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Automating vessels berthing, docking and stevedorage operations: The MOSES project

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Abstract: *About 74% of imports/exports and 37% of exchanges go through ports, making Europe highly dependent on ports for external and internal trade. In the European container supply chain, Short Sea Shipping (SSS) as well as inland waterways are not so well integrated in contrast to Deep Sea Shipping (DSS) ports (also referred to as Hub ports). MOSES is a European project, funded under the Horizon 2020 Work Programme, which aims to significantly enhance the SSS component of the European container supply chain by addressing the vulnerabilities and strains that relate to the operation of large containerships. The project develops a number of components that function as nodes of the Physical Internet, consisting of a number of data sources that when combined can lead to the development of meaningfull applications. Based on the technical innovations that are designed and developed, MOSES aims to reduce the environmental footprint for SSS and ports and improve the efficiency and end-to-end delivery times of SSS mode. In parallel, it will enable the promotion of smart port development with minimal investment and the development of concrete business cases.*

Keywords: *Waterborne transport; Container supply chain; Automated docking; Container handling; Horizontal logistics collaboration; Green logistics; Short-sea and deep-sea shipping*

Conference Topic(s): *autonomous systems and logistics operations (robotic process automation, autonomous transport/drones/AGVs/swarms); logistics and supply networks; PI implementation.*

Physical Internet Roadmap *(Link): Select the most relevant area for your paper: ☒ PI Nodes, ☐ PI Networks, ☒ System of Logistics Networks, ☐ Access and Adoption, ☐ Governance.*

1 Introduction

The physical internet is a conceptual vision for the future of logistics and transportation. It is a proposed network of interconnected physical infrastructures, such as roads, railways, ports, vehicles, vessels, trains and warehouses, that are designed to be more efficient, sustainable, and resilient than the current logistics systems.

The physical internet is inspired by the way the digital internet works, where data is broken down into small, standardized packets that can be easily transmitted and reassembled across a network of interconnected devices. Similarly, the physical internet would consist of a number of physical logistics nodes, producing and sharing data from a number of sources, that can be combined to produce meaningful applications for the optimization of the operation of the supply chain.It is perceived as a way to reduce transportation costs, increase resource utilization, and reduce environmental impact by minimizing empty or underutilized cargo space. The concept is still in the early stages of development, but several research initiatives and pilot projects are underway to explore its feasibility and potential benefits.

2 The Physical Internet and Short-Sea-Shipping

Short-sea shipping interconnectivity is a key component of the physical internet concept. Short-sea shipping refers to the transportation of goods by sea along the coasts and across the seas of a region, rather than by land. It is seen as an important element of the physical internet because it allows for the efficient transportation of goods over long distances, using standardized, modular containers that can be easily transferred between different modes of transportation.

Short-sea shipping is an important link in the physical internet because it provides connectivity between different logistics facilities, such as ports, vessels, warehouses, and distribution centers, which are all part of the physical internet network. The use of standardized containers, combined with efficient transfer mechanisms at ports and other intermodal facilities, allows for seamless connectivity between different transportation modes, including ships, trucks, and trains.

By leveraging short-sea shipping interconnectivity, the physical internet can achieve greater efficiency and sustainability in logistics operations, by reducing the number of empty or underutilized cargo spaces and minimizing the environmental impact of freight transportation.

The physical internet has the potential to significantly impact the future of maritime transportation and ports. As the concept is implemented, it could transform the way goods are transported, handled, and stored in ports and other maritime facilities. The increased use of automation and digital technologies could introduce a significant impact in ports and other maritime operations as well as reduced congestion and delays at ports and other maritime facilities.

3 The MOSES project and relevance to the Physical Internet

The EU-funded MOSES project will significantly enhance the SSS component of the European container supply chain by reducing total time to berth for TEN-T Hub Ports and by promoting the use of SSS feeder services to small ports with limited or no infrastructure. MOSES includes an innovative SSS feeder vessel outfitted with a robotic container handling system. It also includes a swarm of autonomous tugboats, an automated docking system for Hub Ports, and a machine learning-driven digital collaboration platform for logistics stakeholders.

