methods) of digital vessel performance monitoring, as well as in the developed applications and modules, is critical for later implementation successes. As much as possible, training efforts should be tailored to individual availability (in time and space) and requirements and emphasise building job-related skills.

Furthermore, in the Island Ferries case, the fuel typically used for these ferries is MGO due to SECA regulations, and as it remains untaxed in Denmark, the cost of fuel is approximately 50% lower than standard diesel fuel, which in principle gives the ship owners and operators less incentive to save fuel despite political intentions. However, it enables the municipalities to offer an improved service for the islanders.

Let it be mentioned also that in Island Ferries case electricity delivered to ships for use in port has a tax exemption. The exemption is given to the supplier of the power in port holding the 'consumer number' (in Danish: 'aftagenummer'). Transferring this tax exemption to the shipowner will encourage the ship owners/operators to use an onshore power supply, as the electricity price becomes competitive with the already tax-exempted marine fuel. Thus, a level playing field should be ensured in the long-term.

3. OPTIMISING CARGO STOWAGE PROCESSES

Description of the case and methods

The second technology case in ECOPRODIGI includes the loading, stowage and discharge processes of ships at ports. The industry end-user in this specific case is DFDS, which was founded in 1866, as a merger of three independent shipping companies, and is today one of Europe's largest shipping companies. DFDS operates one of the largest networks of roll-on/roll-off passenger (RoPax) and roll-on/roll-off (RoRo) ferry routes in and around Europe, including their own terminals in key locations. All routes operate on fixed schedules and are strategically located to provide freight services to forwarders, haulers and manufacturers of heavy goods. Passenger services include overnight and day crossings. In 2018, the revenue of DFDS was 15.7 billion DKK/2.109 billion EUR, and EBITDA[4] was 3 billion DKK/401 billion EUR. Its total number of employees is approximately 7,200.

DFDS is organised into two divisions: the ferry division and the logistics division. The ferry division operates (mostly owned vessels) 53 ferries of up to 6,700 lane meters in capacity sailing on 22 routes in geographical areas of:

- North Sea
- Baltic Sea
- English Channel
- Mediterranean Sea

The ferry division had the following key figures in 2018:

- Revenue: 11.1 billion DKK
- Routes: 24
- Freight lane meters: 40.1 million
- Passengers: 5.4 million

The logistics division provides European door-to-door transport solutions to manufacturers of consumer and industrial goods. The main activity is providing full- and part-load solutions that are ambient and temperature-controlled. Logistics solutions are developed in partnership with retailers and producers, including warehousing services and just-in-time concepts. Solutions are supported by a European network of road, rail and container carriers and DFDS's ferry routes. The logistics division had the following key figures in 2018:

- Revenue: 5.3 billion DKK
- Sales offices/warehouses: 31/18
- Units transported: 56
- Tonnes transported: 417,000.

For the ECOPRODIGI project, the focus has been on the ferry division, and particularly cargo and not passenger transport. A team of researchers and industry experts from AAU, SDU, University of South-Eastern Norway (HSU), Kockum Sonics and Logimatic, together with DFDS staff, conducted a set of visits to and studies of several ferry routes and terminals from autumn 2017 to spring 2019 to investigate the current state of the end-to-end stowage process, systems and baseline eco-efficiency performance.

The scope of the visits/studies covered the following routes:

- Karlshamn–Klaipeda
- Gotherburg–Gent/Immingham
- Esbjerg–Immingham
- Vlaardingen–Immingham/Felixstowe.

[4]EBITDA = Earnings Before Interests, Taxes, Depreciation and Amortisation

Moreover, meetings and workshops were organised among the different parties. The project team mapped processes, collected and analysed several sets of operational data from sample routes, terminals, and ships, such as, booking data, terminal and vessel operations data. The main findings are presented in the following sub-sections.

Current state and the most critical eco-inefficiencies

DFDS joined the ECOPRODIGI project to reap eco-efficiency benefits from further integration and digitalisation of their logistics processes. DFDS has invested in digital technologies and processes as well as sustainable shipping solutions (for example, installing scrubbers on several ferries) over recent years, and still maintains a strategic focus on operating their ferries and related logistics processes in a more eco-efficient manner with less CO2 emissions. The company has a threefold strategy of supporting the marine environment, being a responsible neighbour and improving air quality in respect to the Sustainable Development Goals of United Nations.

Project scope was in line with DFDS's determination to map the end-to-end cargo stowage process, which includes the following sub processes:

- Booking of cargo units (for example, unaccompanied trailers, accompanied trucks, vehicles, Mobile Loading Platforms [MAFIs], Out of Gage [OOG] and dangerous or heavy cargo)
- Gate in of units in port
- Positioning of units in yard/terminal
- Planning of stowage onboard vessel
- Load planning/dispatching of tugs
- Load and lash cargo units (if required)
- Vessel departure, operations and arrival
- Discharge planning/dispatching of tugs
- Unlash and discharge cargo units
- Positioning of units in yards
- Pick up of trailers
- Gate out of terminal

In combination with the on-site visits, the observations, process and system maps, and datasets enabled the team to make following observations regarding the end-to-end cargo stowage process:

- Information/data on cargo unit dimensions, weight, position, conditions, status as well as asset (tugs and vessel deck and cargo holds) geometries across the end-to-end process are not sufficiently available in digital formats and quality on a real time basis to allow for optimal planning and execution of stowage, loading and discharge processes in 1/2 or even 3 dimensions.
- Routes and terminals apply for historical reasons only to some degree standardised process and identical set of IT tools for planning of stowage, loading and discharge operations; for several routes, local solutions are frequently applied for one or more tasks (as in the case of the port of Esbjerg and Karlshamn, for example).
- Organisational setups and work processes also vary from route to route due to for example DFDS not being owner or operator of all terminals.
- There are disconnects in the data flow and formats across typical applications applied across functions (bookings, Phoenix), terminal operations (GTMS), stowage planning and stability (Loadmaster™), and voyage performance data (Sertica) causing extra work and lack of real time data input for specific work tasks.
- Complete systems and data integration or sharing with customers and suppliers (for example, freight/haulage companies) appears to be lacking, which potentially impacts possibilities for optimising client haulage as well as DFDS operations.
- There is a dedicated work force on all sites and onboard vessels relying on existing technology and years of robust work practises; they are, however, not sufficiently equipped with decision support tools, such as, using AI models to forecast cargo unit arrival patterns and time, and optimise or simulate stowage, loading and discharge work. For example, optimisation or simulation models could potentially be used to simulate cost and emission impacts of applying alternative strategies for loading and discharging vessels with dual cycling methods (loading and unloading operations are conducted simultaneously, meaning that each tug master picks up a trailer to discharge/load after loading/discharging one if possible to minimise inefficiency in tug utilisation).
- There appears to be a professional and safe execution of vessel and terminal operations, but there is still room for further improvement when it comes to optimising vessel stowage, gaining efficiencies in the terminals and reducing port stay duration and ballast water intake. All these aspects have a significant impact on (tug master and vessel) fuel consumption as well as emissions.

Potential of digital technologies for solving the eco-inefficiencies

Based on analysis of the current state, the project team drafted a vision for the year 2025 which depicts how DFDS can operate a more digital, integrated and eco-efficient end-to-end stowage process in the future **(see Figure 8).**

In order to achieve the vision, the following set of systems and data integration initiatives and digital solutions are to be accomplished in the shorter and longer term:

- Smart gates, which in addition to existing Optical Character Recognition (OCR) functionality can validate cargo unit ID, weight, dimensions, and condition of cargo units by using several means, such as, cameras, Lidar technologies, weight bridges, and AI algorithms.
- Digital data capture of cargo unit positions and conditions at the yard: DFDS is in parallel with ECOPRODIGI engaged in pilotings where cargo and yard information is collected using drones. The software is developed by an external vendor but data and information gathered will support the ECOPRODIGI project.

