

**Interreg**  
Baltic Sea Region



EUROPEAN  
REGIONAL  
DEVELOPMENT  
FUND



# EXOPRODIGI

Digital tools for eco-efficient  
maritime industry





**UNIVERSITY  
OF TURKU**

**PUBLISHED BY:**

EXOPRODIGI Project  
Pan-European Institute,  
Turku School of Economics  
University of Turku  
Rehtorinpellonkatu 3 FI- 20014  
University of Turku, Finland

Project website: **[ecoprodig.eu/exoprodig](http://ecoprodig.eu/exoprodig)**

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## FOREWORD

The Baltic Sea region is a significant region for Europe in more ways than one; financially, ecologically, and socially. Different countries around the region are interconnected through the Baltic Sea, which is known for its busy sea traffic. The state of the Baltic Sea has long deteriorated, and people around the Baltic Sea Region are cognisant of the fact that actions must be taken in order to improve its state. Moreover, the European Commission recently launched the European Green Deal – a forward-looking and ambitious strategy for Europe to become the first climate-neutral continent by 2050. The Green Deal imposed requirements upon different industries to take measures in the endeavour to reach the climate-neutrality. The maritime industry was one such industry, and this has had a major impact on our region as well. Indubitably, shipping and shipbuilding industries across the Baltic Sea Region have been under immense pressure to adjust their operations to become greener and more sustainable.

The Interreg Baltic Sea Region extension stage project “Expanding efforts to bring eco-efficiency to maritime industry processes in Baltic Sea Region

via digital tools” (EXOPRODIGI 2021) has supported the goal set in the Green Deal by cutting emissions in shipping and shipbuilding industries. The objective of EXOPRODIGI has been to develop digital tools to support decision making, to create transparency, to reduce working hours, and most importantly, to decrease waste, emissions, and energy consumption in the region. At the same time, this project would address the ever-increasing environmental regulation, global competition, and customer requirements that demand more sustainable services. Thirteen partner organisations, including shipping companies, shipyards, universities, a local authority, solution providers and expert organisations have collectively developed digital tools for vessel performance monitoring, cargo stowage processes at ports, and shipbuilding processes at shipyards simultaneously striving for a better and cleaner future. We have built on the work that was done in the regular project ECOPRODIGI (2017–2020) by improving the prototype solutions developed in that project, developing new digital functionalities and tools, testing them further with existing and new pilot cases, and confirming their functionality and usability by target groups.

We had altogether nine months to carry out these tasks, and I can now safely say that the project has made great progress towards its objectives. The EXOPRODIGI project indicates that different digital tools can reduce waste, fuel consumption, and emissions, thus leading the Baltic Sea Region to a more sustainable future.

The accomplishment of the project has been possible due to our partners and stakeholders as well as to the funders of the project. With this foreword, I send a warm thank you to all EXOPRODIGI partners for your great efforts and for the fruitful collaboration during the project. Moreover, a warm thank you to the Interreg Baltic Sea Region Programme and national funders for seeing the potential of our project and for fostering the welfare of the Baltic Sea Region. I hope that the collaboration continues in future projects as well.

**Elisa Aro**

*Research Manager /  
EXOPRODIGI*

*Pan-European Institute at the University of Turku*



This report is based on the work carried out during the project titled *EXOPRODIGI – Expanding efforts to bring eco-efficiency in maritime industry processes in Baltic Sea Region via digital tools (1.1.–30.9.2021)*. The project partners from Finland, Sweden, Denmark and Lithuania would like to thank the Interreg Baltic Sea Region Programme and the national funders for the financing as well as for the fruition of this project.



# INTRODUCTION: Charting the course for eco-efficiency

Julia Ajanko, UTU

Shipping is a cornerstone of the world economy and plays a vital role in the daily lives of almost every one of us. The international merchant fleet comprises about 56 000 vessels, divided into cargo, tanker, container, and passenger ships<sup>1</sup>, and around 90 % of global goods are transported around the world on the sea<sup>2</sup>. As any other transport mode still mainly relying on fossil fuels, shipping causes negative impacts on the environment. Combustion of fuel generates sulphur oxides, nitrogen oxides, particulate matter, and CO<sub>2</sub> into the air. Besides greenhouse gases, the maritime industry is even responsible for transferring invasive species through ballast water, discharge of oil, garbage, and sewage, as well as anti-fouling pollution<sup>3</sup>. **Despite all this, we are highly dependent on maritime transport.** Furthermore, the transport volumes are only expected to grow in the future e.g. due to globalization, climate change, population growth, urbanization, and increasing distance between food production and freshwater versus their consumption sites<sup>4</sup>. As for any industry and any sphere of life, we need to find ways to return to living within the planetary boundaries, and as a consequence, we

need to find ways for more eco-efficient shipping, shipbuilding, and the whole maritime industry.

**The Baltic Sea is particularly sensitive to the environmental pressure resulting from ceaseless human activities.** As one of the world's largest reservoirs of brackish water, the Baltic Sea is ecologically unique, and the species populating the sea life is on the edge of their salinity tolerance. More than 85 million people populate the coastal regions around the Baltic Sea; thus, the sea and its catchment area are imposed on a magnitude of human activities and pressure. In addition, the Baltic Sea is connected to the North Sea only through a strait narrow, making it a semi-closed environment, where the circulation time of water is long. Therefore, the pollutants and nutrients accumulate easily, aggravating the circumstances<sup>5</sup>. At the same time, the Baltic Sea as a transport route has a long history. Even today the sea is a busy place in terms of shipping. At any given moment, there are around 2000 ships in the Baltic Sea, utilizing around 100 internationally important ports around the region to load and

discharge their cargo and passengers<sup>6</sup>. Above 40% of the ships are general cargo ships, which mainly remain inside the Baltic Sea or Northern Europe. These ships represent up to 15% of the world's cargo traffic and the amount of vessel traffic on the Baltic Sea is not expected to decrease; on the contrary, the vessel traffic is expected to witness steady growth<sup>7</sup>. In addition to shipping and ports, the importance of the shipbuilding industry at the Baltic Sea is well recognized. Despite the fact that the industry has undergone major changes during the last thirty years, mainly in terms of significantly diminished production volumes, specialisations on high-value sub-areas of production have provided new possibilities for the region<sup>8</sup>. Rising fuel costs, stricter environmental restrictions and pressure, and stronger demand attributed to the security aspects, coupled with the rapidly advancing technology create even new kinds of opportunities and enhance the progress of even smarter maritime clusters<sup>9</sup>. **New digital maritime solutions can open up new business opportunities for the Baltic Sea region, but what more, digitalization can contribute to more environmentally friendly human actions and to diminishing pressure on the sensitive Baltic Sea marine environment.**

1 Number of ships in the world merchant fleet 2020

2 Future ship powering options 2013; Shi et al. 2018.

3 Shi et al. 2018; Eyring et al. 2010

4 Key trends influencing the maritime sector

5 Madjidian et al. 2013

6 Madjidian et al. 2013; Matczak 2018

7 Madjidian et al. 2013; Matczak 2018

8 Nömmela & Purju 2016

9 Nissilä & Kokkonen 2015

The aim of the EXOPRODIGI project (1.1.–30.9.2021) has been to improve the eco-efficiency of the maritime industry with the help of digital tools and solutions. The project partners have concentrated on three key areas of the maritime industry during nine intensive months: 1) *digital performance monitoring*, 2) *cargo stowage optimization*, and 3) *optimising shipyard processes*. The work done in EXOPRODIGI builds on the findings of a previous three-year-long ECOPRODIGI project (2017–2020), and therefore, the focus of EXOPRODIGI has been specifically on upgrading of tools, broadening of concepts, spreading and piloting the solutions in new contexts.

### Digital performance monitoring

The Baltic Sea has several archipelagos, where car and passenger ferries of different sizes are in charge of the transportation between the islands. A great deal of the ferries are old, and updating their equipment and machinery to more environmentally friendly systems is not always an alternative, e.g. due to the cost of the equipment. During the EXOPRODIGI project, the researchers from the University of Southern Denmark have collaborated with the Danish Island Ferry Secretariat to further develop means and solutions for improving the eco-efficiency of small ferries in Denmark without having to renew the equipment onboard. Digital

performance monitoring has provided the research team with a way to collect data and to develop digital decision-making tools, which support emission and energy consumption reduction with simple operational acts. Larger container ships, tankers, and gas carriers then again transport their cargo

**ECO-EFFICIENT CARGO STOWAGE PROCESSES NOT ONLY DECREASE FUEL CONSUMPTION AND EMISSIONS BUT ALSO LOWER OPERATIONAL COSTS IN PORTS**

worldwide with demanding machinery onboard, consuming hundreds of litres of fuel per day. A cost-efficient way of operating the ships increases fuel efficiency and decreases emissions. During the EXOPRODIGI project, a Danish shipping company J.Lauritzen has focused on collecting detailed data from the machinery of their gas carriers to further improve tools, which are used to better survey the functioning of the onboard equipment, and optimally alarm the crew on malfunctions before

any drastic and energy consuming break down occurs. The digital tools even provide credible support for operating these ships in a more cost-efficient manner.

### Cargo stowage optimization

Cargo loading and discharging are operations during which the port, the ship, the crew onboard and on land, as well as the other links of the cargo supply chain are deeply interlinked to each other. To enhance the cargo stowage processes, these different actors and their interlinkages need to be seen as one large and cohesive network where benefits gained in one part of the process are spread across the whole network. Eco-efficient cargo stowage processes ensure that the ships are optimally loaded, that the turn-around time spent in ports is as short as possible, and that the ships can use optimized speed to reach the next port as scheduled. Eco-efficient cargo stowage processes not only decrease fuel consumption and emissions but also lower operational costs in ports. The aim of the EXOPRODIGI partners, namely Kockum Sonics Visinator, and the University of Southern Denmark has been to improve the Danish shipping company DFDS's cargo stowage operations by utilizing software development, 3D scanning, and AI technology to develop integrated digital solutions. These integrated digital solutions provide means

for faster cargo operations and for loading the ships more optimally, therefore augmenting the ships' abilities to sail more eco-efficiently and safely with optimized speed.

### Optimising shipyard processes

Shipbuilding processes are based on complex supply chains, and properly functioning logistics and material management are crucial for the efficient execution of different working phases of the long processes. The large ships are often built with a method where big blocks are first constructed separately by various suppliers and then fitted together to construct the boat's hull. Assembling hulls at the shipyard demands huge facilities, and the lay-out planning of these facilities full of large equipment and assembly line resources is not an easy task. In EXOPRODIGI, a methodology of 3D scanning has been implemented to create a virtual shipyard of the Western Baltic Engineering shipyard in Klaipeda. The work has been carried out by Visinator and Western Baltic Engineering, in cooperation with Klaipeda Science and Technology Park. With the help of the virtual shipyard, the lay-out planning is taken to another level, where different lay-out scenarios can be tested before the final plan, and simultaneous projects can be synchronized more easily, thereby enhancing productivity. With the help of the accurate 3D

measurements of the facility, precise assessments of cost and time requirements can also be made in the early phase of the projects. Regarding complex supply chains and logistics, Carinafour has focused on enhancing the digital material management system of the Meyer Turku shipyard. The enhanced system facilitates several turnkey suppliers' integrated usage of the same digital system, bringing transparency and flexibility to the supply chains, through which overproduction, material waste, and working hours can be decreased. The enhanced digital material management system improves control and productivity of the whole shipyard ecosystem.