Automated tugboats and automated vessel docking are two technologies that are relevant to the physical internet concept, as they can improve the efficiency and sustainability of maritime transportation. Automated tug boats are unmanned or autonomous vessels that can be used to assist larger ships in docking and maneuvering in tight spaces. These automated tug boats can be used to reduce the need for human pilots, improve safety, and increase efficiency in port operations. By automating tug boats, the physical internet concept can reduce the time and costs associated with manual tug boat operations.

Automated vessel docking is a technology that allows ships to dock and undock without the need for human intervention. This technology can be used to reduce the time required for vessels to dock and undock, as well as improve safety and reduce the risk of accidents.

Automated or remotely controlled container handling robotic arms facilitate the movement of goods between different modes of transportation. Automated container handling robotic arms can work faster and more accurately than human operators, leading to increased productivity and throughput. They can also work around the clock without breaks, maximizing terminal utilization.

In the context of the physical internet, automated tug boats, automated vessel docking and automated or remotely controlled container handling robotic arms can improve the flow of goods through ports, reduce the time required for ships to load and unload cargo, and increase the overall efficiency and sustainability of maritime transportation. By reducing the need for human intervention in port operations, these technologies can also improve safety and reduce the risk of accidents.

Moreover, matchmaking logistics platforms can enable the sharing of transportation assets between different stakeholders, such as shippers, carriers, and logistics service providers. This can help to optimize the use of transportation infrastructure and assets, reduce congestion and emissions, and improve the overall efficiency of the logistics network. Matchmaking logistics platforms can also enable new business models and services within the physical internet with the introduction of on-demand logistics services, such as last-mile delivery or same-day delivery, by connecting shippers with local carriers in real-time.

Thus, the physical internet concept is closely related to the MOSES project since it aim at developing a modular, open-source logistics system, that consists of a number of data producing components that act as nodes of the physical internet and can be used to develop services and applications that optimize the operation of the supply chain. In the next paragraphs, the MOSES project and its components will be described in detail.

4 MOSES Components

MOSES aims to significantly enhance the SSS component of the European container supply chain by a constellation of innovations including innovative vessels and the optimisation of logistics operations:

i. For the SSS leg, an innovative, hybrid electric feeder vessel that will prevail from different vessel concepts that will be designed to match dominant SSS business cases and will increase the utilization rate of small ports. The feeder will be outfitted with a robotic container-handling system that is self-sufficient in terms of (un)loading containerised cargo and will simplify the process at the Hub Ports while improving the operational capacity of small ports;

ii. For DSS ports, the adoption of an autonomous vessel manoeuvring and docking scheme (MOSES AutoDock) that will provide operational independency from the availability of port services. This scheme will be based on the cooperation of (a) a coordinated swarm of autonomous tugboats that automates manoeuvring and docking with (b) an automated docking system based on an existing product and (c) the investigation of autonomous voyage/port entrance and mooring manoeuvre for the feeder vessel;

iii. A digital collaboration and matchmaking platform (MOSES platform) aiming to match demand and supply of cargo volumes by logistics stakeholders (shippers, forwarders, shipping lines, ports) using advanced analytics and data-driven assessment (availability of mode, cargo volumes, delivery times) to maximize SSS traffic.

The MOSES concept and relevant innovations are presented in Figure 1, while the following sections describe the main aspects of these innovations.