FIGURE 8. VISION 2025 FOR THE END-TO-END STOWAGE PROCESS

VISION 2025 –KEY ELEMENTS

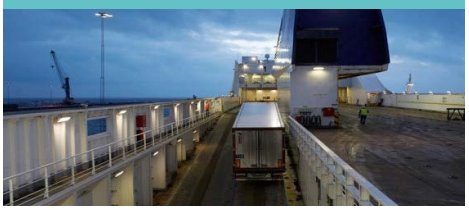
Real time tracking of arrival of cargo units

Smart Gate validates cargo ID, damages, weight and dimensions (2D / 3D)

Cargo unit location and conditions tracked at terminal and on ship

Planning of port, tug and vessel operations using optimisation and simulation tools (2D / 3D)

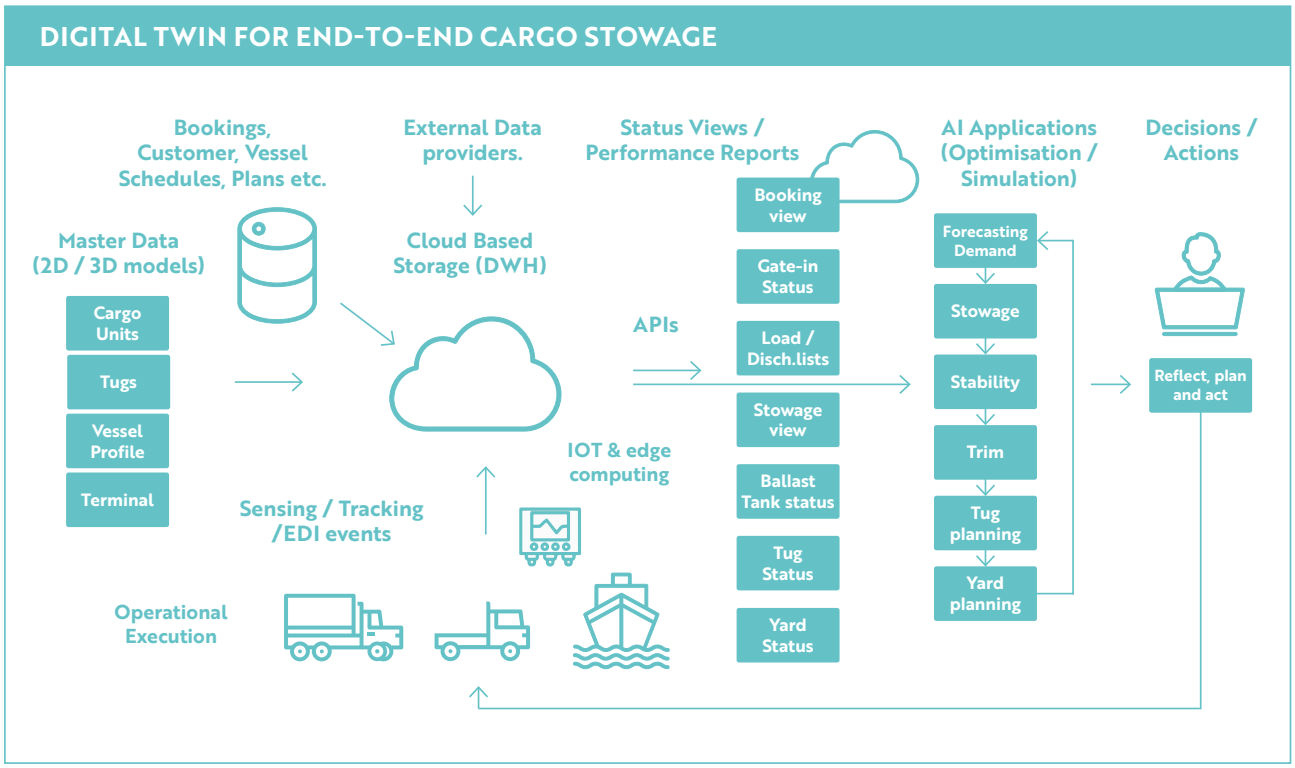
Efficient loading and discharge process



Valid predictions of cargo unit arrival times shared with customers

- Digital data capture of cargo unit positions onboard vessels by using cameras installed on vessel decks or tug masters.
- Cheap dual or triple band tracking devices with long battery lifetime which potentially can be mounted on trailers and/or trucks and function for not only ferry operations, but also for other transport modes.
- Systems integration and data sharing across applications in the end-to-end stowage process, for example, deploying identical data platforms and sharing data formats across applications for bookings, terminal operations, stowage planning and stability calculations, voyage data and performance monitoring. As one example, the FUELSAVER module of Kockumation software onboard vessels, which can potentially be applied in DFDS to indicate when to optimise operations on the sea leg, if it bases its calculations not only on trim optimisation data from the towing tank test results, or CFD calculations, but also on empirical data exchanged from the DFDS systems.
- Develop end-to-end cargo stowage 'digital twin' models, particularly simulation and optimisation simulation models in not only 2D but also 3D which can be used by decision makers in order to run simulations of alternative discharge/loading methods (for example, dual cycling) as well as terminal and vessel designs and, thus,

FIGURE 9. SKETCH OF POTENTIAL DIGITAL TWIN CONCEPT FOR END-TO-END CARGO STOWAGE PROCESSES PRESENTED AND DISCUSSED AT THE DFDS WORKSHOP DURING 2019



develop more optimal and eco-efficient plans for port operations and vessel stowage. Realising a digital twin for end-to-end cargo stowage, which can support multiple use cases, requires including 'enriched' data models of cargo units, vessels, yards, tugs, and real-time data collection describing the position of all cargo and involved operations. See also Figure 9 for a sketch of a future digital twin model.

- Increase use of simple models to support decisions and predict impact of decisions. For example, models for predicting expected discharge (ETD) time of cargo units/trailers upon vessel arrival might be of relevance for clients. Such models might be based on data of loading sequence and time stamps of cargo units from previous port of departure, available tugs at arrival ports and other factors.(Jia et al. 2019). As another example, it might be possible to apply simple regressions models to forecast the amount and time of cargo units arriving per vessel departure better than we can currently.
- Development of methods for simulation-based training and skill building of vessel crew, port and HQ office staff.

The ECOPRODIGI project will finish at the end of 2020, and it was from the outset known that DFDS would not get all aspects of the Vision 2025 developed and tested within project duration. The project team have, thus, as part of Work Package 3 ('Solving eco-efficiency bottle-necks through digital solutions' i.e. the implementation phase) taken time to prioritise the solutions in scope for the remaining part of the project. Regarding the benefit case for the initiatives which will become part of WP3, a business case and set of visionary/stretch targets have been set for the following issues within test scope during the implementation period of the project:

- Accurate and digital information about cargo ID, dimensions, weight, condition, content and position on a real-time basis, as well as improved decision support, enables vessel cargo officers and terminal planners to realise more accurate vessel stability calculations while stowing the vessel. This can potentially enable vessel cargo officers to use cargo units for balancing the vessel instead of only ballast water, as well as to minimise the need for an additional buffer of ballast water to achieve desired vessel stability without compromising safety and passenger comfort. AAU and Kockum Sonics did a deep dive investigation for one route, two vessels and nine departures. Using Loadmaster™ software (Easecon/FuelSaver module) to simulate and optimise the use of ballast water without even taking cargo units into account, it was estimated that the potential ballast water saving might be up to around ~2% fuel saving per route.