**This synthesis sheds light on the digital tools and solutions developed during the EXOPRODIGI project from a practical point of view. How do these solutions function? Which benefits do they bring? How can they enhance the eco-efficiency and sustainability of the maritime industry? For more theoretical and decision-making-related perspectives on the same thematic, please visit the homepage of the previous, more comprehensive ECOPRODIGI project.**



# DECISION SUPPORT TOOL FOR ENERGY EFFICIENT SHIP OPERATION

Marie Lützen (SDU), Søren Vinther Hansen, (The Navigator), Jan Corfixen Sørensen (SDU), Niels Rytter (SDU)

The decision support tool for energy-efficient ship operation is a data-based solution for ferries sailing on fixed routes. The solution can be used for visualizing fuel and energy consumption during different sailing operations and the time used for the passage from one berth to another. What is essential is the solution's ability to provide the ferry crew with recommendations on how to operate the ferries more eco-efficiently, saving fuel and energy, in different circumstances. During the EXOPRODIGI project, three Danish ferries, Orø, Højestene & Sejerø, have participated in piloting the solution.

*Three Danish ferries, Orø, Højestene & Sejerø, from three different ferry routes have participated in piloting the EXOPRODIGI decision support tool for energy-efficient ship operation.*



## VISUALIZING COMPLEX DATA IS ESSENTIAL

The performance monitoring of the vessels is based on data, which are gathered with data loggers installed onboard. The data loggers gather data regarding depth, heading, position, fuel consumption, rpm, and speed over the ground. The data is continuously sent ashore via the MS Azure cloud, where it is handled and integrated with data on external parameters, such as wind and current, obtained from a weather forecasting agency. Finally, all the data is analysed by a software tool, after which a complete picture of the voyage, together with recommendations for eco-efficient sailing, can be given to the vessel crew. The tool is cloud-based, and the ferry Højestene with a more complex navigation route has even been provided with a mobile application for the tool.

The software tool has been developed by the University of Southern Denmark. This development was initiated during the previous ECOPRODIGI project, and the work undertaken in EXOPRODIGI has been built on the previous findings. The tool is made as open source and can be used as a basis for software development for decision support systems for other ferries after the completion of the EXOPRODIGI project. The programming is performed module-based, which implies that only some main parameters must be reprogrammed.



The user interface consists of six main components; a filter tool, a map where the voyages are visualized, a summary window showing key values for selected voyages, a mode-specific window (harbour, manoeuvre, passage), and, finally a diagram window presenting data values for the selected voyages as customized graphs. The software can give the crew a detailed description of their voyages. It visualizes the time and fuel consumption, speed, course, engine settings, and external conditions such as wind and current.

## RAPID ENERGY CONSUMPTION REDUCTION WITH SIMPLE ACTS

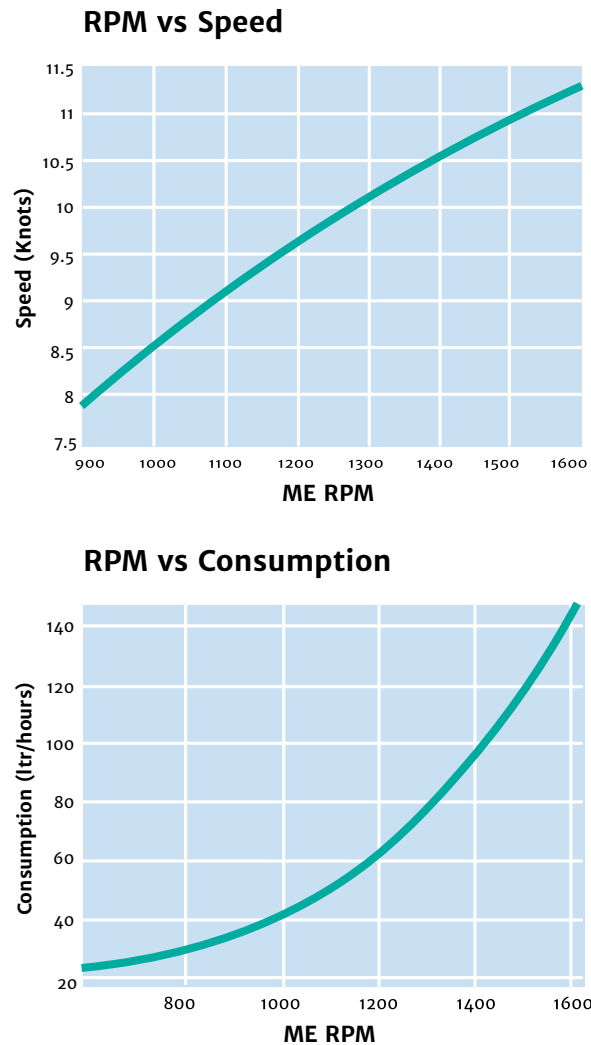
According to the analysis of the gathered data logger data, the energy consumption can be greatly reduced on the ferries merely by changing operational practices and time schedules, as well as by implementing an effective booking system. These initiatives can be implemented fast – the operational practices can be executed immediately, and the time schedule changes from the next season.

## Operational Considerations

The project analyses have shown that by measuring just a few data systematically, it is possible to provide the crew with enough valuable information on the vessel performance. Improving the performance and energy efficiency of the ferry requires the crew to have the tools that help them to estimate the fuel consumption and to be able to identify/evaluate energy savings and cost-effective initiatives. The EXOPRODIGI project has shown that it is possible to provide relatively old ferries with enough information to estimate their performance. Before the commencement of this project, the crew did not have any information on the fuel consumption, due to which they solely relied on their assumptions on energy-efficient operations.

## Baselines

The baseline curves for the speed and engine relationship are of the greatest importance when estimating the vessel performance. The baseline curves are very illustrative, giving the crew information about how even smaller speed reductions can reduce energy consumption drastically.



*Baselines for the vessel.*

## Shallow water and external environmental conditions

When planning the whole voyage, sailing at shallow water in some areas of the route must be considered. Shallow water analysis reveals that it is important to consider the speed setting through the area. In shallow waters the water flowing under the hull speeds up, intensifying the resistance on the hull and causing a so-called 'squat effect', where the ship sinks deeper and increases the wetted area, resulting in a further increase in frictional resistance. Even the waves tend to be larger in shallow water than in deep water. All this added up results in a need for sailing with more horsepower to keep up with the set speed. The external environmental conditions such as wind, sea, and current are unchangeable and the crew must adapt to the current conditions. On a short route with a relatively fixed timetable, it is, in most cases, not possible to make significant changes in the navigational conditions, but it is imperative for the crew to recognize the influence of the different external parameters.



### Correct speed

The analysis shows that it is very difficult for the crew to estimate a proper speed setting for an ongoing voyage without a decision support tool and that the ferries are most likely sailed too fast. If the crew is unaware of the conditions for the entire upcoming voyage, they tend to sail at a higher speed than necessary to avoid being late for the next arrival. The tool helps the crew to adjust the speed to a suitable level, and the vessel will arrive in due time without using unnecessary energy because of having to sail too fast.

**A LOT OF ENERGY CAN  
BE SAVED BY ALLOWING  
LONGER SAILING TIMES**

## STRATEGIC AND ECONOMICAL DECISIONS

### Time schedule and booking

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

### Economy

The cost of equipment is an essential barrier to performance monitoring. Smaller companies do not necessarily have financial resources for purchasing and implementing the equipment. Furthermore, it is difficult for the owner to determine if the investment in monitoring systems and energy-efficient equipment will be cost-effective. Therefore, during EXOPRODIGI, the development of a system that is relatively inexpensive, simple to install, and easy to use has been essential.

## ENVIRONMENTAL BENEFITS HIGHLIGHTED

### Sailing with right speed – arrival just in time

Analyzing data from all voyages for Højestene during the year 2020 shows the importance of having awareness to the speed. The average time used for one voyage was about 70 minutes, which is 5 minutes below the scheduled 75 minutes. The main reason for not using the allocated time is probably that the crew onboard was not aware of the sailing conditions for the whole coming voyage, and therefore sailed with a slightly higher speed than necessary to avoid being late for the next arrival. If these in-effective five minutes are converted to sailing time – the speed of the vessel can in average be reduced from 10.2 to 9.3 knots and the fuel consumption by not less than 20%.

### Time schedule

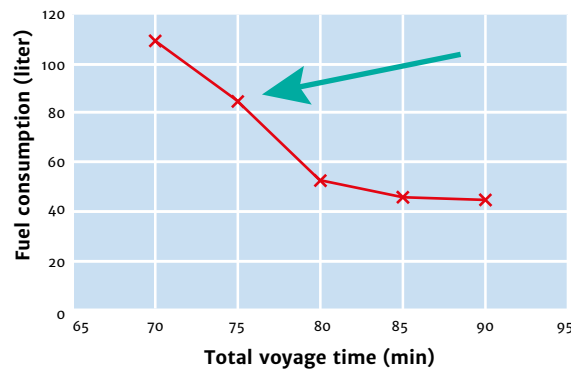
The AI analysis can also be utilized for strategic planning as e.g. rethinking the time schedule. Baselines curves (fuel consumption as a function of speed) can be used to illustrate energy saving if changing the time leads to more time for sailing. Considering the example of Højestene with a sailing time fixed at 75 minutes, if the time is decreased to 70 minutes, the fuel consumption will increase by approx. 30%. On the other hand, if the time is increased 5 minutes to 80, the fuel consumption can be reduced by nearly 40%.

### Shallow water

Most island ferries are passing several areas where the water depth is low. The low water depth greatly

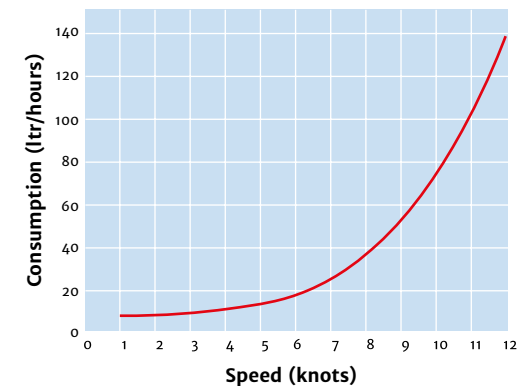
influences the vessels' speed for a given RPM. When passing the area, the shallow water effect will result in a relatively large speed reduction. This effect is clearly shown for Højestene. If RPM, and thereby the fuel consumption, is maintained as given for 10 knots at the deeper water, it will lead to a speed reduction of about 4%, 8%, and 15% for water depths of 8m, 6m, and 4m respectively. If on the other hand the speed of 10 knots is maintained when passing the channel, and the RPM increased for maintaining the speed, the increased fuel consumption will be 8%, 24%, and 70% for the same water depths.

Voyage time versus fuel consumption.



Fuel consumption (total voyage time) Svendborg – Skarø – Dreje					
Min	70	75	80	85	90
Fuel consumption (L)	11,3	84,8	52,0	46,8	45,4
Difference (%)	+31	-	-39	-45	-46

Speed versus fuel consumption



## POSSIBLE BENEFICIARIES OF THE SOLUTION

Direct beneficiaries of the solution include the Danish Ferry Secretary and the ferry routes which have participated in the project. According to the estimates, the ferry routes can achieve a 5–20% reduction in fuel consumption and the same (in percentage) amount in emission reduction. Having said that, this study has been conducted for smaller ferries sailing in Danish waters, but it is assumed that the findings can be used as guidance for smaller ferries and vessels with shorter sea passages worldwide. Ship-owners and ship operators, municipalities, tech vendors, and universities can use the knowledge and know-how shared by EXOPRODIGI, when developing their own business and activities in a more eco-efficient direction, or doing further research related to similar topics.