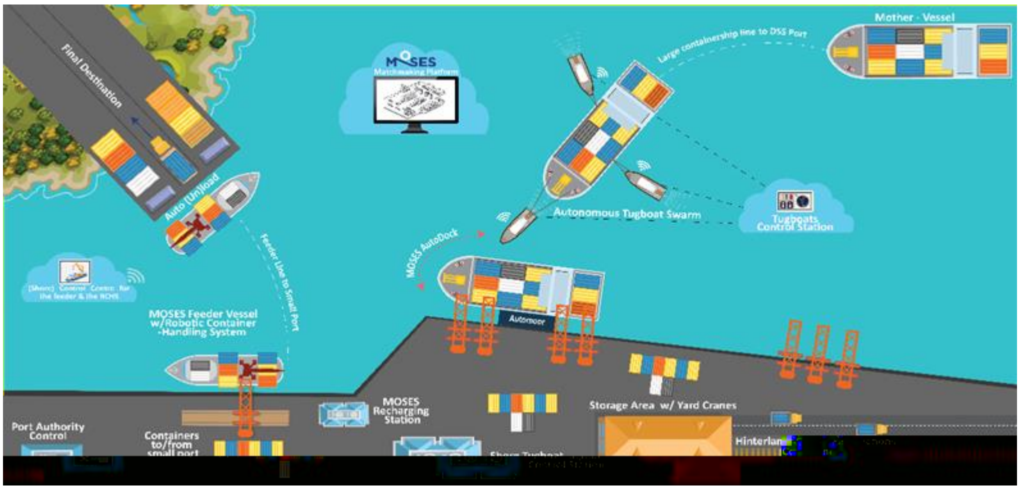

Figure 1. MOSES concept and innovations.

4.1 Innovative Feeder Vessel and Robotic Container-Handling System

The innovations for the vessels are concentrated on two different directions, in which the innovations for the maritime industry are being developed and demanded by society. The first one is the ambition to reduce or eliminate harmful emissions by designing environmentally friendly vessels. The second one is the ambition to design a highly autonomous feeder vessel, that is able to sail large part of its route without human intervention. Main drive here is to reduce the number of accidents due to human errors followed by a reduction in cost. MOSES develops three different designs for the innovative feeder that are fit for purpose for the requirements of the MOSES business cases. Compared to existing container feeder vessels, the MOSES feeder includes the following innovative features: low cargo capacity (ranging from approx. 90 – 680 TEU), environmentally sustainable engine configuration; superstructures positioned at the fore and mid ships; enhanced maneuverability; and automated onboard crane. For achieving (near) zero emission operation, several engine configuration alternatives have been evaluated, with the selected ones resulting to an estimated 10% lower operating costs.

Furthermore, the concept design for the MOSES feeder is compatible with the MOSES AutoDock system (see Section 4.2) by including thrusters and azimuth propulsion, which provide enhanced maneuverability for the feeder and therefore minimize the required number of tugboats, while the hull form of the feeder has adequately large flat surfaces for facilitating the connection with the MOSES Automated Mooring System. It can also operate in parts of its voyage with a certain degree of autonomy. Due to the selected engine configurations, the MOSES Innovative feeder can have (partly) zero emissions throughout all operational phases, contributing to the reduction of the environmental footprint of SSS services from large container terminals to smaller ports. The feeder is also expected to reduce the environmental footprint within the port area and in its vicinity by: 1) having been designed to use its onboard battery systems and shore power connections for the required power while berthed, and 2) capturing part of the hinterland container traffic, currently moved by container trucks. A recharging station for automated vessels is also developed providing a fully automated shore power connection solution without the need for assistance from the vessel and ensuring the minimization of energy transfer losses from the port's electric grid to the ship.

In most port terminals, moored container ships are loaded and unloaded with shore cranes. In that case, a crane operator controls the crane based on their hand-eye coordination, knows which container to move according to the provided plan, finds the position of the container, estimates the distance between the spreader and the container, reduces speed if necessary and hooks the spreader to the container, etc. The safety of the operation is ensured by a direct line of sight to the operation, relatively high degree of supervision by others and the creation of a safe and closed operational area. In contrast, many small European ports do not have their own terminal facilities. The port usually consists of a concrete quay or pier for the mooring of Roll-On-Roll-Off (RoRo) ferries for passengers, cars and trucks. The fact that these ports cannot accommodate a container service reduces the economic value and growth potential of these ports.

The solution envisaged within the MOSES project is that of a self-sufficient (autonomous) Robotic Container Handling System (RCHS). Mounted on and integrated with the MOSES feeder vessel concept, it enables safe container loading and offloading operations to small local ports without the need for additional terminal infrastructure. The RCHS innovation fits the MOSES-project aim to significantly enhance the Short Sea Shipping (SSS) component of the European container supply chain by implementing a constellation of innovations including innovative vessels and the optimization of logistics operations. The RCHS consists of a crane, software that drives it, a sensor suite that provides information about the operational area through object detection algorithms (e.g. the location of a container) to the crane software enabling autonomous operation, and a shore control centre from which operators remotely monitor and supervise the crane's operation. This makes the RCHS a collection of innovations – a system of systems (Figure 2).