- Digitalising data sources, integrating different applications, and moving in the direction of implementing digital twins including simulation/optimisation models will also allow terminal planners and vessel cargo officers to plan and execute end-to-end stowage operations more efficiently. Efficiencies might be gained in the form of improved utilisation of assets (including for example, tugs, crew, and yard space) as well as less driving of cargo units in terminals, but also shortening of port stays enabling DFDS to sail slower and save fuel on the sea leg for the ferries. DFDS's own studies indicate a theoretical potential for reducing fuel consumption and emissions from 2-10% across sample routes and ferries in the near future by sailing slower on the sea leg. For example, for the Copenhagen–Oslo route, shortening the port stay by only 15-30 minutes might allow the equivalent of up to 5% of fuel savings per voyage.

- Digitalisation can also enable better service benefits for clients. By knowing the exact load sequence and positions of cargo units on a ferry at the departure port, as well as being informed in due time about available tugs at arrival port, DFDS can more precisely provide an estimated ETD of their cargo units to their clients. The clients can therefore plan dispatching and routing of trucks in a more eco- and cost-efficient manner.

As mentioned earlier, digitalisation, sustainability and eco-efficiency of their ferry and logistics operations will be essential elements of DFDS's growth, profitability and CSR strategy in the coming years (see DFDS [2019]). DFDS is a stock listed company where the majority of the shares are controlled by the Lauritzen Foundation with a long-term mission and strategy in place for donating funds to the public from the dividends received from its investments in various (shipping) businesses.

DFDS operates in competitive markets for short sea shipping, where a portfolio of other RoRo and RoPax shipping operators (for example, Stena Line, Color Line, Viking Line, TT Line, Fjord Line, Tallink and PolFerries) compete for market share on the different routes. The RoRo/RoPax industry is however not currently as competitively intense as the container shipping industry, as there is a reasonable balance between vessel tonnage availability and market demand and growth. The situation is however likely to change in the coming years as several of the bigger ferry operators in the EU currently have new buildings, and particular so-called 'Mega' RoRo vessels with up to 7,000 lane meter capacity. Shipping segments such as large RoRo car carriers and short sea container shipping can also be considered a competitor to DFDS and other ferry operators, as they offer competing/substitutable products on many routes.

DFDS and other ferry companies in EU mainly operate their ferries in coastal zones and in waters where SECA and stricter requirements for safety, water and air pollution are applied (for example, the Baltic Sea) which the company must comply with in the coming years. DFDS has, over the last decade, invested significantly in scrubbers for their fleet and will continue to do so (see, for example, DFDS [2018]).

In addition, IMO is imposing new regulatory requirements on the shipping industry in order to reduce CO2 emissions by 50% for the whole industry by 2050, as well as a sulphur cap of 0.5% by 2020. It has also initiated the IMO Ballast Water Convention. Thus, there is a significant regulatory and competitive incentive for DFDS in digitalising

their terminal and vessel operations further in the coming years as this potentially will bring them improved asset and resource utilisation, reduced operational expenses and emissions, as well as service and brand benefits towards their clients, society and stakeholders in a broader sense.

Challenges and requirements

The following steps are required in order to be able to implement new digital technologies successfully and achieve eco-efficiency:

Similarly to the factors presented in Case 1, from a technical perspective, the digital data capture solutions being piloted must meet requirements for performance (uptime, flexibility, scalability, quality) and be sufficiently robust so they can on daily basis and for reasonable costs provide real-time quality to multiple applications in the end-to-end cargo stowage processes. It is relatively easy to acquire and purchase individual technology components from different vendors, but it is a resource-demanding and difficult challenge to integrate the components so they perform robustly in combination. This is also made more complex as there is a general lack of standards for, for example, operational or logistics data capture, storage and performance monitoring in the industry.

Distributed ownership of assets and lack of willingness to share data across the end-to-end cargo stowage process (haulage companies, ports, terminals, ship operators) is likely to impact speed of adoption of digital and eco-efficient solutions for this segment of the shipping industry.

Domain expertise in shipping and engine operations combined with sufficient data availability and quality, as well as computing power, is required for researchers, vendors and DFDS to develop AI models which can perform and quickly produce decision recommendations with high accuracy and quality to terminal and vessel cargo officers.

Similarly to case 1 results, researchers and industry professionals must succeed in building AI models and scripts, which perform well on set criteria for not only a small sample but broader set of vessels, terminals, data sets, voyages, and time periods. Furthermore, it is critical in the longer term for shipping companies and software/AI model vendors to enter into business partnerships enabling them to adjust and fine-tune data capture, models, and visualisations on an ongoing basis.

Also in line with requirements presented in Case 1, it is critical that terminals, DFDS and vendors can get AI models integrated into production ready (tested) software and develop integrated visual tools which are quickly applied by and user-friendly for crew onboard and staff onshore. Onshore staff and vessel crew are ultimately accountable for meeting business and eco-efficiency targets set by the company for the short and long term, and if data and recommendations are not transparent and trustworthy, they are likely to rely more on their gut feeling and years of working experience when taking actions to solve problems.

Training of terminal and onboard crew as well as clients in the benefits, principles and methods of digital and integrated logistics can be critical for implementation success at a later stage.

Regulatory frameworks which exist in, for example, the container shipping industry, such as the Safety of Life at Sea (SOLAS) amendment covering container weighing regulations, might also benefit the RoRo and RoPax industry from a safety as well as fuel consumption and eco-efficiency perspective. In container shipping, a packed container is not allowed to be loaded onboard vessels unless its verified gross mass (VGM) has been provided by the shipper to the ocean carriers and/or port terminal representatives prior to the load list cut-off date. By enforcing this rule, the IMO has increased maritime safety and reduced dangers to cargo, containers and all those involved in container transport throughout the supply chain. The rules have also had the additional benefit of enabling container carriers to optimise their stowage and stability calculations with respect to use of ballast water and fuel consumption. As weights of cargo units can be inaccurate and are generally unvalidated compared with what is declared in booking/gate in documentation, before loading in the RoRo and RoPax industry, as earlier mentioned, it becomes difficult for RoRo ferry cargo stowage officers to make very precise vessel stability calculations and optimise stowage and use of ballast water as buffer in more detail.

4. OPTIMISING SHIPYARD PROCESSES

Description of the case and methods

The third technology case of the ECOPRODIGI project deals with optimisation of shipbuilding processes at shipyards. Often, eco-efficiency is discussed in relation to shipping operations, but the project partnership wanted to expand the scope and involve shipbuilding processes in order to take a broader perspective on the ship life cycle. In this case, a shipyard and a ship design enterprise, technology vendors, a research institution and a business support organisation collaborate together **(see main partners in Figure 10).** Additionally, a shipping company, DFDS, was involved in some project activities in the beginning of the project. DFDS did not, however, take part in the rest of case 3 activities. On this basis, three participating end-user enterprises have been involved in the activities.

Meyer Turku in Finland is a shipyard that was originally founded in 1737. At present, the shipyard is owned by the Meyer family and it is well positioned in the European market. Meyer Turku produces high quality cruise ships, car-passenger ferries and special vessels, and has received several orders during the recent years. Due to the increase in orders, the shipyard has steadily grown and more than 2,000 employees work at the shipyard currently. (Meyer Turku 2019a). Meyer Turku has several subsidiaries. In 2018, the turnover of the enterprise was 969.7 million EUR (Meyer Turku 2019b).