## MORE INFORMATION ON THE SOLUTION

### *Scientific publications*

- Lützen, M. Hansen, S.V., Sorensen, J.C., Rytter, N.G.M., Greening smaller ferries by optimizing operations, 6th Hull Performance & Insight Conference (HullPIC), Pontignano, Italy, September 2021

### *Publications in press*

- Ø-Færgerne, Beslutningsstøtte til færgenavigatører (EXOPRODIGI), Press, November 2019.
- Søfart, Digitalisering kan give mere energieffektive småfærger, Marts 2021, [https://www.soefart.dk/article/view/779337/digitalisering\\_kan\\_give\\_mere\\_energieffektive\\_smafaerger](https://www.soefart.dk/article/view/779337/digitalisering_kan_give_mere_energieffektive_smafaerger)

### *Websites*

- <http://hullpic.info/>

### *EXOPRODIGI blog & videos*

- EXOPRODIGI continues developing digital performance monitoring solutions to tackle inefficiencies in shipping: <https://ecoprodigie.eu/exoprodigie-digital-performance-monitoring>
- EXOPRODIGI Digital tools for eco-efficient maritime industry: <https://ecoprodigie.eu/animation>

## INSTITUTIONS AND ORGANIZATIONS INVOLVED IN THE DEVELOPMENT WORK

### **University of Southern Denmark (SDU)**

SDU is the developer of the software tool. SDU has even performed a detailed analysis of the gathered data, and the outcomes of the analysis have been presented for the crew and office of the vessels to promote better practices of energy efficiency onboard. Furthermore, analyses and results have been documented in a scientific article and presented at academic conferences and different workshops.

### **Danish Ferry Secretary**

The Danish Ferry Secretary has provided the project with access to three different ferries and ferry routes. The crew and people from the office have been deeply involved and eagerly shared knowledge about their vessels.

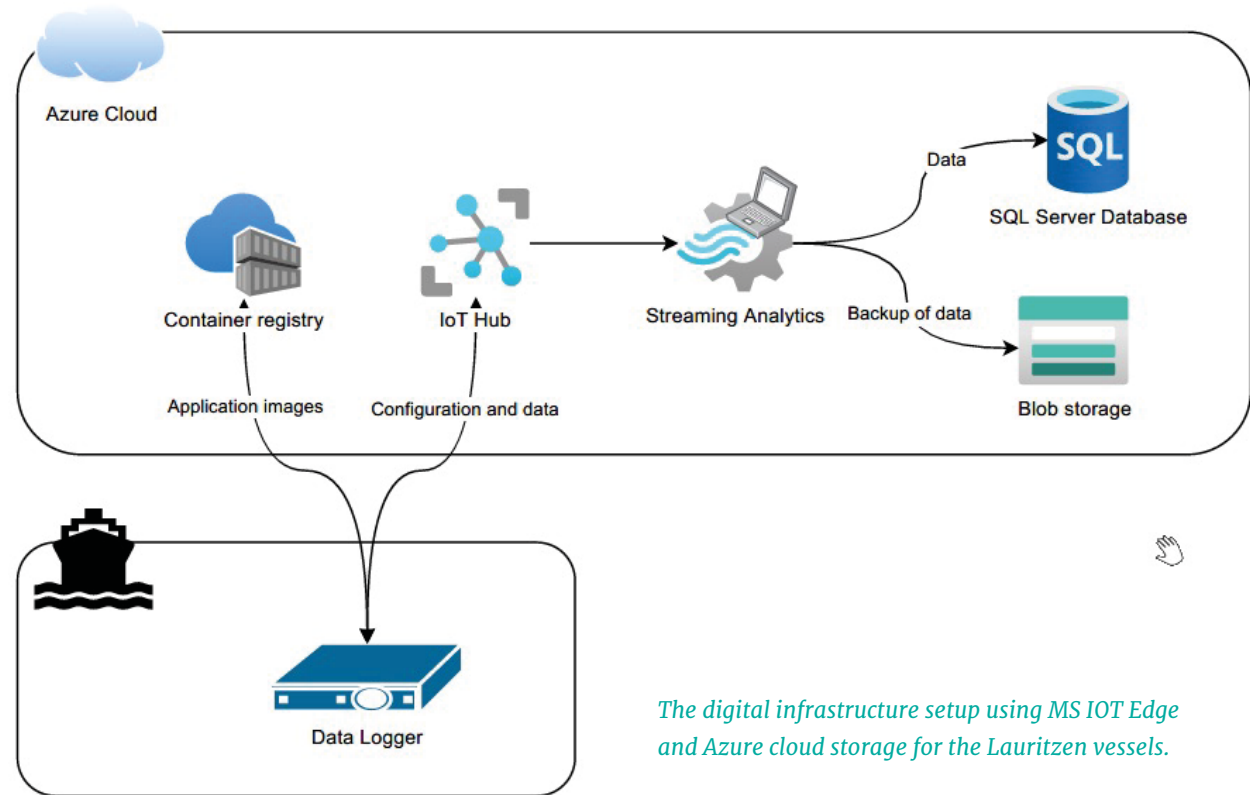
### **Danske Maritime**

Danske Maritime has been a driver for the promotion of making ferries more energy efficient by using digital solutions. The knowledge gained in the project has been presented to a wider audience through the organization. Danske Maritime has also been used as a sparring partner for technical expertise and knowledge.

# DIGITAL ENGINE PERFORMANCE MONITORING SYSTEM

Niels Rytter (SDU),  
Sverre Patursson Vange (J. Lauritzen)

The digital engine performance monitoring system is a high-frequency-based Internet of Things (IoT) system, where data loggers gather data from various sources onboard a vessel. The data can be sourced from the motor, bridge systems, flowmeters and power meters and stored in cloud services and databases onshore, where decision makers can pull, clean, model and analyse the data. During the previous ECOPRODIGI project, high-frequency data loggers were built and installed on three vessels of the J. Lauritzen fleet and connected via satellite/broadband to a data repository in an Azure cloud via MS IOT Edge. The scope of the EXOPRODIGI project has included working with high-frequency (1Hz) data logged from alarm and control systems of the main and auxiliary engines on the J. Lauritzen vessels.



*The digital infrastructure setup using MS IOT Edge and Azure cloud storage for the Lauritzen vessels.*

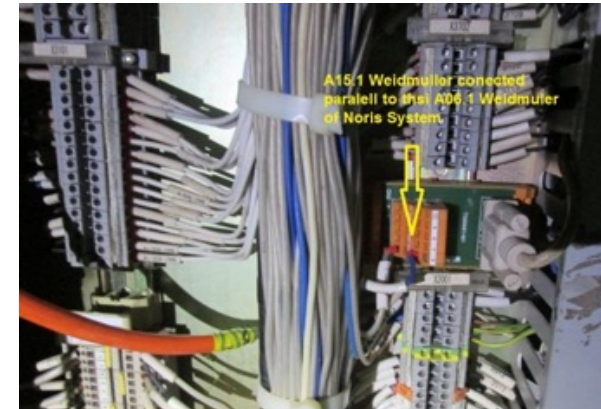
## STATISTICALLY SIGNIFICANT CHANGES IN ENGINE PERFORMANCE PROVIDE ALERTS FOR POSSIBLE PROBLEMS

As part of EXOPRODIGI, a set of Artificial Intelligence (AI) based scripts (e.g. for calculating the standard deviation of exhaust gas temperatures across seven cylinders) were developed for the auxiliary engines to monitor deviations in engine performance compared to 'normal' operations performance. The vessels in scope had one main engine and three auxiliary engines. Statistically significant changes can provide alerts for possible engine breakdowns or other needed maintenance work before the problems occur during daily operations on the vessels. A user interface was developed running onshore in Power BI to support technical staff/vessel managers in monitoring operations.

The scope of EXOPRODIGI has been to further implement and to embed these solutions in vessel operations, as well as their installation onboard vessels, enabling crews to take quick action when needed. The developed solution was initially expanded to run on nine J. Lauritzen gas carriers. Later in the project, the solution was configured to work for not only the auxiliary engines but also the main engines for six vessels in the gas carrier fleet.



*Linda Kosan. One of the six sister vessels on which the engine performance monitoring system was installed during EXOPRODIGI.*



*Detailed view of the data gateway. The NORIS system was updated with data loggers during EXOPRODIGI.*



*A view of the NORIS 3000 alarm system in the engine control room on one of the Lauritzen vessels.*

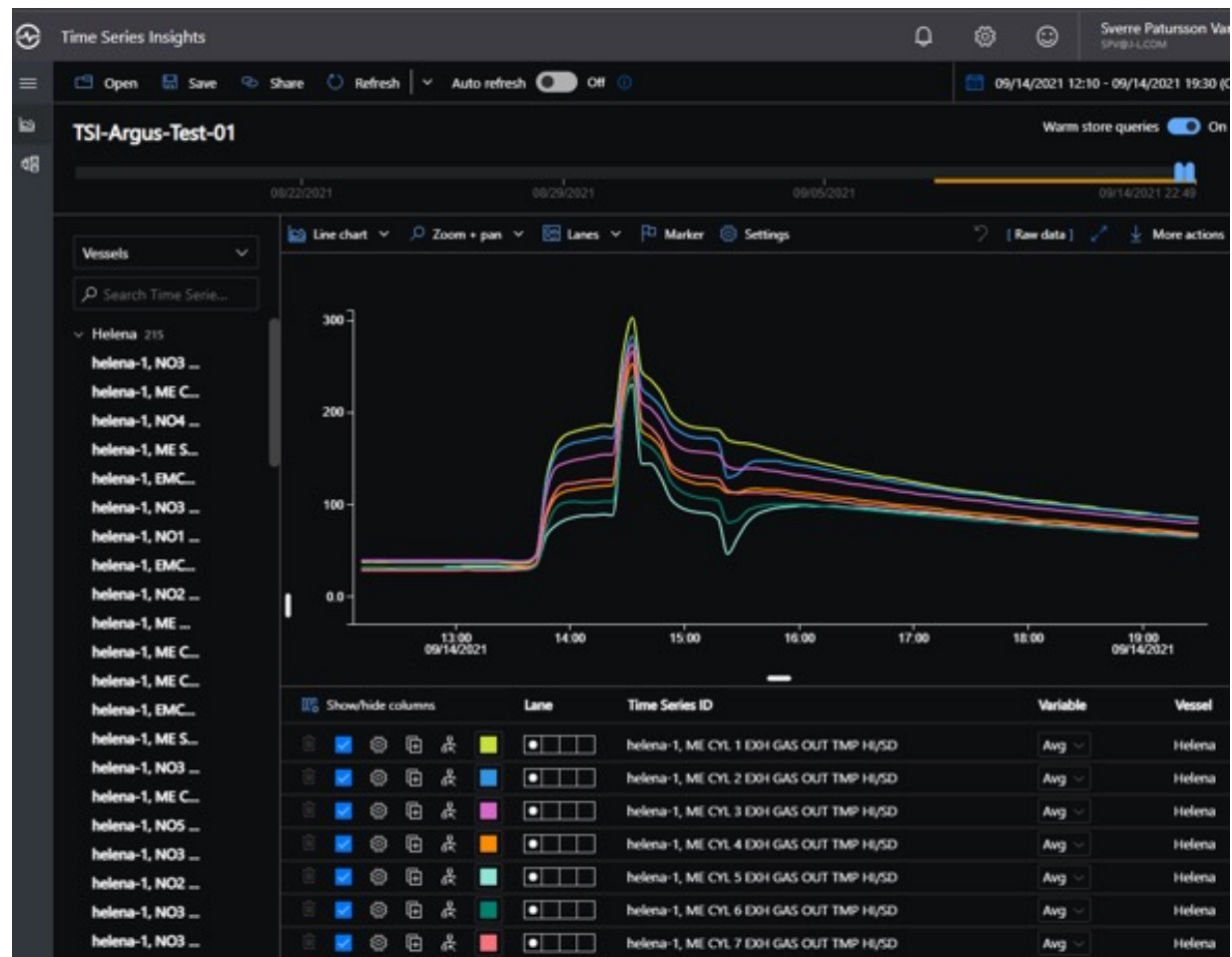


*A picture from the main engine where the StratoPI is connected to the NORIS data gateway, and the vessel's LAN.*

The main engine type is a four-stroke engine, which is similar to the auxiliary engines, and the onboard data source is the already existing alarm system, where data are read and transmitted through the IoT/Edge-based StratoPIs to an Azure account.