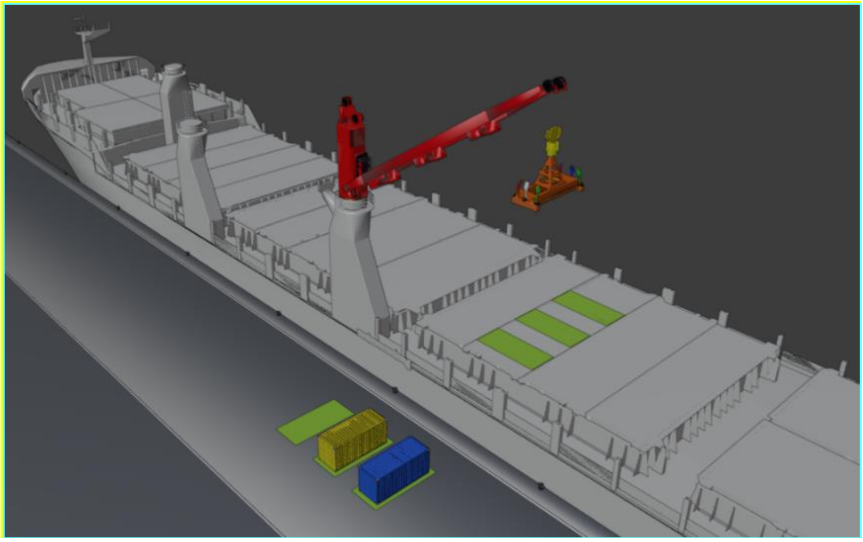

Figure 2. Innovative feeder vessel equipped with Robotic Container Handling System

The intended future operational scenario is the following: When the vessel with the RCHS arrives at its destination port, it receives a list of containers to unload and load. The loading and offloading operation is conducted automatically with the help of the sensor suite to monitor its surroundings and the control software that steers the crane. In parallel, the remote operator, who is potentially hundreds of kilometres away, supervises the process and is responsible to intervene when the crane or sensors experience difficulties of any kind. The sensor suite system acts as the sensing system of the crane and provides information over container position and orientation and is able to dynamically detect and classify objects like people and trucks. Its main role is to feed the necessary information to the control software of the crane to enable both the control of the crane and high-level decision-making (e.g., which container to pick up first and where to stow it on the vessel). It also conveys this information to the remote operator support system to enable it to timely bring the operator in the loop. The remote operator support system is developed for a shore control centre concept allowing multiple operators to supervise multiple autonomous operations effectively and efficiently. The combination of these innovations supports a concept where dozens of small vessels can handle containers autonomously while being supervised by only a handful of remotely located operators.

4.2 AutoDock

The MOSES AutoDock system aims to automate the maneuvering and docking of large containerships in DSS ports, which is currently conducted with manually operated tugboats in a typically complex and time-consuming process. This is an intelligent system comprising autonomous tugboats operating in a swarm configuration at various levels of autonomy and supported by the MOSES Shore Tugboat Control Station (STCS), which will cooperate with the MOSES Automated Mooring System; a re-engineered version of Trelleborg's AutoMoor system (Figure 3). MOSES develops an architecture for autonomous tugboat operation that is compatible with existing equipment on conventional tugboats and therefore can be used for retrofitting. The architecture includes sensors that provide situational awareness to AI algorithms that control steering and propulsion. The automated mooring system is a vacuum-based system for hands-free mooring that includes rubber damping elements to allow and control surge motion of a connected vessel and energy harvesting systems. The MOSES STCS acts as a communication hub between the tugboat swarm and the mooring system, as well as a central platform for supervisory control of the process.