Western Baltic Engineering in Lithuania forms part of the Western Shipyard Group in Lithuania and specialises in ship design and engineering solutions. Western Baltic Engineering provides several types of services, such as, naval architecture services, workshop drawings of ship's hull construction and hull piping documentation (see WSY 2019). The enterprise has 87 employees currently, and its turnover amounted to 4.3 million EUR in 2018.

The shipping enterprise DFDS has partly been involved in the shipyard case as the dry docking and repair process of the company's vessel was studied in the beginning of the project at a shipyard. The description of the end-user company can be found in the previous section.

The project work in case 3 is multifaceted, as activities simultaneously take place in various countries. The work thus far proceeded through different stages and the participating enterprises in each stage differed to some extent as is described next.

1) Core capabilities for sustainable shipyard processes, organisational readiness for sustainability and further analysis of shipyard processes

In ECOPRODIGI, Researcher Barletta from Chalmers University of Technology carried out, in total, four in-depth interviews and two focus groups with 13 representatives involved in the management of shipyard processes and/or corporate sustainability at project partner enterprises in case 3. A study visit was also arranged at Turku shipyard alongside interviews. The purpose was to identify core capabilities for sustainable processes at a shipyard environment, characterise the concept of organisational readiness for sustainability and gain general understanding of shipyard processes. Part of the data obtained was utilised for creating a survey tool 'Organisational sustainability readiness tool' (Barletta et al. -) that serves as a self-assessment tool for the management and executives of enterprises. The design of the survey started from an established yet still conceptual 'template' of a capability maturity model (Mani et al. 2010), which was re-elaborated with a focus on sustainability and digitalisation based on qualitative data shared by study participants in interviews and focus groups. The qualitative data was gathered also from enterprises outside the ECOPRODIGI project and from several manufacturing industries (for more information on the research method and crea-

FIGURE 10. MAIN PROJECT PARTNERS PARTICIPATING IN PROCESS OPTIMISATION AT SHIPYARDS

Leading research partner	• Chalmers University of Technology, Department of Industrial and Materials Science, Sweden
Shipyard/ship design company	• JSC Western Baltic Engineering, Lithuania: ship design company, which forms part of the Western Shipyard Group. • Meyer Turku, Finland: shipyard that specialises in cruise shipbuilding.
Suppliers/developers of solutions and concepts	• OSK-ShipTech A/S, Denmark: expertise in marine consulting and vessel design. • Carina Solutions Oy (Carinafour), Finland: specialises in developing and optimising production systems and processes in the supply chain. • Sininen Polku Oy, Finland: specialises in quality management, supply chain management and IT systems.
Organisation facilitating collaboration between businesses and research organisations and contributing to the content of the case work	• Klaipeda Science and Technology Park, Lithuania

tion of the survey used, please see Barletta et al. [-]). In ECOPRODIGI, the purpose was to use the assessment tool to determine the readiness of a shipbuilding or ship repair enterprise in performing sustainable operations that enforce a manufacturing strategy that is sustainable. However, based on the response rates, the results could only be drawn from Meyer Turku shipyard that yielded six responses.

Furthermore, additional analysis of the overall state of shipyard processes and supply chain management at Meyer Turku was carried out by several partners participating in ECOPRODIGI, for example, the following methods were used to investigate the shipbuilding process and possible inefficiencies:

- Chalmers University of Technology: organiser of a workshop
- Meyer Turku: carrying out analysis of own internal processes
- Carinafour: interviews, observations, work research methods and analysis based on data obtained from information systems at Meyer Turku
- Sininen Polku: interviews with procurement and sourcing department, process mapping and value chain analyses (supplier lifecycle management) at Meyer Turku.

2) The manufacturing process of blocks

An industrial phase included in the shipbuilding process was investigated, namely the manufacturing process of two specific modules or blocks. Western Baltic Engineering is currently supplier of Meyer Turku, whereby these project activities aimed at identifying eco-inefficiencies that take place in the collaborative processes of the two enterprises and the potential of 3D technology for improving them. Overall, close collaboration took place between all main partners in this case **(see Figure 10).** The activities carried out in this work were the following:

- **Study visits to shipyard environments and organisation of hackathons, which refer to specific collaborative events where the partners jointly worked with this area of development. The hackathons involved scanning of blocks and processing of data, among other activities. In addition, post-processing of data and development of common guidelines were started after the hackathons.**

3) Dry docking and repair operations

- **DFDS and Chalmers University of Technology: 3D scanning, measurement and post-processing of data.**

The following sub-sections present the main project outcomes of case 3, which were summarised based on project documents and consultation of participating organisations. Moreover, the majority of outcomes were compiled based on recorded interviews and discussions carried out with researchers from the coordinating organisation of the case. Thus, all case 3 partners contributed to the report. The interviewed researchers of Chalmers University of Technology were the following:

- **Ilaria Barletta**
- **Jonatan Berglund**
- **Björn Johansson**
- **Clarissa González Chávez**

Current state and the most critical eco-inefficiencies

As indicated in the description of the case and methods, three main work stages took place in case 3. In the following, the main findings are presented within these stages.

1) Core capabilities for sustainable shipyard processes, organisational readiness for sustainability and further analysis of shipyard processes

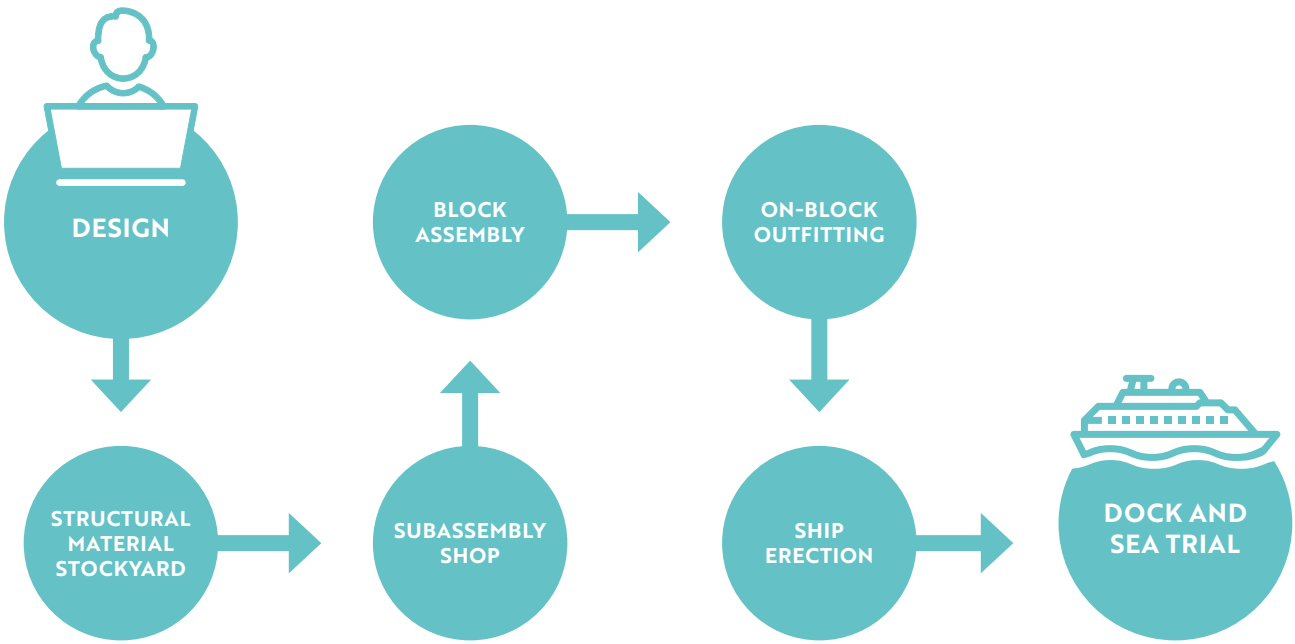
The overall shipbuilding process differs from that of several other manufacturing industries[5], including its several stages. In order to have a thorough understanding of the lifecycle, the main phases were examined in an internal workshop in the project **(see Figure 11).**