### Continuous updates are needed when processing and storing data

During EXOPRODIGI, data storage and the processing of AI scripts in the Azure cloud have been reconfigured to accommodate increasing amounts of time-series data. The data are now transferred from many more vessels compared to when pilot testing was done in ECOPRODIGI. These adjustments were required as the ECOPRODIGI setup was becoming increasingly expensive, and data processing and user queries in the database started to time out. The reconfiguration has enabled J. Lauritzen to implement a more cost-efficient scale-up of prototype solutions while enabling users to receive real-time reports and access relevant raw data instantly during daily work. Preparations have been made to enable AI scripts and data logged to be accessible to onboard crew in the near future.



During EXOPRODIGI, MS Power BI visualisations were substituted with MS Azure cloud-based analytical tools using the Time-Series Insights functionalities.

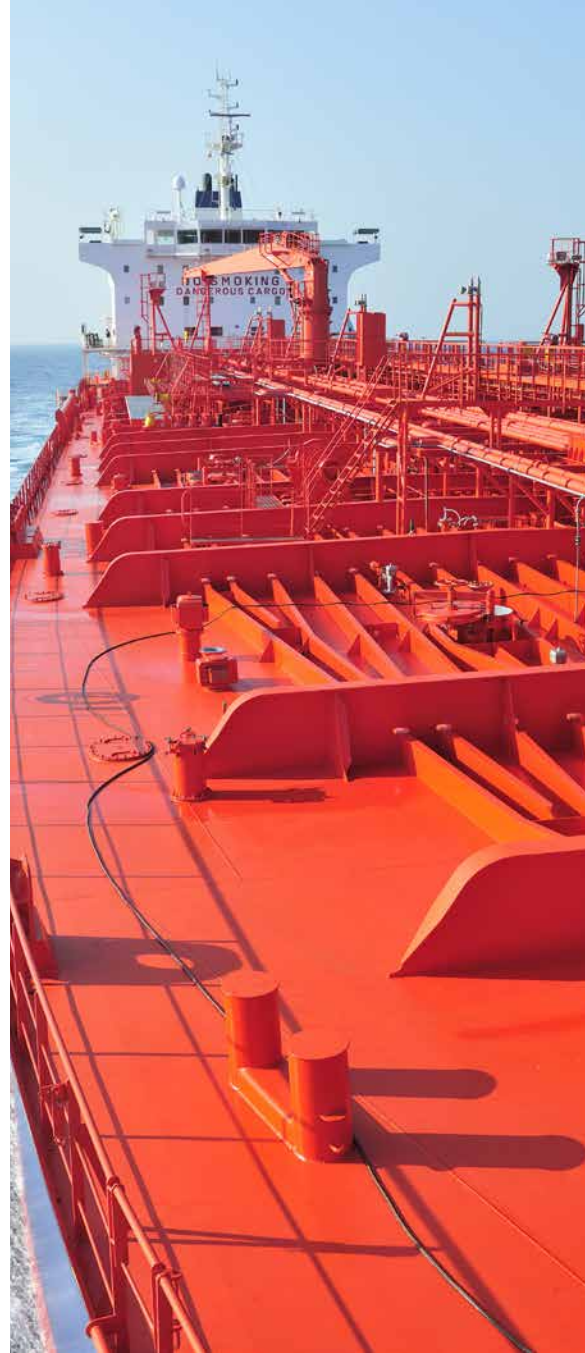
## ECO-EFFICIENCY IN NUMBERS

During EXOPRODIGI, an updated estimate of the costs and benefits from investing in and implementing digital solutions for engine performance monitoring tools has been developed for a vessel that is assumed to be a general medium-sized tanker (e.g. gas carrier, product tanker, etc.). The estimations are based on previous research<sup>10</sup> and calculations on J. Lauritzen vessels.

Estimated return on investment (ROI) per vessel:

- Reduction in time spent on maintenance/repair/inspection = 5%; savings of 37,500 USD per year
- Reduction in costs of items purchased = 10%; savings of 10,000 USD per year
- Less likelihood of safety-critical breakdowns at sea and daily ship off-hire costs = savings of 15,000 USD per year
- Improved energy efficiency of 1% in the relative specific fuel-oil consumption (SFOC): Normal fuel consumption 20 tonnes/day = 5,000 tonnes fuel per year (250 days). A 1% savings per year = 50 tonnes. Price average: 500 USD/tonne → calculated savings = 25,000 USD per year

In addition to these calculations, there will also be fewer spare part inventory turns at our own or supplier warehouses and visible emission reduction benefits.



### Putting the benefits in the right context

The benefits achieved should be compared to the investments made in digital solutions for engine performance monitoring. Investments are generally related to the use of advisory services, software and programming hours and IT infrastructure and systems/data integration rather than to acquiring specified IOT hardware. An estimate of the ROI time has indicated that the engine performance solutions, when fully implemented for Lauritzen, will meet the requirements for payback time for the company. However, the ROI for any other general tanker operator will depend on to what degree the company is able to reuse ECOPRODIGI/EXOPRODIGI results and knowledge, use alternative vendors in the marketplace and convert these for successful implementation in their own business. The current state of vessels and the likelihood of unexpected breakdowns will also impact the benefit case calculations. However, it is likely that an investment of, for example, 25,000 USD per vessel + yearly operations and maintenance costs of 3,000 USD per vessel will be paid back in a few years' time.

<sup>10</sup> Balog et al. 2017; Eriksen, Utne & Lützen 2021

## ENVIRONMENTAL BENEFITS HIGHLIGHTED

For Lauritzen and most other shipping companies, the focus on digitalising fleets and reducing fuel consumption, emissions and operational costs is likely to continue. This will be further promoted by the industry market and regulatory requirements currently being developed by the European Union and the International Maritime Organisation.

In ECOPRODIGI, a potential reduction of 3–7% in fuel consumption and emissions per vessel was identified. This was, however, based on using both engine performance monitoring and another solution that included models for hull and propeller performance. In EXOPRODIGI, the main effort has been to address stretch targets relating to the impact on fuel consumption from auxiliary or main engine operations as follows: **1)** to prevent costly and safety-critical auxiliary and main engine breakdowns and reduce spare part logistics costs via better predictability of the lifetime of components and breakdowns and repair tasks and **2)** to cut fuel consumption and emissions by 1–3% by enabling improved operations and improved energy efficiency in SFOC.

## POSSIBLE BENEFICIARIES OF THE SOLUTION

A direct beneficiary of the IoT solution is the Danish shipping company J. Lauritzen, which has been part of the EXOPRODIGI project, including active participation in the development work and pilot phases of the project. The solution has been customised for J. Lauritzen, but the findings from EXOPRODIGI are being shared publicly to provide valuable information and knowhow, even to other shipping operators or vendors who can continue working with similar solutions to make them commercially attractive. Other shipping companies in Denmark are installing and exploring several components of the solution.

The solution is relatively easy to scale up at J. Lauritzen or any other shipping company. However, the main focus is tailoring the solution to specific ship classes/fleet composition and engine alarm/control systems, IT infrastructures and operational practices. This must be done at the implementation stage for any other shipping company embarking on this journey. The effort will thus require visible investments in more than only hardware or software licences. Additional training of staff onshore and crew onboard is needed for shipping companies to obtain savings/results.

## INSTITUTIONS AND ORGANIZATIONS INVOLVED IN THE DEVELOPMENT WORK

### J. Lauritzen

J. Lauritzen has had the main responsibility for executing further development, implementation and scale-up of the solution on the J. Lauritzen vessels.

### University of Southern Denmark (SDU)

SDU has participated in coordination of activities, and provided consultation when needed regarding the solution and its further development.

## MORE INFORMATION ON THE SOLUTION

### Websites

- J. Lauritzen: <https://www.j-lauritzen.com/>

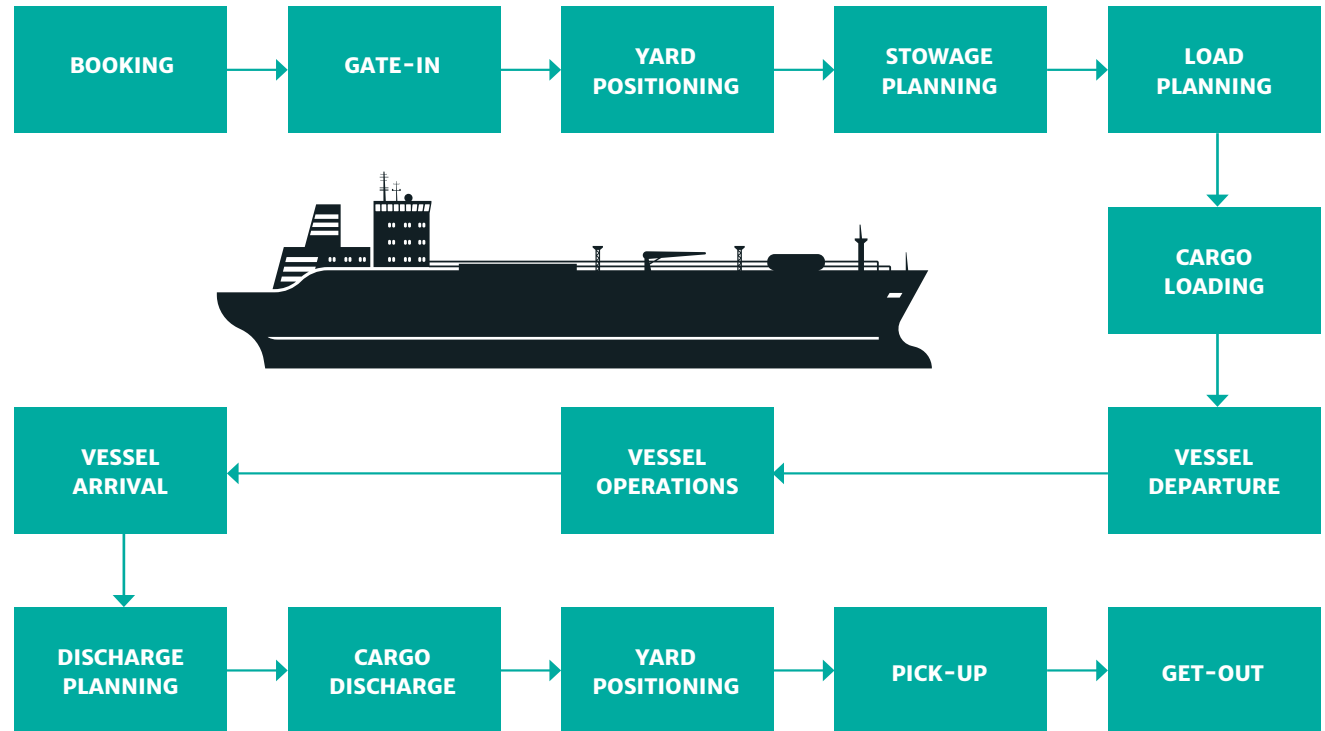
### EXOPRODIGI blog & videos

- EXOPRODIGI continues developing digital performance monitoring solutions to tackle inefficiencies in shipping: <https://ecoprologi.eu/exoprologi-digital-performance-monitoring>
- EXOPRODIGI Digital tools for an eco-efficient maritime industry: <https://ecoprologi.eu/animation>

# ECO-EFFICIENT END-TO-END STOWAGE PROCESS

Niels Rytter (SDU), Jonatan Berglund (Visinator),  
Mads Bentzen Billesø (DFDS)

The scope of the EXOPRODIGI cargo stowage optimization has been to develop the Danish shipping and logistics company DFDS's end-to-end cargo stowage process. The work carried out in EXOPRODIGI leans heavily on the work and findings accomplished during the previous ECOPRODIGI project. During ECOPRODIGI the project team drafted a vision for the year 2025 depicting how DFDS can operate a digital, integrated, and eco-efficient end-to-end stowage process in the future after outlining specific solutions deriving from the vision. In EXOPRODIGI, the development of the solutions has continued from the point where ECOPRODIGI was finished.



