MOSES PROJECT: ENHANCING SHORT SEA SHIPPING WITH AUTOMATED TECHNOLOGIES

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ABSTRACT

The MOSES Project (AutoMated Vessels and Supply Chain Optimisation for Sustainable Short SEa Shipping) aims to enhance the short sea shipping (SSS) component of the European supply chain. The MOSES project aims to create sustainable SSS feeder services to small ports with an expected 10% modal shift to SSS in designated areas. To attain this target, MOSES proposes a combination of automated/autonomous technologies and supply and demand matching optimisation, like its AutoDock system for containerships in large terminals, which consists of the MOSES Autonomous Tugboat Swarm, supported by MOSES Shore Tugboat Control Station, and the automated docking scheme. Loading times for feeder vessels in large and small ports are expected to decrease by 20% from the operation of MOSES Robotic Container Handling System outfitted on MOSES Innovative Feeder. Supply chain optimisation aims at increasing the attractiveness of SSS. The Innovative Feeder will be designed for a net reduction of greenhouse gas emissions of more than 90%. The MOSES solution expects to attract stakeholders to SSS for a more sustainable EU container supply chain from the environmental, cost, and societal perspectives.

Keywords: autonomous vessels, port optimization, clean technologies, safety, modal transport, SSS.

1 INTRODUCTION

Ports play a decisive role in the EU's external and internal trade. Although ports and especially deep-sea shipping (DSS) ports are integral nodes within multimodal logistic flows, short sea shipping (SSS) and inland waterways are not so well integrated. As the European Union (EU) has aimed for a modal shift from road transport to other more sustainable transport modes, such as rail or waterborne transport, SSS has gained more attention. After liquid bulk, containers have been the dominant type of cargo in EU SSS. The Mediterranean is one of Europe's major sea basins. The perspectives of container shipping in the western Mediterranean side reveals a trend of expansion of major infrastructure in the main ports while in the eastern side of the Mediterranean Sea, Black Sea and Suez Canal offer a significant opportunity in the container transportation to eastern European trade areas. MOSES addresses these challenges in a collaborative manner. This paper presents the main outcomes of this project, developed by a consortium of European companies and research centres, such as MARIN, Trelleborg, CIRCLE, Fundación Valenciaport, McGregor, coordinated by the National Technical University of Athens (https://moses-h2020.eu/).

The aim of the MOSES project is to enhance the SSS component of the European supply chain by addressing the vulnerabilities and strains related to the operation of large containerships. A two-fold strategy has been followed from the beginning, in order to reduce the total time to berth for TEN-T Hub Ports and to stimulate the use of SSS feeder services to small ports that have limited or no infrastructure. Fig. 1 summarises the MOSES concept.

2 IDENTIFICATION OF MARKET OPPORTUNITIES AND BUSINESS CASES

In the context of the MOSES project, a two-fold strategy to reduce the total time to berth for TEN-T hub ports, and also to stimulate the use of SSS feeder services to small ports that have limited or no infrastructure, have been followed in this assessment. In this respect, a typology

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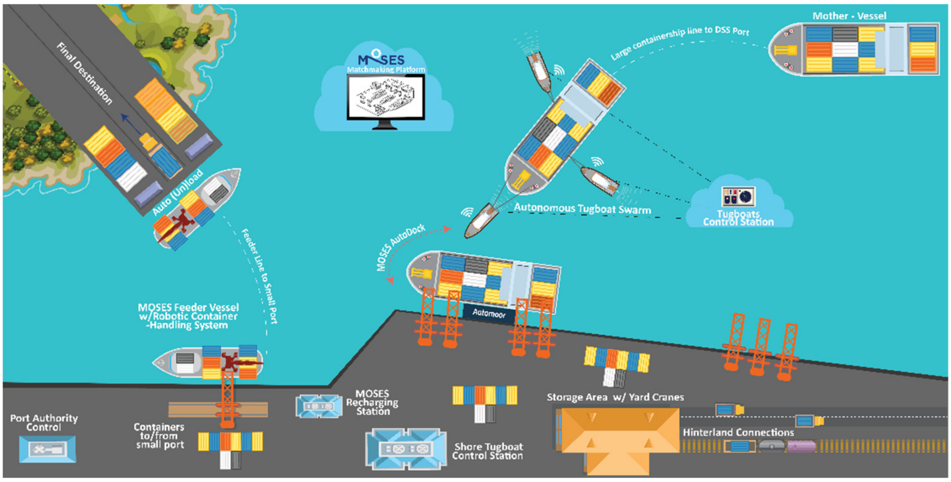

Figure 1: MOSES concept.

of the ports was suggested for the Innovative Feeder vessel and Robotic Container Handling System innovations.