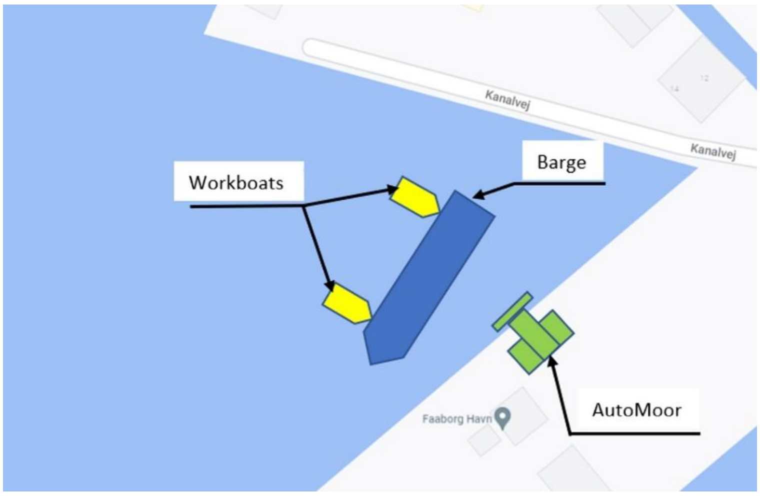

Figure 3. AutoDock system

More specifically, the AutoDock system supports the AI-optimized navigation and remote monitoring and control of the tugboats, enabling functionalities such as path planning and implementation, collision avoidance with static and dynamic obstacles, mission scenario management and achievement, fail-safe operation, compliance with navigational restrictions, situational awareness, switching between levels of autonomy, and fail-safe operation. The architecture consists of the following modules: 1) detection, 2) path planning, and 3) control. The detection module includes sensors and monitoring devices that feed data into the Data Acquisition Board, which consists of a data processing unit and a local database for storage. The sensors that have been identified for enabling autonomous operation are the following: AIS, Radar, IMU, Camera system with 360 FOV, SWATH Sonar, GPS, LIDAR, and an Engine and rudder monitoring system. The following sensors provide input to the AI navigation algorithm in real-time: IMU, LIDAR, GPS. The path planning module consists of the Auto Pilot unit that will host the AI navigation algorithms. The Auto Pilot receives data generated from the sensors as input to the AI algorithm and generates steering and propulsion commands that are passed on the control module. One of the main requirements for the Auto Pilot unit is adequate processing power for real-time operation, which has been satisfied by featuring a GPU that results in significant faster execution of mathematical operations compared to a CPU. The control module is the part of the architecture that physically controls the steering and propulsion machinery systems installed on the tugboats.

The design for the MOSES autonomous tugboats targets a mixed autonomy level that consists of: 1) manual navigation with decision support by the remote operator in the STCS (Decision supported function), and 2) autonomous swarm operation with remote control capability (Self-controlled function, human-in-the-loop). With regards to the required software and hardware interfaces for integrating the different components of the architecture, one of the main requirements is the ability to exploit existing equipment that is typically installed onboard tugboats and required by regulation. This is satisfied by featuring multi-protocol data buses for ensuring interoperability with legacy systems. The wired interfaces mainly include ethernet connections, which are handled by an ethernet switch and ensure minimum latency in data transfer between the different modules. The wireless interfaces include 4G cellular modems that enable the communication of the tugboat with other external resources, such as the STCS and the re-engineered MOSES AutoMoor system. A CAN bus enables the communication between the different components of the architecture without a host computer.

As for the mooring process, the MOSES Automated Mooring System shall form an attachment between the terminal wharf and vessel hull. The system consists of a single mooring unit that can hold a vessel with a holding capacity of up to 5T, with an additional safety margin to accommodate for unexpected environmental or meteorological conditions. The control system shall consist of both the existing operator-based control module and an autonomous module that can send and receive appropriate signals to interact with other autonomous control systems such as the Tugboat system and the STCS. In parallel, the STCS serves as a central control platform that acts as interface between the tugboat's operator, the AutoMoor units and the port, supporting decision-making of the Port Control Authority. The main functionality provided by the STCS is to monitor the autonomous manoeuvring, as well as the real-time communications protocols with the Port Authority management systems, Port Community System (PCS), the Vessel Traffic Services (VTS) with the STCS.