Furthermore, it was essential to understand what the main production and business-based capabilities were needed for sustainable shipyard processes. The identification of sustainability capabilities is important for organisations in order to be able to decide on what capabilities to invest in and determine the use of relevant KPIs. Based on the views of several business representatives, the main sustainability capabilities identified for shipbuilding and ship repair sectors were the following:

- **Rapid and virtual prototyping for product and production quality**
- **Pollution prevention**
- **Cost-efficient remanufacturing**
- **Minimised service/warranty claims (for ship repair only)**
- **Zero waste production and maintain asset in circular economy**
- **Information transparency of the bill of materials (BOM) across the product's life cycle**
- **Resource efficiency at the shipyard.**

[5] Shipyards do not manufacture identical items that pass through the same production lines (Jeong et al. 2018, p. 171). Instead, the ships are built using a block construction technique, which means that blocks are first manufactured in their own manufacturing processes before they are mounted to form part of the ship hull (see Park et al. 2014; Tokola et al. 2016).

FIGURE 11. SHIPBUILDING PROCESS



Followed by the identification of capabilities needed for sustainable actions, the purpose was to investigate how the shipbuilding process currently works and how ready project enterprises are in supporting these sustainability capabilities (Barletta et al. -). An 'organisational sustainability readiness tool' (ibid.) measured the readiness of sustainability on a scale of 0-3 of six different organisational areas/systems:

1) process management
2) asset management
3) materials management
4) information systems
5) data-driven decision support
6) organisational competences

The findings of Meyer Turku shipyard showed **(see Table 2)** that its readiness concerning information systems represented the highest level, which indicated that the systems in place are on a good level in supporting the sustainability capabilities. Process management, which refers to the knowledge and tracking of processes (Barletta 2019), posed the lowest readiness. As far as the organisational competences are concerned, this system scored the second lowest level. The organisational competences refer to the knowledge which the personnel and the enterprise possess (Barletta et al. -). The finding indicated that the people have plenty of tacit knowledge of running operations and solving problems, which may not be passed on in the organisation (Barletta 2019).

In addition to the survey, enterprises carried out further analysis on the current state and main eco-inefficiencies within the shipyard processes and supply chain management. Partly in line with these survey and interview findings, the analysis carried out by one of the supplier enterprises, Carinafour, indicated that the areas subject to improvement in determined process phases at Meyer Turku shipyard were mostly related to process management and some organisational issues. For example, planning of the work, formation of working teams and the coordination of material had room for development. In terms of the management of the complex supplier network, the analysis of another project partner company, Sininen Polku, indicated that there were

TABLE 2. RESULTS FROM SUSTAINABILITY READINESS SURVEY

	SUSTAINABILITY READINESS SCORE PER SYSTEM (ON A SCALE OF 0-3[6])	
SYSTEM	**MEAN**	**STANDARD DEVIATION**
Process management	1.5	1.2
Asset management	2.2	0.4
Materials management	1.8	0.9
Information systems	2.6	0.5
Data-driven decision support	1.75	0.94
Organisational competences	1.6	1.2

some eco-inefficiencies that could be improved. The process of managing the supplier lifecycle was unclear and not based on systematic documentation as far as the phases of supplier onboarding, use phase and exit were concerned.

In addition to the mentioned results, a study visit was organised to Meyer Turku to discuss the sustainability related to shipyard processes and what actions had already been taken to improve sustainability. The findings showed that the shipyard capitalises on several circular economy benefits in terms of material, focusing on the reuse and best usage of materials. To mention a few examples, the optimal use of steel is considered essential, as it is a heavy and valuable material. In addition, the reuse of plastic reels used for welding wires and producing a composite material from the textile waste has been on the focus. Meyer Turku has further modernised some of its old equipment, for instance, through investing in a new and modern crane. (See also Meyer Turku [2017]).

2) The manufacturing process of blocks

As far as the manufacturing process of blocks is concerned, the first analysis of this process phase indicated some eco-inefficiencies that could be subject to improvement. When Meyer Turku builds new cruise ships at the shipyard, some of the blocks are designed and manufactured by subcontracted producers – for example, a detailed design of some specific blocks is carried out by Western Baltic Engineering, after which the blocks are produced in Lithuania and delivered to the customer Meyer Turku. After delivery, these blocks are aligned with the rest of the ship hull by Meyer Turku. This is an essential phase as far as the efficiency is concerned as modifications to the blocks are more expensive and often more difficult to make when the block is already mounted on the hull (see also Tokola et al. 2016). Indeed, the project analysis indicated that when the blocks arrive to Turku and are measured, sometimes deviations appear, but the shipyard continues reworking the blocks in order to fulfil the functional requirements and requirements concerning classification admission (Berglund 2019). For instance, the shipyard may need to drill holes and redo welding and painting in order to correct the deviations and make individual blocks fit together to form the ship's hull. The rework means loss of resources and adding extra man-hours in order to keep up with the original ship building schedule. (Barletta 2019; Berglund 2019). Sometimes the rework is carried out near the keel of the ship, which

[6] Meaning of the scale: The enterprise is 0) not ready to create/develop the capability, 1) is creating it, 2) has created the capability but does not improve it on an ongoing basis, 3) has created and constantly improves it.

Photo: Tapio Karvonen

also represents challenging working conditions (Berglund 2019). On this basis, the quality of the product plays an important role, and possible errors related to its manufacture in the supply chain may produce inefficiencies to the process. Moreover, some potential inefficiencies were observed in terms of the process of working with data to meet standards of different customers. For example, standards for ship repair and building new blocks differ to some extent. The measurement process and the need for process control seems to be higher in the new building sector than in ship repair sector, and it could be further developed. (Berglund 2019).

The findings of the project indicated that both the shipyard and the ship design and engineering company involved in ECOPRODIGI are rather advanced in the use of digital technologies. For instance, 3D technology and digital twins of the products are utilised. Software and measurement tools for processing and working with data are also available. (Barletta 2019; Berglund 2019). Nevertheless, the project partnership searched for additional license-based and open source software that the Lithuanian enterprise would benefit from (Berglund 2019). Overall, the current state of digital technologies in use, such as 3D, is elevated (Barletta 2019), but more effort in the project is now placed on the improvement of the process that the technologies and solutions entail as well as to create some new solutions to those operations that have proved to involve eco-inefficiencies.

3) Dry docking and repair operations

In addition to the above mentioned activities, Chalmers University of Technology analysed the current state of operations related to dry dock and repairs of a vessel of the case company DFDS at a shipyard environment. The findings showed that the planning phase of dry dock operations and repairs as well as the inspections of the repair outcomes are based on visual inspections of the hull. Therefore, the assessment of the actual defects and repair work is difficult to carry out in an objective way.

Potential of digital technologies for solving the eco-inefficiencies

Several solutions for the eco-inefficiencies identified in the shipyard processes are under development or consideration in the ECOPRODIGI project. Some of the methods used in the project have been adopted from other industries, such as the automotive industry, in order to capitalise on the lessons and benefits learned earlier (Berglund 2019).