Furthermore, the market opportunities have been exploited for the MOSES innovations in the context of the SSS part of the container supply chain and develop the MOSES Business Cases: western Med-Spain and eastern Med-Greece, in view of the MOSES Transferability Business Case. The focus was on a preliminary analysis to evaluate the viability for container feeder lines, with some innovations in the feeder vessel, versus the current transport system for the case of the port of Piraeus, and also for the case of the port of Valencia. As regards the port of Piraeus, the scope of work concerns a potential feeder line between the port of Piraeus, Mykonos, and some nearby Greek islands. In the current situation, all the general cargo traffic between Piraeus and Mykonos and nearby islands is handled by Ro-Ro or Ro-pax vessels. On the other case, for the port of Valencia, the scope of the work concerns a potential feeder line between three ports managed by the Valencia Port Authority: Valencia, Sagunto, and Gandía. For our case, the containers that reach Sagunto and Gandía hinterlands are loaded/unloaded in Valencia port.

For the case of Piraeus, it concluded that nowadays, the whole general cargo traffic between Mykonos and nearby islands is Ro-Ro traffic, composed of trucks and trailers. Therefore, to develop a container feeder line, the cargo should not only be transferred from the Ro-Ro logistic chain to the Lo-Lo logistic chain but should also be consolidated/unconsolidated in a different way, which will be a significant added difficulty. The expected demand for the container Greek feeder is shown in Table 1.

For the case of Valencia, the analysis showed that despite the longer land distances to the Sagunto and Gandía hinterlands, the shortage or absence of container lines in Sagunto and Gandía port has as a result that most of the traffic is handled through the port of Valencia and carried to the hinterland by truck or rail depending on the case. To evaluate the possibility of developing a container feeder line that links the three ports managed by APV (Valencia, Sagunto, and Gandía), it has been proposed a feeder service with a frequency of three weekly services, with geared ships. And it has been observed that the feeder line would be competitive around Sagunto and Gandía, where the expected container demand for this line is shown in Table 2.

Table 1: Container potential traffic of the feeder line Piraeus port and the islands of Mykonos and nearby islands.

Port	Full containers			Empty containers (TEUs)	Feeder line demand (TEUs)
	Load (TEUs)	Unload (TEUs)	Total (TEUs)		
Paros	730	999	1,729	269	1,998
Mykonos	**2,353**	**34**	**2,387**	**2,319**	**4,706**
Naxos	870	149	1,019	721	1,740
Kea	647	1	648	646	1,294
Syros	569	102	671	467	1,138
Tinos	461	65	526	396	922
Total	**5,630**	**1,350**	**6,980**	**4,818**	**11,798**

Table 2: Container demand of the feeder, by ports and cases (TEUs/year).

Port	Region	Demand captured by feeder line (TEUs/year)		
		Pessimistic scenario	Base scenario	Optimistic scenario
Sagunto	Castellón	13,697	18,263	22,829
	Valencia	38,832	51,776	64,719
	Total Sagunto area	**52,529**	**70,039**	**87,548**
Gandía	Valencia	25,203	33,604	42,006
	Alicante	1,982	2,643	3,303
	Total Gandía area	**27,185**	**36,247**	**45,309**
Total per year		79,714	106,285	132,857
Average per week		1,532	2,043	2,554
Average per service (assuming three weekly services)		511	681	851

3 MOSES INNOVATIVE FEEDERS

The MOSES project ambition is to design innovative feeder vessels. The innovations for the vessels were concentrated on two different directions, in which the innovations for the maritime industry are being developed and demanded by society. The first one was the ambition to reduce or eliminate harmful emissions by designing environmentally friendly vessels. The second one was the ambition to design a highly autonomous feeder vessel, which is able to sail large part of its route without human intervention. Main drive here was to reduce the number of accidents due to human errors followed by a reduction in cost.