In a future operational scenario, during the manoeuvring to/away from dock, the tugboat Captains manually navigate the tugboats in position and after communicating with the Pilot on the vessel establish the tow connection. The STCS switches the tugboat swarm to the autonomous navigation operational state and the swarm begins the vessel's manoeuvring process by conducting AI-optimised path planning and collision avoidance. In case an off-nominal situation is detected, the swarm transitions to either the Fail-safe/Emergency or the Hot-swap state. Once the vessel is approaching the berth, the automated mooring system requires notification of vessel arrival when the vessel is being manoeuvred by the pilot and/or the autonomous tugs. At this point, the system would shift into "ARM" mode. Following notification of imminent vessel arrival, the next signal the automated mooring system would require is that the vessel is parked in position against the fender-line, ready to be moored. At this point, the "MOOR" sequence would commence, the mooring units would form an attachment to the vessel and pretension as necessary to pull the vessel against the fenders. Once the vessel is securely moored, the mooring system would indicate to the pilot and the autonomous tugboat swarm that the mission has been completed, the STCS switches back to manual navigation and the tugboat Captains navigate back to base.

4.3 Matchmaking Logistics Platform

The Matchmaking Logistics Platform aims to offer match-making services to logistics stakeholders. It has been developed to support digital and horizontal collaboration among shippers and carriers, aiming to maximize Short Sea Shipping (SSS) demand and balance backhaul traffic. More specifically, the Matchmaking Logistics Platform is a digital collaboration and matchmaking tool that aims to maximize and sustain SSS services in the container supply chain by matching demand and supply of cargo volumes by logistics stakeholders using data-driven analytics. It can dynamically and effectively handle freight flows, increase the cost-effectiveness of partial cargo loads and boost last-mile/just-in-time connections among the transport modes and backhaul traffic. In this way, its users can experience the benefits of a collaboration and optimization tool that prioritizes SSS and is able to deliver impactful results for all stakeholders involved. The platform advances current state-of-the-art by supporting cargo consolidation (at container level) and fully exploiting the bundling potential among different shippers to enable multimodal transport routes containing at least an SSS leg. This is done in existing but underutilized SSS routes, currently not preferred by shippers due to increased costs or low service frequency and reliability.

The platform focuses on collecting available information and datasets related to logistics supply and demand from relevant stakeholders, such as shippers, carriers, freight forwarders, shipping lines etc. Through the combination of these datasets, valuable information can be extracted, supporting the optimization of the logistics process. The main benefit of this analysis is the provision of multimodal transportation options, combining different transportation means and modes that can reduce the delivery time and the overall cost. In parallel, the combination of multimodal transport services with freight cargo bundling can increase the efficiency of transport operators and improve the management of empty containers. As already mentioned, the stakeholders that are involved in the logistics process may include shippers, carriers, freight forwarders, shipping lines and agents, etc. However, two discrete user groups have been identified as the main user roles of the platform based on their role in the logistics process and the supported interactions with the platform. These groups are the following:

- the logistics services supply group **(service providers)**, i.e. the owner of transport means (ships, trains, trucks) offering transport services;
- the logistics services demand group **(end users)**, i.e. owner of cargo to be containerized and shipped, placing transport requests.

Based on the involvement of each user group in the logistics process, specific functionalities are provided by the platform, in order to fulfil the needs of each user group and improve the shipping process. In a typical use case scenario, the platform is initialized by the data provided by the service providers, which inform the platform for vessel schedules for a rolling period of at least 2 months, with no major changes foreseen. End users can place transport orders and get notified once the service provider confirms the agreement for this order. The usage of the platform by a specific end user consists in the following sequence of steps/functions.

1. Any time an end user places an order, the platform is triggered to find feasible, optimal transport schedules satisfying the specification of the order.
2. The transport schedules found in the previous steps, along with already found transport schedules concerning other orders (i.e. the intermediate results) are used to find matching orders in the sense described above.
3. Once matchings are found, the end user is notified about them.
4. Service providers and end users involved in the matchings found in step 3 are notified.
5. As long as the order remains open, the end user is regularly notified in case new orders matching his/her order are found or if any of the already matched orders are fulfilled/closed or cancelled.
6. The platform aims at a near real-time to periodic response, i.e. end users are notified at periodic basis.