First, resulting from the analysis, Meyer Turku, Carinafour and Sininen Polku investigated the potential for using new concepts and solutions in the shipyard processes and supply chain management. One type of concept applied for more eco-efficient processes relates to situational awareness (Barletta 2019), which provides a more detailed overview of the processes. Situational awareness is applied in the ECOPRODIGI project in combination with the use of digital solutions and applications with the aim of improving the eco-inefficiencies observed within process management. For instance, based on the analysis of eco-inefficiencies, Carinafour set KPIs and carried out initial pilots at the shipyard. Based on the pilots, focus in the project will be placed, among others, on the planning of work, team building, and improving the coordination of material, including the development of new digital solutions and applications in order to make processes more eco-efficient and to reach increased productivity at the shipyard.

The development of a more controlled supply chain management should also involve supplier enterprises. This means that companies not only focus on the quality of their own processes, but also the quality across the supply chain, for instance, through improved information systems, which increase efficiency (Barletta 2019). Sininen Polku, has started to create a novel solution for Meyer Turku in the project for the purpose of managing its complex supply chain. The solution enables supplier quality managers to create visibility for the whole supplier network, including second- and third-level suppliers, as well as to analyse risks and to find weak nodes in the network chain. Currently the supply chain is managed more on a reactive manner and the aim of the solution is to have a more proactive way of working to understand risks related to deliverables and sustainability. The solution concept is under evaluation after which development and testing will start.

Second, based on the first project observations, the researchers of Chalmers University of Technology see great potential in 3D technology in improving the manufacturing process of blocks. When blocks are produced, they can be scanned whereby the 3D scans function as digital twins of the products and they can be sent to the customer prior to the real block. The potential considered is multifaceted:

- As indicated earlier, deviations in the block preparation may cause some eco-inefficiencies in the building process. With 3D scanning, enterprises obtain more precise drawings and gain more knowledge of the process, which leads to fewer mistakes and saves extra working hours and materials (Barletta 2019), and thereby costs. The earlier errors are identified, fewer resources will need to be applied. For example, errors can be detected and adjustments made while constructing the block at the producer's site instead of detecting them at a later stage. (Berglund 2019). Another benefit is related to the fact that, if new measurements are implemented in a systematic manner, shipyards can learn about the 'patterns of deviations' and be better able to detect their sources. This allows the shipyards to improve their processes. (Berglund 2019). As far as the concrete improvement is concerned, one may see the potential when comparing a manufacturing process where 3D scanning is not used and another one where 3D and new processes are being implemented. The assessment of the module or block geometry delivered from Lithuania to Finland and its compatibility with the specification takes approximately one to two working days. Due to 3D technology and new processes, such assessment work can be moved upstream to the Lithuanian supplier and conducted before the shipment of the module or block to the customer. Therefore, the lead-time can be reduced when the block arrives in Finland. In addition, if deviations are detected before the shipment

is received, the work required for their correction may be planned and executed before the module is assembled to form part of the vessel, which saves potentially several hundreds of man-hours in rework.

- Another benefit observed in the project is related to the fact that 3D scans and measurement reports can contribute to more detailed reporting practices and transparent data sharing between partnering companies, which contributes positively to product and process quality. On this basis, the proof of quality can be improved when blocks are delivered. A more detailed and transparent process between the producer and customer improves the communication between them and, ultimately, may positively contribute to their business-to-business relationship. (Berglund 2019).
- During the research it was also detected that 3D scans could potentially aid the classification societies in some of their inspection activities. For example, time could be saved when physical visits to the ship and some documentation activities could be avoided due to digital documentation. (Berglund 2019).
- In addition to the above mentioned benefits of 3D and digital twins, augmented reality (AR) was tested in the project to showcase its ability to support specific onsite inspections related to block manufacturing process, which can be carried out faster with the technology (Berglund 2019). Also, virtual reality (VR) solutions were tested to concretely visualise and test how individuals and organisations can increase eco-efficient actions.

Third, Chalmers University of Technology identified the potential for using 3D scanning to improve the dry docking and repair operations. Instead of a visual inspection, 3D imaging could be utilised to a more effective assessment of defects and verification of repairs. In addition, 3D imaging could provide an objective and holistic analysis of the hull as it could be compared with either ship models or 3D imaging data collected at previous dry dockings. Thus, 3D technology could provide more accurate geometrical data that would take into account any changes or upgrades made since the 3D model was created.

To sum up, based on the work carried out so far in the project, it is safe to say that there is certainly potential in using digital technologies for improving eco-efficiency and optimising shipyard processes. Organisations are better able to monitor and control the situation, as well as make necessary adjustments to operations and processes, with the help of new digital technologies (Johansson 2019). On this basis, organisations reach better awareness and understanding of operations with digital technologies and can better plan and prioritise work, which will ultimately help in the decision-making (Johansson 2019). In future activities of ECOPRODIGI project, the mentioned new solutions will be tested in the processes in order to analyse the real effect.

Challenges and requirements

Several challenges may appear when implementing digital changes in shipyards, which require specific actions from organisations. The following aspects were brought up in the interviews with the researchers.

First, even though digital technologies ultimately aid organisations in monitoring and controlling the business operations, some actions need to be carried out before the new types of digital technologies are planned to be implemented. In order for the implementation to be successful, one of the requirements for an organisation is to define and improve the processes related to the implemented digital technologies (Barletta 2019; Berglund 2019). Indeed, without putting effort into their optimisation, it is difficult to carry out major digital changes. However, an organisation can be in a transition phase in terms of the use of digital technologies. In one of the interviews, it was mentioned that it is important to think of a way how to integrate the digital technologies into the current way of working and the analogue systems (Berglund 2019). For instance, if an organisation needs to carry out some tasks in parallel with both analogue and digital systems, the organisation should make sure that right qualifications and efficient integration of both systems are in place (ibid.).

Photo: Julius Silver

Second, a possible barrier is related to the large operational environment of a shipyard, which may complicate the control of some operations; for instance, tracking material may become a barrier if effort is not made to ensure its efficient control. The supplier network is partly linked to this matter; for example, if a shipyard aims at reducing waste, all the subcontractors will need to comply with the instructions in order to reach set targets. This creates another possible challenge related to control, which emerged from interviews outside ECOPRODIGI partnership, namely, how to manage a common culture at a shipyard when a large group of different companies is present. This can partly be assured with the usage of certifications that ensure that all companies follow same standards, as it is done already in several industries, but additional actions may need to be carried out. (Barletta 2019). Moreover, suppliers need to be able to adapt to the digital changes. For instance, they may need to put effort into developing new working methods and processes (Berglund 2019).

Third, enterprises may face challenges related to the scalability and integration of technology between customers and partnering companies. For instance, in terms of producing digital twins with 3D scans, a challenge could be the measurement format that the producer and customer communicate with; therefore, a neutral and standard measurement format is needed (Berglund 2019). In fact, at a later stage of the project, recommendations will be given on the way data should be filtered and deviations expressed taking into account both the producer and customer's perspectives. In other words, a standard measurement format, as well as new guidelines/process descriptions will be provided. (Berglund 2019). It is also worth mentioning that, even though digital technologies provide great potential for organisations to share information in a transparent manner and on a real-time basis, organisations need to be ready to share information (ibid.). It is evident, however, that open information sharing might also create data protection issues that need to be addressed first.