The design of both zero emission and autonomous vessels of this size is beyond the current state of the art of technology. Especially for seagoing vessels the steps that are made in this field are very small. Up to now most zero emission and/or autonomous vessels are operated in a small and coastal area or at inland waters. The design of larger seagoing vessels with a capacity of 100 or more than 600 TEU (twenty-foot equivalent unit) and an increased autonomy range, has not been done before. In addition, the vessels were equipped with an autonomous robotic crane.

Concept designs were made using information from a Greek and Spanish business case in combination with the concept of operation and requirements.

In the design of the vessels, partly autonomous operation of the vessels has been considered. This was done in the selection of the equipment but also considering the effects autonomous operations might have on the potential safety of the vessel.

3.1 Zero-emissions concept

With the first ship parameters, the route and cargo volumes, a so called “trip simulation” was done. In this simulation, the sailing and logistic operations are calculated for a period of two years. From the results of these simulations, it was concluded that the presented logistic ambitions could be fulfilled with a smaller vessel, which lead to the introduction of a second Greek case for which the design process was repeated.

The design studies for the Greek case showed that it is technically possible to aim for three different power solutions.

(1) A hybrid powered solution, where a methanol fuelled ICE in combination with a battery, which enables partly zero emission operation of the feeder vessel.
(2) A hydrogen fuel cell option is also an option space-wise but comes with many complications. Particular attention in terms of safety, maintenance and bunkering. Bunkering of hydrogen should be feasible time-wise, as the ship’s schedule is typically not very busy, but compressed hydrogen bunkering could still take many hours and requires five truckloads of hydrogen, with support of a land based compressor to reach 700 bar. As an alternative, a large shore-based facility is needed to fuel hydrogen.
(3) A full battery-electric alternative seems disproportional given the large amount of battery storage needed at cost of both available cargo space and a reduced payload.

From these three options, a hybrid powered solution is the most appropriate, making use of shore power and charging during sailing, providing sufficient battery capacity to operate the vessel in the ports of the Greek islands. At open sea, the vessel will be using methanol as a fuel for sailing and charging of the battery.

The operational cost of the hybrid methanol solution (1) is found to be about 15% more than those for a conventional feeder vessel. This is attributed to the higher price of the selected energy carriers for the innovative feeders. The cheapest solution is a vessel with a capacity close to the requested demand per trip rather than an oversized one.

The design study for the Spanish case showed that three power options are feasible.

(1) A battery-electric option is technically realistic, despite that it also requires a rather large battery compared to existing electric newbuilding’s, which are much smaller compared to this vessel. In comparison to the total available volume and weight, the battery option seems to fit well.
(2) A methanol hybrid powered solution is more compact, but still features a relatively large battery (6.5 MWh compared to 29 MWh for full electric).
(3) Liquefied hydrogen may be an option space-wise, but compressed hydrogen would require additional deck space which is currently not included in the design. In any case, when it comes to hydrogen, there are many complications to consider. Particular attention is needed in terms of safety, maintenance and bunkering. Due to the limited free time in the schedule, bunkering at a designated area (as required for hydrogen) may be completely unfeasible. Instead, battery charging can be done when moored below a crane, facilitating sufficient time for batteries to be charged.

For the Spanish case both a methanol hybrid powered solution and a battery electric solution were found to be feasible from a technical and operational point of view. The operational cost of the methanol hybrid solution is about 10% lower than those of a conventional design. The cost reduction is derived via the increased autonomy and manoeuvrability of the vessel, which results into lower cost for pilotage and tug assistance.

The PHA for the innovative feeder concepts has resulted in a non-exhaustive list of 12 hazards that are the sources of specific hazardous events. The identification was a result of brainstorming sessions and structured approach to rating the frequency and consequence severity of each event. The identified events relate to the following system components, focusing on innovative aspects of the feeder:

- Propulsion machinery;
- Fuel/energy storage system;
- Cargo space;
- Superstructures;
- Hull.