*An end-to-end stowage process is a chain of agents such as trucks, cargo units, tugs, vessels, trailers, and crew, whose actions are dependent on each other and linked by different data systems, in order to accomplish stowage operations.*

# VISION 2025 – KEY ELEMENTS

*Illustration of the Vision 2025 for end2end Cargo Stowage processes developed as part of ECOPRODIGI for DFDS (2018).*

Real time tracking of arrival of cargo units



Efficient loading and discharge process



Valid predictions of cargo unit arrival times shared with customers



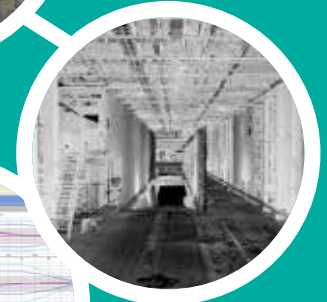
Smart Gate validates cargo ID, damages, weight and dimensions (2D / 3D)



Cargo unit location and conditions tracked at terminal and on ship



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



To achieve the vision 2025, the following set of solutions were drafted to be implemented in shorter and longer-term:

- Smart gates, which in addition to existing Optical Character Recognition (OCR) functionality can validate cargo unit ID, weight in motion, dimensions, and condition of cargo units via implementation of digital solutions such as cameras, LIDAR, AI algorithms, etc.
- Digital data capture of cargo unit information, inclusive positions and conditions at the yard, and onboard vessels with the help of Internet of

Things (IoT) trackers, GPS, or cameras/ vision solutions.

- Systems and data integration across applications in the end-to-end stowage process, for example, enabled by standardized data formats and APIs across applied IT applications
- Develop and implement end-to-end cargo stowage ‘digital twin’ models. Particular emphasis should be on simulation (2D /3D) and optimization models, which can be used by decision-makers to simulate alternative asset layouts, vessel stowage methods, cargo operations procedures/ sequences, etc. (for example using dual

cycling) for multiple or individual voyages to create eco-efficient plans for port operations and vessel stowage.

- Increase use of simple models to support decisions and predict the impact of decisions. For example, models for predicting the expected discharge (ETD) time of cargo units/trailers upon vessel arrival might be of relevance for clients.
- Development of methods to train and build skills of terminal staff, vessel crew, port, and HQ office staff.

The ECOPRODIGI and EXOPRODIGI projects have contributed to the realization

of several of the components in the 2025 Vision for end2end cargo stowage, focusing mainly on three key elements of the vision: Cargo unit location and conditions tracked in a terminal and on the ship; planning of port, tug and vessel operations using optimization and simulation tools and efficient loading and discharge process. In EXOPRODIGI, the project partners engaged in the work have included Visinator, the University of Southern Denmark, and Kockum Sonics (read more on Kockum Sonics’ work in the following article *Deckmaster – a smarter cargo loading system*).



## DIGITAL DATA CAPTURE FOR CARGO UNITS

As part of both ECOPRODIGI and EXOPRODIGI, the project team has worked on enabling better digital capture of data on cargo units, inclusive tracking, along the maritime supply chain. Ideally, cargo unit information such as type, dimensions, weight, position, conditions, and status should be identified, shared, and validated across various transport modes of an accompanied/unaccompanied trailer during road, rail, and vessel transport. There are multiple digital technologies in place to accomplish this purpose, such as:

- Vision solutions (QR Codes, OCR for trailer ID, license plates, logo) using Stereo Cameras, Line Scanners, LIDAR solutions, etc. Mounted optionally at the gate, on drones, tugs, vessels, etc.
- IoT and Track units/sensors (GPS, RFID, Bluetooth LTE, UWB) for monitoring cargo unit positions and conditions
- Connectivity options (WIFI, LORA, 5G, Bluetooth Smart, UWB, NB IOT, LTE etc.) and data formats (MQTT, HTTP etc.)
- Hardware processing (NVIDIA, Google Coral etc.)

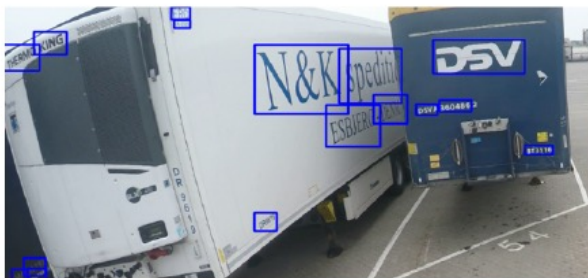
- Cloud based IT infrastructure (AWS, Azure, Google Cloud etc.) for data storage, modelling, computing and analysis and integration with existing DFDS applications / databases
- Machine Learning (ML) algorithms enabling detection, recognition, categorisation, condition monitoring and weight-in motion estimation of cargo units using one or multiple sensor / camera setups

Based on testing of different digital solutions, considering cargo unit information in databases available at the booking or gate-in stage, the EXOPRODIGI research team has sketched a recommendation for how to combine IoT and vision technologies in a coherent solution able to accomplish the following:

- Detect trailers and persons using ML
- Recognize trailer ID code and category using ML
- Detect trailer location on the ship deck area
- Detect trailer location on the yard
- Automatic detection of dangerous situations

The final digital solution that will accomplish the aforementioned tasks will be built by Tallin University of Technology, during an innovation project titled RoRoGreen (2020–2023). The final solution is likely to include among others:

- Sensor setup consisting of RGB camera, RTK GPS, and Bluetooth smart
- NB–IoT/LTE–Cat M1 wireless comm.
- 24V vehicle power compatible
- A Deep Learning hardware accelerator
- Software processing unit



*Example on testing/evaluation of two alternative Machine Learning Algorithm detecting trailer logo and trailer IDs. (Esbjerg Port, March 2021)*

A benefit of the planned solution is that investments will have to be made by the terminal owner/operator or shipping company and not the owners/operators of the trucks and trailers. Owners and operators of trucks/trailers are still today hesitating to make the required investments in IoT technology and IT infrastructure, as they sometimes doubt whether they can expect to achieve benefits from optimizing transportation and storage across the maritime RoRo value chain.

### 3D SCANNING OF VESSELS AND CARGO UNITS

Visinator has planned and carried out 3D scanning of the four cargo decks of a DFDS RORO ferry, the Ficaria Seaways. The resulting data represents a 1:1 digital replica of the spatial properties of the cargo holds and can be accessed on local computers using 3D software or over the internet using a browser. In addition to the digitalization of the vessel, several cargo units have also been digitalized using 3D scanning.

Besides the scanning, Visinator has piloted and tested data processing stages for creating simulation ready 3D models of the material handling vehicles used for loading and unloading. These models will enable using not only 2D but also 3D simulation technologies for analysis of strategical decisions on investments in assets as well as allow for optimal planning and execution of stowage, loading and discharge processes.



*Equipment for 3D Scanning applied on a DFDS vessel to scan Cargo Decks.(Gothenburg Port, September 2021)*



*Example of cargo unit digitalized using 3D scanning and processed to simulation ready 3D-model.*

## ENVIRONMENTAL BENEFITS HIGHLIGHTED

Digitalising data sources, integrating different applications, and moving in the direction of implementing digital twins including simulation/optimisation models into decision support tools will 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), reduced driving of cargo units in terminals, as well as shortening of port stays, thus enabling DFDS to sail slower and save fuel on the sea leg for the ferries. DFDS's 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 instance, for the Copenhagen-Oslo route, shortening the port stay by merely 15-30 minutes might allow the equivalent of up to 5% of fuel savings per voyage.

## INSTITUTIONS AND ORGANIZATIONS INVOLVED IN THE DEVELOPMENT WORK

### Visinator

The Swedish company Visinator has executed the 3D scans of the Ficara vessel and made them available for future use in DFDS as well as future projects applying 3D simulation models.

### SDU (AAU)

The University of Southern Denmark (with one resource also affiliated with Aalborg University Copenhagen) has contributed to several of the task deliverables which have been a continuation of ECOPRODIGI efforts. For example, development and testing of solutions for digital data capture and enhancement of optimization models for cargo stowage.

### DFDS

The Danish logistics and shipping company DFDS has provided the project knowledge on cargo operations, and given access to the terminal operating systems, thus facilitating the development of new digital solutions.

## MORE INFORMATION ON THE SOLUTIONS

### Scientific publications

- Jia B., Fagerholt K., Reinhardt L.B., Rytter N.G.M. (2020) "Stowage Planning with Optimal BallastWater." In: Lalla-Ruiz E., Mes M., Voß S. (eds), Computational Logistics. ICCL 2020. Lecture Notes in Computer Science, vol 12433, pp. 84-100. Springer, Cham.
- Jia B., Fagerholt K. (2021) "Step-wise Stowage Planning of Roll-on Roll-off Ships Transporting Dangerous Goods." Maritime Transport Research, vol. 2, p.100029. Elsevier Ltd.
- Jia B., Tierney K., Reinhardt L.B., Pahl J. (2021) "Optimal Dual Cycling Operations in RoRo Terminals." Submitted.
- Jia B., Rytter N.G.M., Reinhardt L.B., Haulot G., Billesø M.B. (2019) "Estimating Discharge Time of Cargo Units - A Case of Ro-Ro Shipping." In: Paternina-Arboleda C., Voß S. (eds) Computational Logistics. ICCL 2019. Lecture Notes in Computer Science, vol 11756, pp. 122-135. Springer, Cham.
- Jia, B., Sustainable Short Sea Roll-on Roll-off Shipping through Optimization of Cargo Stowage and Operations, Ph.D. thesis (upcoming), Aalborg University Copenhagen, 2021

### EXOPRODIGI blog & videos

- Efficient cargo stowage processes for the benefit of maritime supply chains: <https://ecoprologi.eu/exoprologi-efficient-cargo-stowage-processes>
- EXOPRODIGI Digital tools for eco-efficient maritime industry: <https://ecoprologi.eu/animation>

# DECKMASTER – A SMARTER CARGO LOADING SYSTEM

Oscar Grossmann (Kockum Sonics), Mads Bentzen Billesø (DFDS)

Deckmaster is a tablet-based application, fostering smarter and faster cargo stowage. The application has been developed during the EXOPRODIGI project as part of a larger cooperative whole, aimed at augmenting the eco-efficiency of the multifaceted cargo operations of commercial ports. Deckmaster is designed as a supplement to the existing Loadmaster X5 loading computer, but it can be simultaneously integrated with any booking system, thus enhancing data transfer and facilitating operations in the ports.