Fourth, in regard to the utilisation of 3D technology in dry dock and repair operations, some further challenges and requirements have been identified. The lack of digitalisation skills and knowledge forms a challenge. In order to produce reliable results with 3D imaging, qualified guidance and methods are required, especially as far as such large structures as ship cargo holds and ship hulls are concerned. In addition, the volume and size of data produced are large, which leads to the fact that plenty of computational capacity is required in order to share and view the data online. Furthermore, the point cloud data is not directly adjusted for use with some specific software needed in the process, such as, flow and drag simulation software. Thus, additional processing steps are necessary to facilitate the use of such software. However, no robust automated options are available and plenty of work is carried out manually, which makes the work expensive and exposed to errors. Also external factors may produce challenges, for example, the hull fouling can invalidate calculated, theoretical flow or drag parameters.

Fifth, in ECOPRODIGI, several enterprises are already using advanced technologies, whereby the technological barrier has proved not to be as high as expected when the project started (Johansson 2019). Instead, a greater barrier may be related to the efficient control and running of operations (Barletta 2019; Johansson 2019) or whether the organisations opt for choosing new technologies and new ways of working as part of their daily operations (Berglund 2019). In addition, capabilities needed for certain roles in organisations may change (Barletta 2019), which should be taken into account. These changes may have consequences on the personnel and further produce challenges to organisations, for instance, in terms of how technologies are accepted and implemented throughout the enterprise (Barletta 2019). On this basis, instead of a pure technological barrier, a major barrier related to the implementation of digital technologies deals with organisational factors (Berglund 2019) and change management (Barletta 2019).

Sixth, in the light of this type of transformation, change in the mindset amongst people become more emphasised (Johansson 2019). All the interviewed researchers discussed the importance of education and presented various means that facilitate the implementation of digital technologies. In addition, the way in which benefits are presented is essential. For example, using gamification and simulation models in the presentation of digital technologies can be efficient (Barletta 2019; Johansson 2019). One respondent noted that the benefit of AR and VR applications relates to the fact that they help organisations to showcase the changing environment as people can walk around the ship and add information on the 3D environment (Johansson 2019). Additionally, drafting process descriptions (Berglund 2019), as well as applying lean management principles, visualisation boards of workflows and digitalised Gantt charts, can facilitate the transition within the organisation as they help in current and future planning (Johansson 2019).

Finally, a challenge mentioned in the interviews relates to knowledge management. The personnel in enterprises have plenty of specific know-how, and it would be useful for enterprises to make the most of it by gathering it into a 'digital infrastructure'. However, a challenge may be to get the personnel to share their knowledge and incorporate it into the system. (Barletta 2019). This factor is related to the earlier mentioned 'organisational competences', and it is essential in the sense that improved knowledge sharing within organisations could speed up the process of enhancing eco-efficiency through digitalisation.

5. FUTURE DEVELOPMENTS OF MARITIME INDUSTRY DIGITALISATION

This section steps back from the operational analysis and seeks to view the maritime sector from a broader perspective, providing some ideas about the obstacles and most likely future developments of digitalisation in the maritime industry. The ECOPRODIGI partner companies were given an opportunity to have a say as to what they think about the current situation, obstacles for development and future prospects. These themes were first explored in a workshop in April 2018, which was facilitated by Chalmers University in Gothenburg, Sweden. The participants of the workshop discussed how the maritime industry in the Baltic Sea Region will look like in the coming years. Afterwards, to elaborate on the future challenges and deepen the level of analysis, a questionnaire consisting of open-ended questions was created in collaboration with University of Turku and Danish Maritime and then circulated amongst the consortium. The respondents were asked to describe (1) the most critical eco-inefficiencies in maritime processes and (2) the potential of digitalisation in solving them. It is worth mentioning that the purpose of this section is to provide an industry-level examination, thus, the remarks are general observations about the maritime industry and do not refer to any particular organisation involved in this project.

The questionnaire generated many insightful answers and concrete suggestions for the future. It became evident that the maritime industry, as a whole, is facing similar issues in terms of eco-inefficiency; the questionnaire collected several similar answers even though the respondents represented different fields. The most common explanations for the relatively low-level of eco-efficiency in the maritime industry were generally linked to limited incentives for investments in new technologies and for developing international standards.

On the other hand, some varying emphases arose. From the shipping point of view, the eco-inefficiencies were explained by a combination of lack of competitive or regulatory incentives for investment in technologies but also for lack of digital capabilities and lack of focus on improving energy efficiency in daily operators. Furthermore, the lack of preceding eco-efficient operations, lack of transparency and complicated streams of information with inefficient coordination of vessels and ports were considered challenges for many actors. From the cargo handling point of view, the most critical eco-inefficiencies of the industry were the processes related to loading and discharging, and achievable turnaround time. In this sense, improved data on cargo could result in optimised stowage and thereby reduction in ballast intake, but also improve loading and discharge with positive impact on terminal efficiency and port stay shortening. From the shipyards point of view, the key issues were related to, for example, waste reduction and virtual manufacturing.

The underlying root causes for the eco-inefficiencies were commonly recognised. First, the vessels are not always operated optimally, as ships are designed for a certain condition and speed, but may be operated outside the optimum range in respect to their design. Second, lack of planning of seaborne transportation between different actors, such as ports, vessels and operators, creates coordination issues. Third, conflicting interests and lack of common incentives amongst some of the players may hinder development. Finally, difficult access to data regarding cargo information and cargo arrival times obstructs the development of better solutions.

In general, the respondents saw great potential in the development of physical modelling and digital

Photo: Tapio Karvonen

processing, as well as other advanced technology and equipment. All of the organisations agreed that the potential of digital solutions in solving the eco-efficiency bottlenecks is great as long as the industry becomes more transparent and data more accessible and reliable. The data of vessel conditions, speed, cargo and weather – and structured use of such data – was seen as an important enabler to improve the environmental performance and energy efficiency. Although, as one respondent pointed out, there is a significant collection of data already available that needs to be properly utilised before collecting more.

The openness of the industry, in terms of exchanging data, models and even algorithms, was seen as a very important factor. However, as one respondent noted, this requires global and regional legislation and standardisation as some parties may avoid disclosure of their activities. Easily accessible data could help improve the required transparency and allow better optimisation of the commercial and technical operations. However, before this is possible, companies need to support interfaces with other applications, and interfaces need to be built so that retrieving data is possible.

The respondents saw the preconditions for the digital transformation as being good, but the industry still needs much more commitment and investments. Eventually, easier and cheaper business models and working methods would improve the situation. Most of the organisations shared similar concerns in terms of applying the digital solutions in practice. Most notably, the cost of applying new technology is high, and to undertake research and development requires significant investments. Furthermore, it was considered necessary to develop models for decision support and automation of load planning as the operations requires accurate and timely cargo information. The information needs to be

obtained with trackers and smart gates with a number of different sensors and onboard technology for positioning, but applying all this is costly. However, as one respondent replied, to be at the forefront is a strength in itself, so R&D is essential despite the costs.

In general, the respondents saw the potential of improving eco-efficiency by developing digital solutions. However, they suspected that outdated practices, lack of standards and overall conservatism in the industry are factors, which slow down the development. As an example, one respondent noted that the low price of old technologies and cheap traditional ship fuels makes new energy sources less competitive and less attractive, which does not encourage making new investments. Business-wise, this makes the transition to new technologies more difficult. Overall, according to the respondents, the industry still requires more motivation, dedication and reliable suppliers, but also stable political conditions across borders and international cooperation.