Most relevant identified hazards are listed in Table 3 and have included technical failures, human factor issues, properties of the energy source used, and issues related to the limits of the operational envelope. In addition, the hazards relate to the following operational phases of the feeder: sailing, cargo operations, and hazards that can arise during all operational phases.

The concept designs of the innovative feeder vessels prove to be feasible for a zero emission and an autonomous ready design feeder vessel for routes that currently are not being served. Thus, the concepts are not only new, but the various evaluations of the selected hybrid concepts show that the realisation of these concepts is feasible and beyond current practise.

Finally, it must be noted that the future costs of the innovative vessels will be lower than those of the conventional ones once a tax related with CO_2 emissions is introduced.

3.2 The autonomous crane

To increase the possibilities for expanding container supply chain to ports where the infrastructure is not supporting lifting containers from/to vessel, the feeder vessel will be outfitted with a robotic container-handling system that is autonomous, i.e., self-sufficient in terms of (un)loading containerized cargo.

Because the on-board robotic crane is able to operate autonomously, i.e. does not need an onsite or on-board crane driver, it is a key innovation for enabling a short-sea container supply chain completely independent from small port infrastructure. In short, the robotic container handling system is designed as a fully self-supporting system that does not need any local help except a quay for berthing and for placing the containers, while maintaining safety of operations.

The MOSES scope is:

- Develop and demonstrate a Robotic Container Handling System (RCHS) capable of handling standard containers.
- Shore control interfaces to landside infrastructure and vessel loading computer.
- Creating a 3D-world model, including sensor suite, for the robot container handling system.
- Virtual reality assisted remote supervisory control of the robotic container handling system.

Table 3: Summary of top hazardous events.

(System comp.) Hazard (ID)	**Hazardous event**	**Consequence**	**Risk mitigation measures**
(Propulsion machinery) System complexity	A technical failure of the hybrid propulsion installation cannot be handled by the crew on board	• The need for specialised support leads to unplanned downtime • Disruption of operation while sailing may lead to injuries/fatalities • Personnel on board unable to manage complex incident	System design (e.g. operator's assistance, autonomous features) and manning need to account for equivalent or higher safety level at engineering compared to baseline, reduction of human error compared to baseline, and optimal number of crew on board for handling systems complexity (issues to be addressed in T3.2)
(Propulsion machinery) Extreme weather/ technical failure	Failure of the generator system when it cannot cope with the load variations in extreme weather conditions	• The energy conversion system will not follow the dynamic loading required by the system. DC grid voltage may drop resulting in a loss of available propulsion power • Possible need to abort operation and subsequent failure to meet demand	• More diesel fuel will be injected to increase the engines dynamics • Alternatively, the battery system should be designed to cope with the dynamic loading as it has a much faster response time. The generator should then only need to run at the average load, and the batteries will provide power in the peaks, and will be recharged in the "lows" • Assessment of system power capacity (incl. redundancy) and power/battery management systems' capacity to handle extreme weather events
(Cargo space) Crane operation	Position of the container crane on board impedes operation of port cranes	Slower cargo handling when using port cranes	• Optimisation of the crane's position on the main deck • Detailed risk assessment to identify required safety systems/barriers during cargo operations • Further considerations in the detailed design of the crane to include limits switches and emergency stop, according to Class rules

Table 3: Continued.

(System comp.) Hazard (ID)	Hazardous event	Consequence	Risk mitigation measures
(Cargo space) Situation awareness	Relative longitudinal position of accommodation and crane limits visual monitoring of the cargo space from the bridge	Fire in cargo space or cargo shift/loss is not detected on time due to failure in manual supervision	• 360-degree visibility from bridge • Equip the cargo space with sensors for early detection with less dependence on visual monitoring • (DNV-RU-SHIP Pt.6 Ch.5 Sec.2), for open top container holds the mechanical ventilation is interpreted to be required only for the lower part of the cargo hold for which purpose ducting is required
(Hull) Extreme weather conditions	Water accumulates in cargo hold in harsh weather conditions due to open top design	Stability degradation and damage to cargo	An analysis based on model tests as well as intact and damage stability assessment following the procedure and the requirements described in MSC/Circular.608/Rev.1 respectively shall be carried out. The additional class notation **Hatchcoverless** includes requirements related to this risk, including for example strength requirements in the intact flooded condition (DNV-RU-SHIP Pt.6 Ch.5)