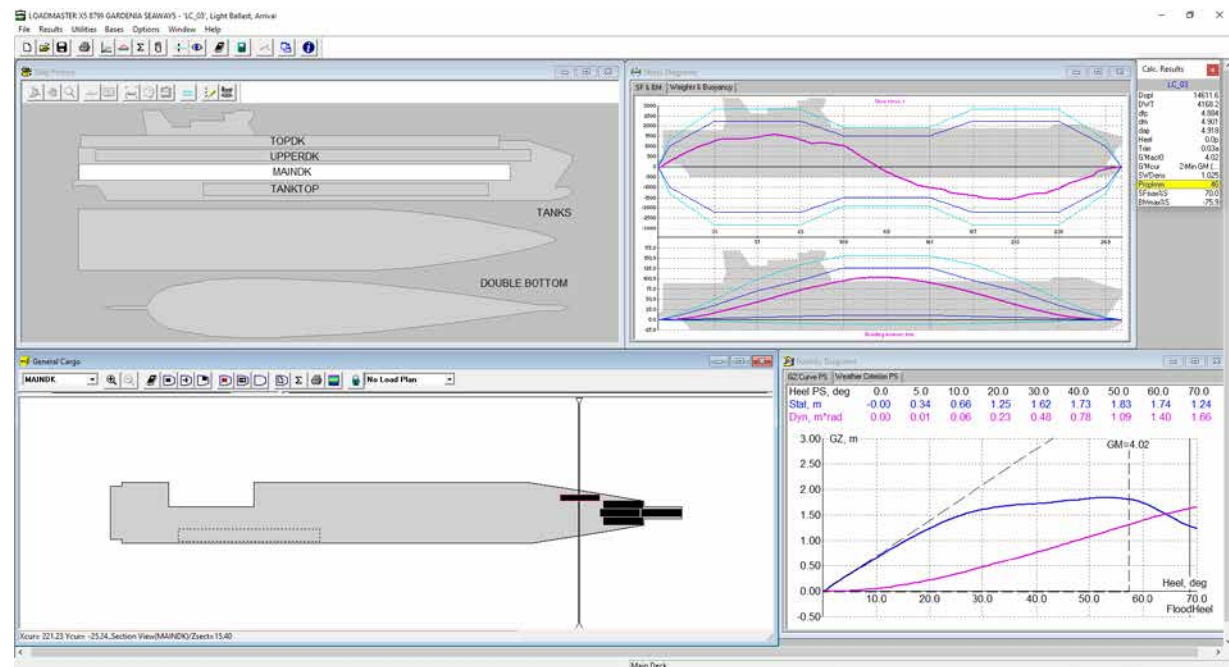
## OPTIMIZING CARGO PLACEMENT ONBOARD

The application will obtain the booking list for a specific voyage from the terminal system, including information about all cargo units that are to be shipped. Subsequently, specific units are selected from the booking list and placed onboard the vessel in the application. Simultaneously, the data is sent to the loading computer, which will

revert with relevant stability parameters, such as floating position to the Deckmaster. Deckmaster can therefore be used to plan a voyage so that the loading of a vessel is carried out properly. The cargo units are placed onboard in a strategic way and used to level out the vessel, hence less ballast water will be needed to acquire the desired trim and heel values.

Usage of the Deckmaster application will improve the cargo loading and unloading of ships, and thus decrease the turn-around time spent in the harbour.

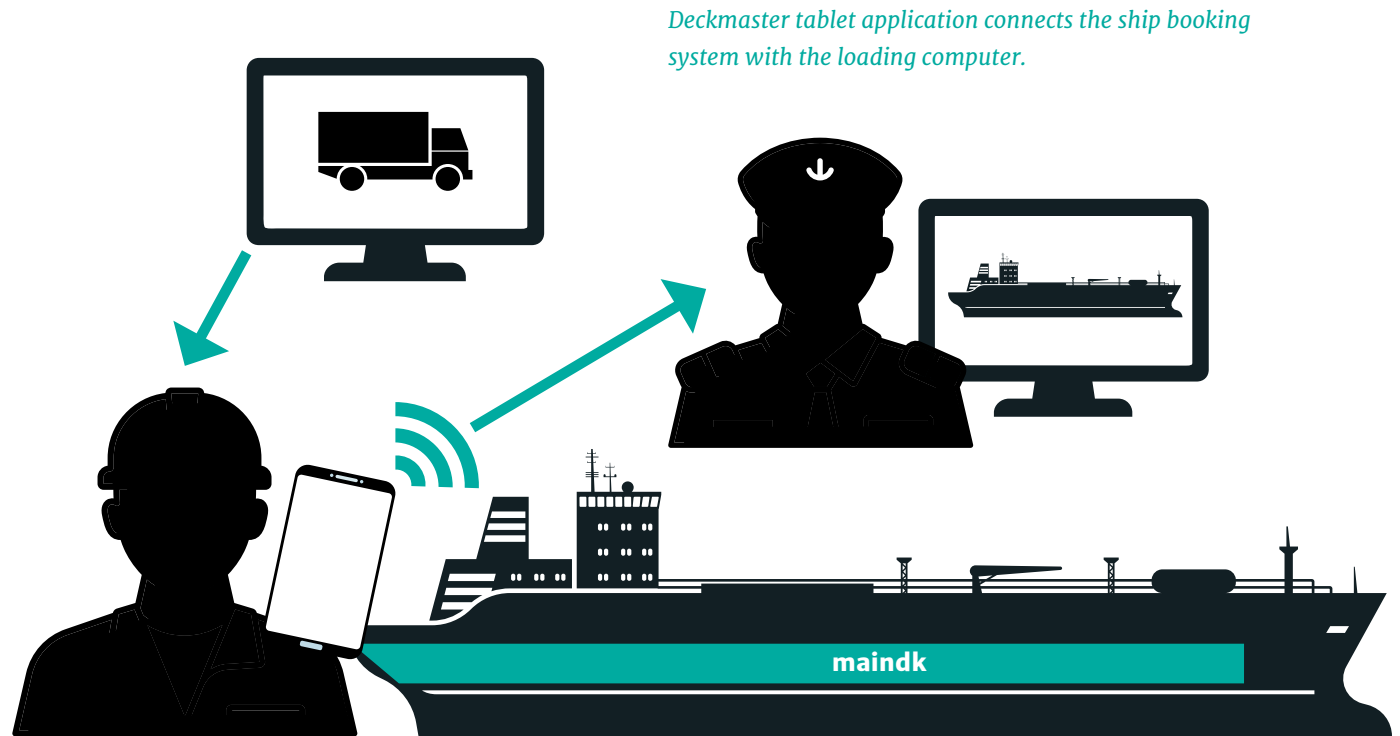
The time saved in harbour operations can instead be used for optimizing the sailing speed of the ships. Even small changes and slightly decreased sailing speed will lead to decreased fuel and energy consumption. The application even helps to optimize the vessel stability with proper cargo placement, resulting in a reduced need for ballast water. Even a diminished amount of ballast water onboard will help attain fuel savings and lead to a reduced risk of transferring aquatic invasive species by transporting ballast water from one harbour to another.



The interface of the loading computer, showing the placement of cargo units onboard the main deck.

## FLUENT DATA FLOW BOOSTS ECO-EFFICIENCY

Port operations such as bookings, terminal operations, stowage planning, and stability, as well as voyage performance, often rely on several different applications, which all might be using different data formats. This causes severe disconnects in the data flow, causing extra work and a lack of real-time data input for specific work tasks. By integrating the applications and harmonizing the data, it is possible to transfer data automatically between the different applications and provide real-time data input and knowledge otherwise not known during the operations. By connecting the booking system to the stability computer one can use the known characteristics of a vessel, such as floating position, amount of ballast water, and tank locations while loading. When commencing the loading of a vessel, only approximately 50% of the cargo units are present in the terminal, and the rest will arrive while loading is underway. By combining the knowledge of units that are ready to be loaded and how it affects the floating position of the vessel during the loading operation, it is possible to plan the operation in a manner where there is a continuous flow of cargo units entering the vessel. At the same time, a stable scenario with the minimum usage of ballast water transfers is more likely to come true.



### Increasing the awareness of the crew

Using the Deckmaster application will also increase the awareness of the crew since they can follow the live loading and stabilizing of the ship, and even receive a precise overview of hazardous cargo; all this leads to reduced handling errors onboard. The integration of applications and increased awareness of the crew will thus lead to more optimized port operations and enhanced eco-efficiency of the whole port.

During the EXOPRODIGI project, Deckmaster has been piloted in cooperation with the logistics and shipping company DFDS, combining Deckmaster with their existing systems and data applications. However, a connection from any type of booking system can be set up to Deckmaster; thus, various stakeholders can find the application and its functionalities useful when aiming to improve cargo operations in different ports.



## ENVIRONMENTAL BENEFITS HIGHLIGHTED

### Shorter turnaround time results in reduced fuel consumption

If the Deckmaster application is used correctly, it can reduce fuel consumption for each voyage of a ship. The application decreases the turnaround time spent in the harbour and thus saves time, which can be used to let the vessel operate at its most optimal speed during sailing. Even a small deceleration in the sailing speed reduces the fuel consumption of the ship.

### Reduced ballast water provides many advantages

As the application is even used to place the cargo optimally onboard and stabilize the ship with a proper cargo placement, the stowage will result in a reduced need for ballast water. A reduced amount of ballast water and thus, a lighter freight, will further cut down the fuel consumption of the ship. Meanwhile, the diminished amount of ballast water even lowers the risk of transporting aquatic invasive species, which are often a threat to biodiversity when relocated into a new living area through the ballast water discharge.

## INSTITUTIONS AND ORGANIZATIONS INVOLVED IN THE DEVELOPMENT WORK

### Kockum Sonics

The Swedish company Kockum Sonics is the developer of the Deckmaster application. Kockum Sonics has a long experience as a supplier of marine and industrial applications, and was even involved in the previous ECOPRODIGI project.

### DFDS

The Danish logistics and shipping company DFDS has provided the project knowledge on cargo operations, and given access to the terminal operating and booking systems, facilitating the development of a new integrated application.

## MORE INFORMATION ON THE SOLUTION

### Websites

- Kockum Sonics: <https://www.kockumation.com/>

### EXOPRODIGI blog & videos

- Efficient cargo stowage processes for the benefit of maritime supply chains: <https://ecoprodigieu/exoprodigiefficientcargo-stowage-processes>
- EXOPRODIGI Digital tools for eco-efficient maritime industry: <https://ecoprodigieu/animation>

# DIGITAL TWIN OF SHIPYARD PRODUCTION FACILITIES

*Jonatan Berglund (Visinator)*

During the EXOPRODIGI project, a digital twin of the Western Baltic Engineering shipyard in Klaipeda has been created using 3D laser scanning. The digital twin denotes a representation of the current state of the shipyard during the time of scanning. Notably, the twin has been edited by removing all the unnecessary objects and work in progress, to be able to provide a neutral representation of the production facility and its equipment. The twin signifies the geometrical and visual aspects of the shipyard and can be used to accurately plan future operations and work tasks in great detail. Product and equipment drawings and models can be placed in the digital twin to simulate processes and material handling tasks.

## DATA PROCESSING TOOL FOR 3D DATA / VIRTUAL PRODUCTION FACILITIES

During the project, Visinator and Western Baltic Engineering have implemented a workflow from



*Scan of shipyard facility / Western Baltic Engineering, Klaipeda*

the automotive industry in the shipyard setting. The workflow includes aspects of both data capture and processing. For data capturing purposes, Traceable 3D equipment developed by ATS AB has been utilized in conjunction with FARO SCENE software for scan processing.

Methods for further processing of the data for use within the shipyard production planning processes are detailed and can be carried out in several commercially available software packages. This processing includes cleaning of equipment and

work in progress, sectioning of equipment, and combining digital twin data with CAD models to verify processes and material handling scenarios. The process developed accommodates the inclusion of cross-functional teams in the planning process. By utilizing highly realistic model representations along with problem-solving and evaluation methods, the solution enables VR visits to the proposed virtual factory solutions and allows subject experts to review the proposed solutions further in detail.