Despite the aforementioned challenges, the respondents were cautiously optimistic regarding the industry. They were also motivated and prepared for developing and implementing new digital solutions. Even though not all of the organisations had clearly stated objectives and visions for the future, they had structured guidelines or roadmaps for the coming years. The organisations were committed to promoting advanced technology, equipment and digital processes. They were also committed to improving the models and data management and developing digital tools to assist operations and vessel crews to make better decisions. Two organisations had a clearly formed vision to expand the use of advanced technology and equipment and to use physical modelling instead of marine field operations, as well as employing advanced digital processing, so lower environmental damage and higher quality of data can be obtained. One respondent emphasised the need for strong innovation in order to succeed in the international markets, and one organisation had a clearly stated objective to be the first movers for implementing and use of the digital twin for vessel performance and ship operations.

In addition, the organisations described their priorities for the future rather ambitiously. One respondent, for example, stated that their company's aim is to create the best possible frame conditions for environmental and sustainable maritime transport solutions. Furthermore, they hoped to achieve a breakthrough in ecologically sustainable shipping with the use of digital solutions and by expanding the use of advanced technology. As to other respondents, automation, AI and machine learning, virtual manufacturing and emission reduction with extended use of alternative fuels were the key priorities for the future.

6. CONCLUSIONS

The Interreg Baltic Sea Region flagship project ECO-PRODIGI project was initiated to address the identified challenges that maritime industry is confronting in the BSR. The increase of emissions in the Baltic Sea has reached a point that requires corrective measures from all actors around the region. Moreover, the maritime industry faces growing global competition whereby those enterprises that are able to provide superior value to their customers with decreased costs will gain an edge over their competitors. However, reaching this goal implies that innovative ways of operating daily business processes are needed. The urgency of the factors that need to be addressed calls for immediate measures, and indeed, there are solutions available to improve the situation by increasingly capitalising on technological development.

ECOPRODIGI project delves into the vast possibilities that digital technologies and processes offer in intensive collaboration with 21 partners around the Baltic Sea. The project results thus far indicate that there are several eco-efficiency bottlenecks that can be solved by implementing various types of digital technologies and making use of new concepts and working approaches in three different phases of the vessel life cycle:

1. In terms of digital performance monitoring of the vessel, the results indicate differences in the level of digitalisation and eco-efficiency depending on which segment, ship or route is in question. However, generally, a great potential exists for reducing fuel consumption and emissions, as well as for preventing engine breakdowns and reducing maintenance and repair costs. These effects can be obtained by using digital technologies and models created for improving and predicting operations of the ship and its various components. In addition, continuous improvement and change of work play essential roles in the improvements. All these factors aid personnel to adjust work tasks and make improved data-based decisions. The project partners estimate that fuel consumption and emissions can potentially be reduced by 2-20% based on data and analysis from distinct ship segments, routes and their baseline situations.

2. As regards the eco-efficiency and digitalisation in cargo stowage, the case results indicate that differences between routes and terminals exist in this case as well. Yet, several inefficiencies have been identified in cargo stowage processes, which can be improved. The increased use of digital technologies and improved utilisation of assets and resources produce several types of benefits. They enable faster port operations, whereby the speed of the ship can be slowed down at sea, and consequently fuel consumption and emissions are reduced. In addition, the amount of ballast water can be reduced, thus decreasing fuel consumption. At the same time, customers at ports will receive faster and improved service due to reduced port time. Overall, expenses and adverse environmental effects can be reduced. For example, fuel consumption and emissions can potentially be decreased by 2-10% per route and ship in the medium term, depending on baseline situation.

3. In shipyard processes, inefficiencies have been identified, for example, in relation to process management and supply chain management. The results further show that the potential of digital technologies and new concepts in solving eco-inefficiency bottlenecks is multifaceted. Optimised and digitalised operations and processes, restructuring of work and capitalisation of new technologies (AR and VR applications, 3D and digital twins as well as other digital solutions), are expected to contribute to improved productivity and more eco-efficient processes. For example, the

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utilisation of 3D technology in block manufacturing process reduces use of material and lead-time as well as potentially saves hundreds of man-hours in rework due to the fact that 3D scanning and measurements enable better process planning and proactive actions.

It should be noted, however, that the potential of digital technologies for solving the identified eco-inefficiencies will be further refined in the upcoming project work in ECOPRODIGI as the project partnership starts to pilot the new solutions to tackle the eco-inefficiencies. After the completion of the pilots, the partners are better able to calculate whether the targets and estimates set initially are met.

Based on the project work, European enterprises offer high expertise and know-how, which form a good basis for reaching eco-efficiency targets through the utilisation of digital technologies. Yet, enterprises are at different levels in terms of development, and the starting level has an impact on the degree of digital change. In a similar manner, the requirements and challenges related to the development and implementation of digital technologies may differ to some extent depending on the enterprises and segments where they operate. The results show that the technology itself does not represent a barrier for most of the ECOPRODIGI enterprises in terms of the availability of technology. However, reaching maximum advantage of digital technologies means that the related processes must be well analysed and technologies efficiently integrated with them and other systems of the organisation. The technologies also need to meet the requirements for performance, be robust and user-friendly for the personnel to use. Organisations need to reserve time, from one to three years, for the development of integrated and robust digital solutions that are tailored to specific needs. This is a shorter timeframe in comparison to some other alternatives, such as, the deployment of alternative fuels or new ship designs.

Furthermore, organisational factors and change management may present the key challenges for some organisations. For example, the successful implementation of new technologies may depend on the willingness of an organisation to adopt the new technologies and ways of working. Indeed, the utilisation of new technologies implies a profound change in working methods with-

in the organisation. Therefore, it is essential to involve people in the change processes. All the actors need to be onboard in the digital transformation that will guide them to improved eco-efficiency. This leads to a situation where appropriate training and demonstration of the benefits of the changes to the personnel and other stakeholders become critical issues. Therefore, the development and piloting of training modules related to digital technologies for different stakeholders will be on the agenda of ECOPRODIGI partners in the near future.

The results additionally show that the actors do not need to carry out the transformation alone. ECOPRODIGI has demonstrated that, at its best, collaboration amongst the different parties produces fruitful and excellent results. The identified challenges can be tackled and new ideas developed as joint actions of several organisations that rely on the multiple expertise of each other. Nevertheless, efficient and digitalised processes often imply exchanging or sharing data amongst several parties in the supply chains. Unwillingness or lack of ability to exchange and share data easily will hamper the speed of the process change.

External factors may also have impact on the speed of change in organisations. Lack of industry standards can complicate the development of digital solutions. On the contrary, regulatory requirements set by the EU and IMO as well as competitive incentives can support the future development of digitalisation and reduction of fuel consumption and emissions.

As the results indicate and as noted throughout the whole synthesis report, and as observed earlier by many others[7], it is clear that digital technologies are still underexplored in the maritime sector. Digitalisation demonstrably increases eco-efficiency, which is the key solution for the dilemma of increasing traffic on the sea and the need to reduce emissions. Thus, digital technologies will undoubtedly play a critical role in the development of clean shipping in the future. Digital industrial transformation with cyber-physical systems will eventually lead to the development of smart(er) ships, shipping processes and manufacturing of the ships after certain preconditions are met (such as increasing computational capacity, data storage capabilities, better networks and cloud infrastructure). Automatisation and robotisation, AR, simulation, and IoT have the potential to improve the processes and working methods and these potential benefits apply to most of the processes in the maritime sector. Thereafter, the benefits of digitalisation will become too great to ignore. The winds of change do not have to sweep past the organisations overnight, but the first steps in the change process should be taken now, if not already taken in that direction.

[7]See e.g. Gritsenko (2016); Carlan et al. (2017); ECMAR (2017); Fruth & Teuteberg (2017); Heilig et al. (2017); Jensen (2017); Helavuori & Bakhtov (2018); Lind et al. (2018).

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