4 AUTODOCK SYSTEM

Due to increased automation-related complexity, there are challenges for autonomous tugs regarding model uncertainty/error, dynamic forces/moments and changes in hydrodynamic coefficients), also present in auto-pilot systems. MOSES relies on systematic robust control design methods, Robust Model Predictive Control and Robust Optimal (H-infinity) Control, successful in many areas, including the control of surface vessels and underwater vehicles Another issue is the complex communication/control among the autonomous tugboat swarm units that increases computational overheads and makes monitoring and fault detection difficult, addressed by applying an appropriate leader–follower cooperative control structure. MOSES provides scalable autonomous operations, in terms of the required number of autonomous tugboats for each task, which make the solution appropriate for ports of various sizes. Finally, MOSES addressed the necessary integration of the swarm of tugboats' intelligent control system with the AutoMoor back-end.

Development of the communication interface between all vessels (tugs and ocean-going vessels) and the automated mooring systems is also a significant challenge.

Currently, AutoMoor requires human input to acknowledge in terms of confirming and acknowledge that the vessel approaching the berth has been correctly identified via automatic identification system (AIS), allowing the mooring operation to commence and providing response to the system warnings.

The advancements of MOSES innovative AutoMoor units include:

1. Developing and converting all of the human confirmation inputs into full autonomy between the tug vessels, ocean-going vessel and the AutoMoor system.
2. Development of an automated mooring product that can moor shallow freeboard and lightly hulled vessels.

4.1 Tugs swarm

Existing tugboat operations use manually operated conventional tugboats that assist large vessels for manoeuvring in port. To cross over from the current system to an autonomous tugboat swarm system, various milestones need to be accomplished. The milestone of creating and developing a virtual environment, which will enable the training of an autonomous tugboat swarm is described in Fig. 2.

This virtual environment is constituted by various objects that represent real-life components, namely water mass, port, containership, and tugboats. To achieve the best possible representation and producing reliable results, the training environment components are introduced with specific characteristics and properties, derived from extensive analyses and simulations. In this way is ensured that the virtual training environment will utilize realistic forces during training of the AI algorithms. For that purpose, a series of hydrodynamic simulations is provided, offering valuable parameters regarding the motion and response analysis of the ship objects. In addition, a finite element structural analysis is presented, which assesses the structural response and the limits of the components in various operations. An example of the simulations conducted is provided in Figs 3 and 4.

The results from this study indicate the maximum allowable approach speed and contact force for the tugboats. Lastly, a validation was processed by defining two categories of test scenarios evaluating respectively the individual behaviour of objects and the interaction between them in the training environment. The results of the first category showcased a good agreement whereas the results of the second a larger disparity led to the conclusion that some adjustments need to be considered.