## DIGITAL TWIN ENABLES MORE ACCURATE LAYOUT PLANNING AND MINIMIZES ERRORS

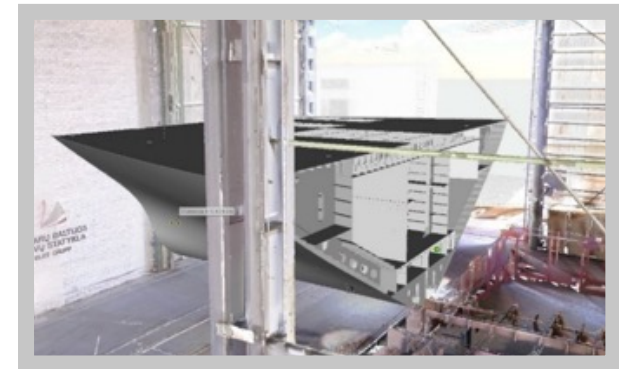
The Western Baltic Engineering shipyard facility is a vast and complicated environment with a plethora of resources and equipment that are themselves large and complex. Measurements are difficult to attain at all, especially with good accuracy. The existing drawings of the shipyard facility are nominal and approximate, without considering any shifts and movements in the ground plan and building structure. This reduces the reliability of the drawings, and can potentially lead to non-feasible solutions being developed. Moreover, the planners could end up taking unnecessary safety buffers to account for the uncertainty when planning the layout, material handling tasks, or other process-related solutions.

### Access to the virtual enhances productivity

The new digital twin provides the process planners access to a 1:1 scale representation of the shipyard facility. The twin facilitates the planners to virtually test and evaluates different scenarios before the physical product exists and before the final layout has been decided upon. All size factors throughout the production of a block can be visualized and measured at their planned locations with accuracy throughout



the shipyard. This allows the planners to make precise assessments of cost and time requirements for a given project early in the tender process. Since an accurate and up-to-date representation of the facility and the equipment there enable the planners to make reliable decisions based on true measurements, the risk of discovering errors during the implementation phase of a project is minimized. By ensuring that the processes are planned more accurately, the area used in the shipyard can be optimized more efficiently. Thus, more products can potentially be processed simultaneously, and with fewer unnecessary internal movements of the products. In doing so, a more efficient product movement plan can be developed at an early stage of the project and in synchronization with other



*Simulating the movement of the ship block inside the shipyard facility.*

ongoing projects. Put succinctly, the digital twin solution improves the process execution in terms of enabling more accurate layout planning, and by extension, a suitable arrangement of the production facilities.

The digital twin improves the workflow of the process and planning engineers mainly. However, by letting them create a better and more optimized plan, even the work on the shipyard floor level becomes easier and more efficient. Getting feedback on conflicts or issues at an earlier stage than previously will allow the engineers more time to find solutions and avoid problems as early as possible. Optimally this will even lead to less firefighting and more preventive work in the engineering department.

## POSSIBLE BENEFICIARIES OF THE SOLUTION

The direct beneficiary of the Digital Twin solution is Western Baltic Engineering, one of the EXOPRODIGI project partners which has not only provided physical shipyard surroundings for realizing the 3D scanning work but has also been an active participant in the development of the solution. This solution has been customized for Western Baltic Engineering, but the findings from EXOPRODIGI are shared publicly, thus providing valuable information and know-how even for other shipyards around the Baltic Sea, which can continue working with similar solutions.

## INSTITUTIONS AND ORGANIZATIONS INVOLVED IN THE DEVELOPMENT WORK

### Western Baltic Engineering

Western Baltic engineering has been responsible for the technical implementation of the project. The company and is located at the shipyard which was selected as a pilot implementation facility.

### Klaipeda Science and Technology Park

KSTP has been responsible for technology transfer and application activities during the pilot. To gain a sufficient disruption and eco-efficiency of the existing processes, it is important for 3D scanning to become standardized for the shipyard's supply chain. Therefore, KSTP is implementing activities that promote the solution along the supply chain and cross-industry to enable business partnerships and share knowledge to innovate production processes in the shipyard and beyond.

### Visinator

Visinator has adapted and developed the methodology for digital twin creation and utilization from the automotive industry to fit the needs in the maritime shipyard setting. It has also supplied the know-how and equipment for the digitalization process and processed the resulting datasets to models for use in shipyard process planning activities. Furthermore, Visinator has developed the methodology for the development and evaluation of shipyard process solutions in cross-functional teams to create faster and more accurate decision-making processes.

## MORE INFORMATION ON THE SOLUTION

### Websites

- Klaipeda Science and Technology Park: [www.kmtp.lt](http://www.kmtp.lt) / Andrius Sutnikas
- Western Baltic Engineering; [www.wsy.lt](http://www.wsy.lt) / Justas Kavaliauskas
- Visinator: [www.Visinator.se](http://www.Visinator.se) / Jonatan Berglund

### EXOPRODIGI blog & videos

- Optimising production planning and processes at shipyards: <https://ecoprodig.eu/exoprodig-optimising-shipyard-processes>
- EXOPRODIGI Digital tools for eco-efficient maritime industry: <https://ecoprodig.eu/animation>

# CALS – DIGITAL MATERIAL MANAGEMENT SYSTEM FOR LARGE SHIPYARD ECOSYSTEMS

*Juha Simula (Carinafour), Maarit Lappalainen (Carinafour), Julia Ajanko (UTU)*

CALS is a digital material management system, meant for controlling the supply chain planning and material logistics flow of industrial processes. During the EXOPRODIGI project, CALS has been developed further by adding new features to the system that enhance the turnkey material management of the Meyer shipyard in Turku and effectively serve the entire industrial ecosystem around the shipyard. The Meyer shipyard ecosystem is a complex entity that includes several turnkey suppliers, who have responsibilities over large entities of the ship construction, and all the turnkey suppliers have their own subcontractors and supply chains. Thus, an enormous amount of data is needed for planning, producing, storing, and moving different materials along the pipeline properly and in a timely manner.

## MORE FLUENCY WITH FOUR NEW FUNCTIONALITIES

During the EXOPRODIGI project, CALS has been developed further by adding four new functionalities to the system:

- 1) System support to manage material-related master data to create a digital interface between design and supply chain more efficiently. Using this feature, CALS supports easy exporting and importing of big material master data loads. The big material master data loads can even be updated and edited with the help of this new feature.
- 2) Planning capability to manage several turnkey suppliers in the same system. Several turnkey suppliers can be included in the CALS system, and the users can independently make their plans in the system. However, it is notable that different turnkey suppliers cannot see the plans of other turnkey suppliers; only the system central logistics operator can see and maintain all the system data. The central logistics operator can, for example, manage data regarding the main warehouse, where several turnkey suppliers store their materials. Different materials and material flows are separated in the system without mixing them.

- 3) System capability to enhance current material ordering and call-in processes. Ordering confirmations by emails or phone calls have been replaced by functionality in the system, where the supplier can confirm the orders. Confirmation will automatically update the orders in the system and create visibility to supply chain material availability.
- 4) Enhanced warehouse management capability. The system can now manage the materials of several turnkey suppliers in one warehouse. New warehouse management capability enables for example goods receiving, put away, picking, packing, and shipping for each turnkey supplier with own controlled warehouse operation.

The development work of CALS builds on the findings from the previous ECOPRODIGI project. The focus in EXOPRODIGI has been on enhanced scalability and flexibility of the system. The new CALS capabilities are mainly based on standard supply chain principles, which is why the system is not designed to support just one type of supply chain setup. The system and its capabilities can be configured to support several different supply chain setups, and therefore many different industrial end-users can find an interest in the system.

## CONTROLLED AND TRANSPARENT MATERIAL PIPELINE ENHANCES ECO-EFFICIENCY

A shipyard ecosystem can all in all include several turnkey suppliers, all with their supply chains and various subcontractors, not all of these always operating at the same place where the ship is assembled. A properly functioning logistics system is, therefore, a premise for a well-functioning shipyard ecosystem. What has been challenging for the Meyer Turku shipyard, is that not all turnkey suppliers and their subcontractors have had proper logistics systems in use, and the existing systems have not necessarily been linked to each other. Thus, the material information has been scattered and possibly inaccurate along the pipeline, thereby making it difficult to get a complete picture of the supply chain situation. This has led to full warehouses where excess materials have been stored since all parties try to buffer to secure the project execution. Some parts have even been re-ordered unnecessarily, due to missing information regarding the material availability.

### Scalability and flexibility in focus

The enhanced CALS tackles the above-mentioned challenges by facilitating the usage of the same system by several turnkey suppliers, who can import their own big data loads for master data into the system. All of them can create and

schedule their specific delivery plans, which the central logistics operator can see and follow up, thus improving transparency and control over the material pipeline. CALS can support turnkey supplier's material planning, warehousing, direct deliveries, and logistics in many different setups, thereby achieving the targeted flexibility.

Fluent data-based material flow enables even shorter storing times and more accurate deliveries, enhancing efficiency in digital pull-model production in the entire shipyard ecosystem. The

system benefits both the material and turnkey suppliers; as a result, managers, planners, and workers along the whole logistics chain can execute and adjust their tasks according to the prevailing situation and timetable. Thus, the CALS-supported planning and material management system ensures better control over the timely materials and their installation operations within the turnkey supplier ecosystem. Hence, it can be seen that continuous improvement of the turnkey ecosystem's overall productivity is enabled through digital supply chain management.

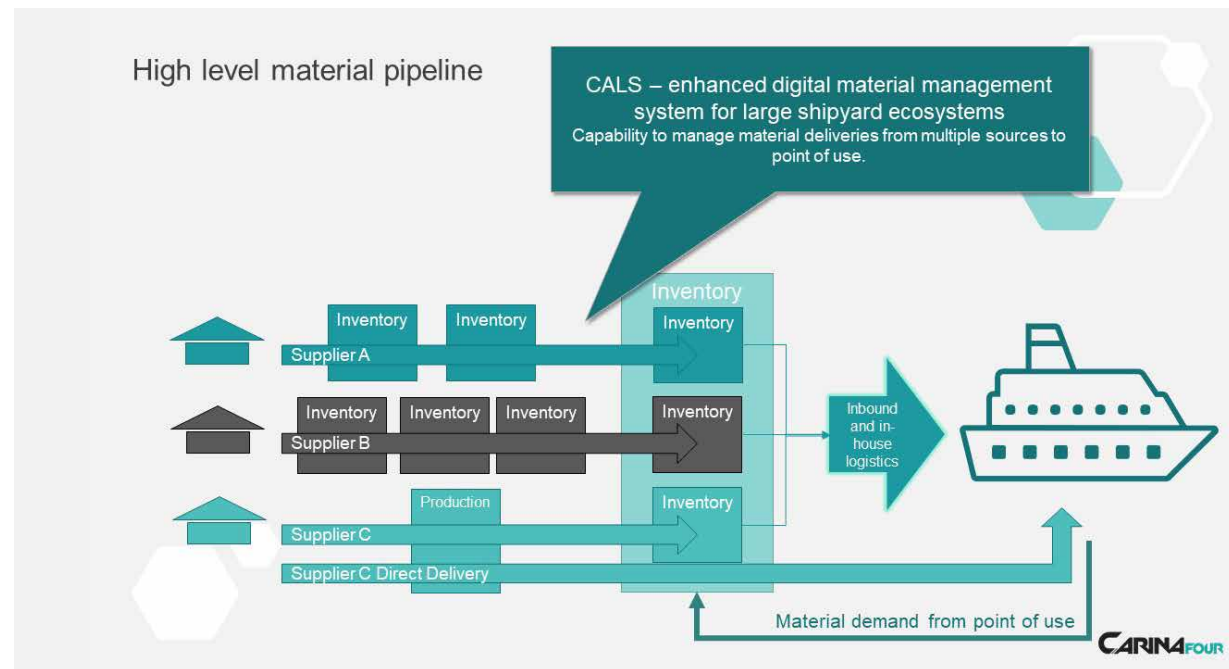


Illustration of a shipyard material pipeline.