The architecture of the platform consists of the back-end module, the storage/database module and the front-end module. These modules include all the subcomponents of the platform, such as the optimization component, the user interface etc. More specifically, the structure is as follows:

- The back-end module is where the search and matching algorithms run and includes the server and optimization component.
- The database module is where all collected resources and intermediate results are stored.
- The front-end module is where all necessary information is collected and includes the available user interfaces that are provided to the users based on their role. In Figure 4, the platform's Dashboard is presented.

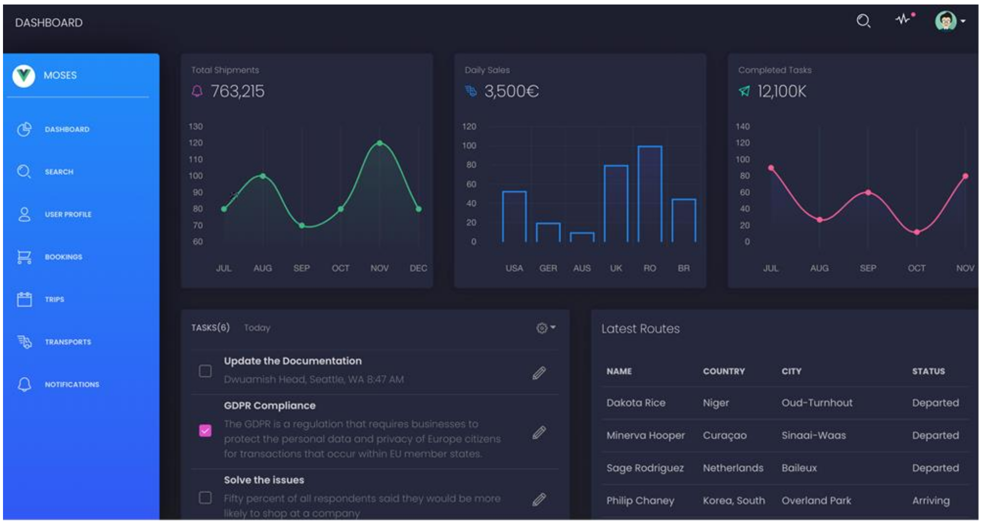

Figure 4. Matchmaking Logistics Platform Dashboard

Summarizing the above, the Matchmaking Logistics Platform is a cloud-based platform that has been designed and developed in order to support and maximise the provided services in the container supply chain by matching demand and supply of cargo volumes by different stakeholders using data analysis algorithms. Based on the user roles that have been identified, the platform usage is separated in two levels. The first one concerns the service providers, including different stakeholders like carriers, freight forwarders, shipping lines etc. which can use the platform in order to upload their routing schedules, see different system reports, examine customer orders and see a complete list of notifications. The second usage level concerns the end users and potential customers such as shippers, who can benefit from the optimisation and collaboration/matchmaking analysis that is made behind the scene, providing an analytic list of best available routes, based on their preferences (search criteria). This matchmaking functionality is the heart of the system and aims to provide to the customers the best options available by combining the transport services and means offered by different service providers.

5 Conclusion

Short sea shipping can play a significant role in the deployment of the physical internet, as it can provide an efficient and cost-effective mode of transportation for goods between nearby ports. By integrating short sea shipping with other modes of transport, such as rail and road, a seamless and interconnected logistics network can be created, similar to how the digital internet enables the transfer of data between interconnected devices.

MOSES innovative and automated components along with the use of the Logistics Matchmaking Platform can help to reduce congestion on roads and highways, lower carbon emissions, and improve overall transport efficiency, which are all key goals of the physical internet. The physical internet seeks to create a more sustainable and efficient logistics network, and short sea shipping can contribute to achieving this goal by providing a reliable and environmentally-friendly mode of transportation for goods.

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