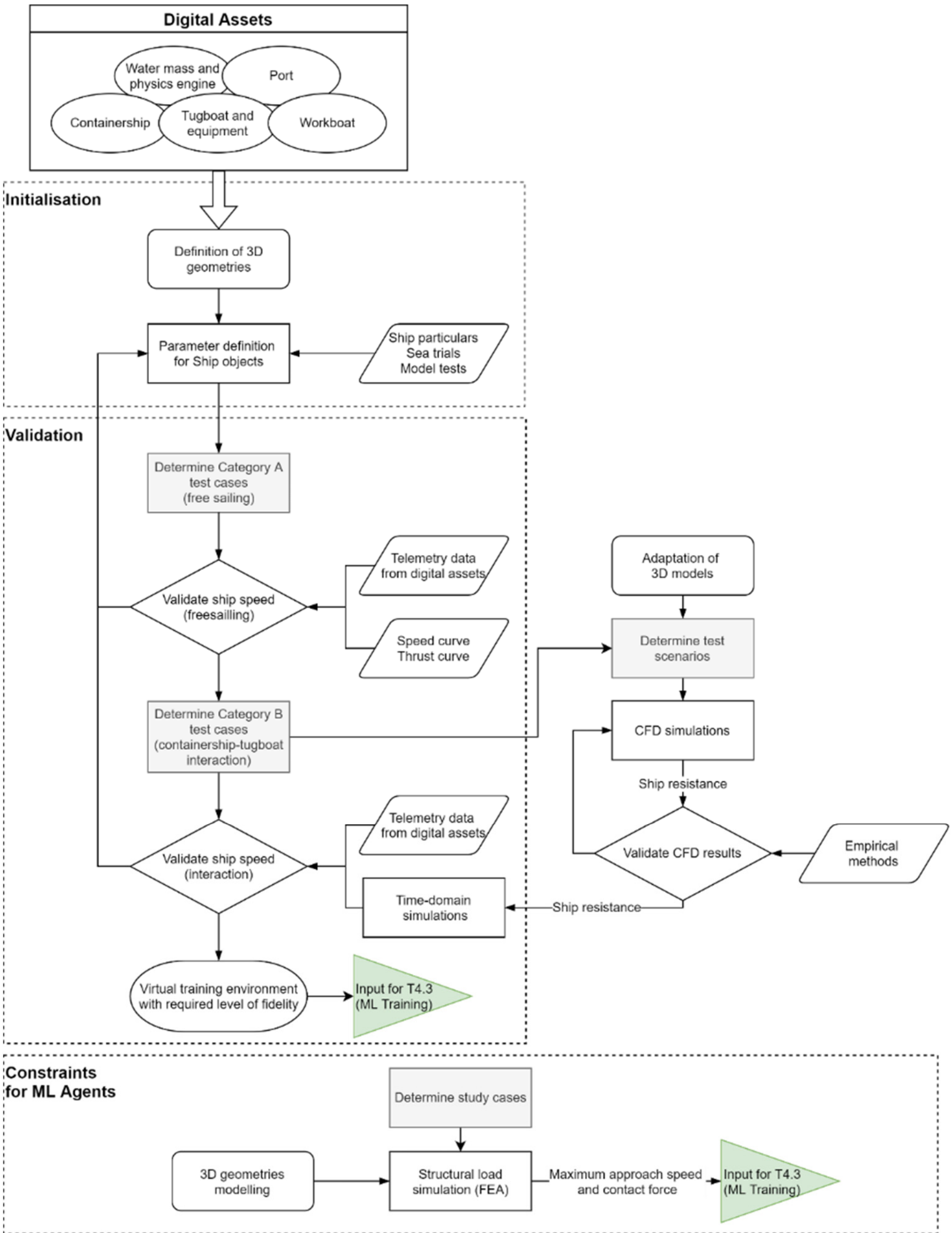

Figure 2: Methodological framework for the development and validation of the virtual training environment.