## ENVIRONMENTAL BENEFITS HIGHLIGHTED

A properly integrated digital material management system facilitates more accurate and transparent planning and production management, and a better-controlled material pipeline leads to more optimized material production and delivery. In practical terms, this means that no excess material needs to be produced just to be on the safe side, and no re-ordering of materials is needed because material productions and information are kept updated and can be followed in the system. Thus, resource efficiency is highly increased and the amount of material waste decreased by using CALS. If a centralized warehouse is taken into use, deliveries to the shipyard can more probably be executed with fully loaded trucks, instead of half-empty trucks. In this manner, even transportation waste and emissions can be minimized.

## POSSIBLE BENEFICIARIES OF THE SOLUTION

The direct beneficiary of the CALS-digital material management system is the Meyer Turku shipyard, the EXOPRODIGI partner which has provided the shipyard ecosystem environment for undertaking development work during the project. Apart from the shipyard itself, the enhanced system benefits even the turnkey suppliers and their subcontractors, the entire shipyard ecosystem around Meyer Turku. However, since the CALS capabilities are primarily based on standard supply chain principles, the system and its capabilities can be configured to support several different supply chain setups. Therefore, even other industrial end-users can find an interest in the system. The EXOPRODIGI findings are even shared publicly, providing valuable information and know-how for other shipyards around the Baltic Sea, who can continue working with similar solutions.

## INSTITUTIONS AND ORGANIZATIONS INVOLVED IN THE DEVELOPMENT WORK AND THEIR ROLES

### Carinafour

Carinafour has been in charge of developing the concept of an enhanced and more eco-efficient shipyard ecosystem and its supply chain. The tool CALS is Carinafour's property, and Carinafour has carried out the development work of the tool in co-operation with an external software supplier.

### Meyer Turku

Enhancing the eco-efficiency of the Meyer Turku shipyard has been the core of the entire development work. Therefore, the shipyard ecosystem with its turnkey suppliers and material supplier network has provided a frame and a testing ground for developing the concept and the logistics tool.

## MORE INFORMATION ON THE SOLUTION

### Websites

- Carinafour: <https://c4.fi/en/frontpage/>
- Carinafour: <https://cals.fi/>

### EXOPRODIGI blog & videos

- Optimising production planning and processes at shipyards: <https://ecoprologi.eu/exoprologi-optimising-shipyard-processes>
- EXOPRODIGI Digital tools for eco-efficient maritime industry: <https://ecoprologi.eu/animation>

# FUTURE PERSPECTIVES ON SHIPPING, GREEN FUELS, AND CROSS-CUTTING TECHNOLOGIES

*Valdemar Ehlers / Danish Maritime*

The EXOPRODIGI project provides a consolidated call for action and engineering solutions on a cleaner and more sustainable shipping and shipbuilding industry in the Baltic Sea Region (BSR). The project builds on the previous EU project ECOPRODIGI (2017–2020) involving a large number of the most significant BSR stakeholders across research organisations, innovation, and knowledge sharing institutions, organisations, technology providers, and municipalities.

*A call for action.* The ECOPRODIGI project focused on obtaining eco-efficiencies without complete renewal but rather clever use of digital solutions at relatively low cost to achieve eco-efficiencies. In EXOPRODIGI we have coordinated and initiated further practical onboard installations, software development, 3D scanning, practical demonstrations, and up-scaling

of activities, focusing on maritime industry cases in digital performance monitoring, cargo stowage optimisation, and optimising shipyard processes. To enable a greener future, the focus from now on should be on further digitalisation and optimisation of all design, construction, and integration processes in the building of ships together with all their integrated systems and arrangements. Similarly, optimum data management in condition monitoring of all shipboard operations, including machinery and other energy-using processes and cargo stowage, needs to be addressed. The ECOPRODIGI and EXOPRODIGI projects have shown the way.

BSR has significant socio-economic potential in utilising the existing stronghold in the maritime and logistics industries. This potential should be better harnessed to strive for a greener future. Further delay or hints of indecisiveness in the support of enabling a green transformation will have pronounced consequences to the ability to further curb BSR pollution & greenhouse gas emissions according to both national and international goals. Initially, it is not only a matter of being the best – it is also a matter of being swift with the right new solutions, thereby avoiding investments spent on less efficient and not entirely sustainable solutions. In recent years, the maritime industry has investigated and researched the usability of fuels.



This has led to an initial focus on drip in fuels which are fuels that may be used immediately without major modifications to ship engines, bunkering procedures, tank pumping, and piping arrangements. However, re-engineering of systems and processes is needed when more radical steps towards de-carbonisation are to be taken.

Here, the future availability of renewable power and the scarcity of bio-based carbon have pointed to **hydrogen, ammonia, and methanol** – besides already being established global commodities, as the most promising fuels. To avoid/minimize energy losses direct electrification should be prioritised and used when possible and practicable, which, in a maritime context, is an on-shore power supply for ships in ports and electricity for propulsion on shorter crossings, today typically of up to a maximum duration of one and a half hours.

Prioritised changes in the regulatory framework conditions will be critical in reducing the risk of the markets for green fuels. Moving towards **levelized prices of green fuels compared to conventional fuel solutions** will thus have significant effects on investment decisions throughout the value chain. This could be through a combination of CO<sub>2</sub> taxes, subsidies, and CO<sub>2</sub>-displacement requirements in a cap-and-trade system.

In tandem with the development of the markets for green fuels, research and innovation will thus allow for more **optimal combinations and scaling of existing technologies towards optimum eco-efficiency**. In the longer term, it could potentially allow for the **breaking of entirely new ground within the technologies** linked to the production of green fuels by researching in optimization of electrolysis and catalytic processes. Hydrogen will become cheaper, and the transformation to ammonia and methanol will become more effective. Research is even required to allow for **optimal use of feedstocks** for green fuels across off-take sectors based on Life Circle and substitution analyses. Finally, the utilisation of green fuels in the different ship types will be optimised.

Green fuels for use in engines in ships require research into efficiency for new or retrofitted engines/energy converters as well as new methods for modelling, forecasting, controlling, and optimizing engines running on green fuel. Higher efficiency translates into less fuel consumed and more space for cargo. Consequently, energy conversion on-board ships should be as efficient and compact as possible which is a second driver for design and development. Finally, green fuels follow **new safety issues** that also call for research and development of new regulations before these fuels are commercially attractive.

Stay ahead. The BSR is already a world leader within shipping, shipbuilding, and maritime equipment as well as catalytic processing. Furthermore, the BSR stronghold mirror the wind energy & forest industry production capabilities and know-how, which is second to none and offers cheap green power throughout the globe. In addition, the openness and trustfulness in the BSR research and innovation environment as well as in related industries constitute the basis for unique collaborations across the entire value chain. By choosing timely to adhere to the necessity of making green fuels a key element at certain stages and in certain areas and regions within transport and industry, BSR's position in the lead of the global transition towards a sustainable future can be sustained. It is essential to ensure, that green fuel technologies in combination with eco-efficiencies, further digitalisation, and possible carbon capture solutions will be a substantial and an increasing part of the sustainable economic activities of the BSR going towards 2030 and beyond.

## FINAL REMARKS

*Julia Ajanko, UTU*

According to the recent estimates, the GHG emissions from international shipping have been steadily increasing during the past decade, mainly due to continuously increasing global maritime trade. Between 2012 and 2018 the GHG emissions from total shipping increased 9.6 %, from 977 million tonnes to 1,076 million tonnes<sup>11</sup>. Without any additional measures taken, it is not difficult to realize that the curve will continue in the same direction, if not steeper. Luckily, much has happened even after 2018. International Maritime Organization (IMO) has adopted a GHG strategy to reduce carbon intensity (CO<sub>2</sub> per tonne) by 40% by the year 2030, and by 70% by the year 2050, in comparison to the 2008 levels<sup>12</sup>. Total emissions from international shipping are aimed to be cut by 50% by the year 2050, compared to 2008. Besides IMO's strategy, European Union has launched its ambitious Green Deal package, including a call for a 90% reduction in GHG emissions from all modes of transports, maritime transport included, and with an overall goal of becoming a climate-neutral continent by 2050.<sup>13</sup>

**TO BETTER EMBED THE BLUE ECONOMY INTO THE GREEN DEAL, THE EUROPEAN COMMISSION HAS EVEN ADOPTED A NEW APPROACH TO A SUSTAINABLE BLUE ECONOMY IN 2021**

To better embed the blue economy into the Green Deal, the European Commission has even adopted a new approach to a sustainable blue economy in 2021<sup>14</sup>. The approach sets focus on the solutions, which can be offered by a sustainable blue economy to achieve the Green Deal objectives, for example, by developing offshore renewable energy and by greening the maritime transport and ports. The approach is not an exhaustive action plan, but some possible future solutions for decarbonizing the maritime sector are mentioned, such as zero-emission vessels, an extension of the EU Emission

Trading system to maritime transport, production and uptake of renewable and low-carbon fuels, use of onshore power supplies, energy-efficient service vessels, ports as hubs for energy, circular economy, communication and business and smart digital solutions optimising handling at ports.<sup>15</sup> Furthermore, the approach calls for maritime and marine research and innovation as essential driving forces for enabling the transformation needed to achieve the Green Deal. Innovative technologies, such as artificial intelligence, advanced modelling, sophisticated sensors, big data, and autonomous systems, are seen as essential for transforming the blue economy in the immediate future.<sup>16</sup>

Within the EXOPRODIGI project, we have dived deep into the world of innovative technologies and maritime industry in the Baltic Sea Region. We have developed, augmented, and piloted new digital tools and concepts to be used during a great deal of a vessel life cycle; from planning to building to operating a ship with the help of the new innovative solutions. On a more detailed level, we have touched upon vessel performance monitoring, cargo stowage processes at ports, and shipbuilding processes at

<sup>11</sup> Fourth IMO Greenhouse Gas Study, 2020

<sup>12</sup> Ibid.

<sup>13</sup> COM/2021/240 final

<sup>14</sup> European Union – Sustainable blue economy

<sup>15</sup> COM/2021/240 final

<sup>16</sup> Ibid.

shipyards, so as to bring eco-efficiency into the core of all of these ensembles. We have worked with data loggers, artificial intelligence, machine learning, software development, big data, data and IT-system integration, and 3D modelling, not forgetting planning, research, and conceptualizations around these technologies. What we have observed, is that the path to eco-efficiency within the maritime industry is not a straightforward or a fixed one. On numerous occasions, it is a matter of trial and error, sometimes a dead end. However, we have also been fortunate to witness that very often, even smaller successful steps can be a trigger for a change in the bigger picture. To arrive at the right decisions and to implement transformative solutions, we need to keep striking while the iron is hot. Pushing forward for eco-efficient maritime industry and seafaring needs dedicated engagement from every related interest and stakeholder groups - including business, decision-making, civil society, research, and financing parties. The IMO GHG strategy and European Green Deal have set proper frames for making this come true. If we work hard and keep pushing now, we can hopefully see the change towards eco-efficiency and sustainability to come about as when Moominpappa was standing beside a slope and rolling stones



*“But Moominpappa wasn't listening, because just at that moment he had got the right grip on a big round boulder, and with a great thud it rolled down the slope. It made two very clear sparks and left a faint but enchanting smell of gunpowder behind. Now it was lying at the bottom, just where it should lie. It was wonderful to roll stones, first pushing with all one's might, then feeling them beginning to move just a little at first -- then a little more -- and then giving way and rolling into the sea with a colossal splash, leaving one standing there trembling with effort and pride.”*

**Tove Jansson, Moominpappa at Sea**

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