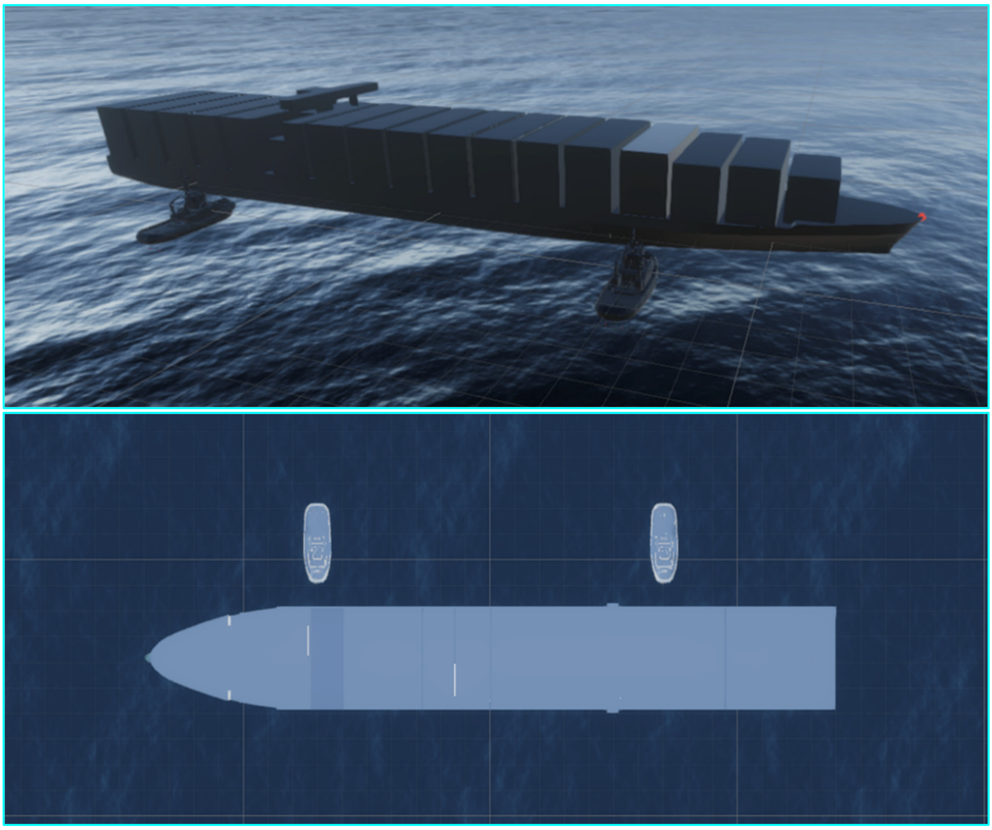

Figure 3: Various views of transverse pushing of the containership by two tugboats in Unity.

Figure 4: MOSES innovative AutoMoor unit.

4.2 MOSES innovative AutoMoor units

The goal of the MOSES project is to push forward innovation and improvements in the design and operation of ports. To achieve this, it is key to address the current challenges the shipping industry faces. Within the scope of automated mooring systems, integration within a fully autonomous port system will be considered, as well as reducing the scale of the AutoMoor unit and its vessel connection system and how the automated mooring control system interfaces with the other port systems. These will allow safe and efficient implementation of automated moorings within the port operations. The updated version of the AutoMoor unit is shown in Fig. 4.

For Trelleborg's future innovations and development of the MOSES project and system platform itself, two areas for innovation have been highlighted. The first being the implementation of rubber damping elements to allow and control surge motion of a connected vessel. The key aspects for improvement are the simplification of surge motion system compared to current hydraulic system used and a reduction in overall costs and energy intensity of the contained parts. The second is the implementation of energy harvesting systems within the scope of automated mooring actuation systems to minimize the environmental impact of the equipment during operation. As there is natural movement of vessels at berth due to environmental factors, and the typical mass of vessels is in the order of thousands of tonnes, even harvesting a small fraction of this energy could offset the net energy consumption of the system. With these innovations, Trelleborg aims to improve the systems performance, reliability, cost and safety and increase port operators access to automated mooring systems.

Based on the optimization of the current automated systems and the scope of new innovations, Trelleborg aims to deliver a key component of a fully autonomous port system.

5 CONCLUSIONS

MOSES is an ambitious project that bares significant innovation potential in the context of European SSS uptake. Its innovation potential covers both vessel design aspects as well as software tools and accompanying governance models to improve related logistics processes.

MOSES innovations will be evaluated with sustainability criteria (environmental impact, safety assessment, cost–benefit analysis) and validated by conducting model tests in test basins and small-scale pilots in relevant testing environments. At the time this paper was written, testing has not yet begun, so the conclusions that can be drawn are very generic. Although the results have only been validated theoretically, it can be concluded that MOSES proves the viability of opening new SSS routes that allows to decongest large ports, while connecting areas relatively isolated.

Namely, the MOSES feeder concept will allow to operate in remote and isolated areas without any specific port facilities. However, the operational cost are 10–15% higher compared with a feeder powered by fossil fuels.

The Autodock system allow safe and efficient implementation of automated manoeuvring and mooring within the port operations. The key aspects for improvement are the simplification of surge motion system and a reduction in overall costs and energy intensity of the contained parts. In addition, collaborative performance of the swarm has been technically proved. With these innovations, MOSES aims to improve the systems performance, reliability, cost and safety and increase port operators access to automated manoeuvring systems.

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