MARITIME TRANSPORT AND LOGISTICS DIGITAL SOLUTIONS OPTIMIZATION USING ADVANCED DATA SHARING PLATFORMS: ePICENTER PROJECTS' CASE

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The maritime transport sector within the multimodal transport chain aims to increase overall efficiency by using advanced technological solutions for planning and management operations, including handling vast amounts of data like cargo, positions, trade flows, vessels, and terminals. All these requires an integrated approach to data management is required in the form of multi-sectoral data-sharing platforms with process interoperability. Hence, this paper describes international legislation requirements related to maritime data sharing provisioned by International Maritime Organization (IMO)and United Nations (UN), along withsome recent technical solutions used in the maritime sector as Maritime Single Window (MSW), Port Community System (PCS), and smart containers on blockchain platforms. Also, the paper provides an overview of the EU-H2020 project ePIcenter focused on multimodal transportation chains efficiency. Some features of high-level data integration, exchange, and decision support modules, such as Transporeon and Synchromodality optimization, are described as well.

Keywords:
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1 Introduction

Contemporary management of multimodal transport flows, maritime routes scheduling, and big port capacities, requires the consistent, harmonized, and reliable networking environment among involved stakeholders. This can be achieved by utilization of safe, advanced, and optimized digital solutions for relevant information and data sharing. For this purpose, the maritime sector goes through a digital transition and adopts the latest technical developments to meet the efficiency requirements of international trade players and optimize the port calls process (Lind *et al.,* 2018; 2020).

In general, data sharing could be considered as a computer-supported cooperative sharing of available resources on the network and through communication channels for establishing the interaction and coordinatedly use of shared databases. Data are organized, stored, analyzed, and retrieved in a systematic way through a Database Management System (DBMS) and shared over cross-platforms that comprise peer-to-peer systems, client-server platforms, and centralized or decentralized platforms (Ahmad, *et al.,* 2011). New technologies, especially those related to data management, already transformed the logistics and transport sector and various applications for data collection and advanced data analytics tools. This encompasses advanced systems and concepts such as the (Industrial) Internet of Things ((I)IoT), blockchain (distributed ledger platforms), Machine learning (ML) algorithms, artificial intelligence (AI)-based solutions, digital twins, etc., (Kirsten, 2018; Surucu *et al.,* 2023).

The purpose of this paper is to review the mandatory documentation and international regulations in maritime data exchange and reporting. It also aims to show the benefits of the latest Information Technology (IT) development trends in the form of data-sharing platforms, including the tools deployed for maritime transport and logistics within the EU H2020 ePIcenter project.

The remaining part of the paper unfolds as follows: Chapter 2 presents the environmental scan of several important initiatives for maritime and transport data sharing platforms supported with Port Community System (PCS) and blockchain technologies for containers and dangerous cargo; Chapter 3 gives research approach; Chapter 4 analysis mandatory regulations, documents, and standards for data-sharing provisions issued by IMO and UN. Within this chapter the MSW concept is reviewed; Chapter 5 provides case study based on ePIcenter project results related to digital transformation and smart containers in the maritime industry and logistics, comprising data sharing and optimization platforms used in the "ePI-Link" demonstrator. Discussions and concluding remarks are given in Chapter 6.

2 Environmental scan

The following is an overview of some of the most recent platforms for the exchange of maritime data. One of the recently introduced data collection and sharing systems among the Adriatic sea authorities is the ADRIREP system. This is a platform for vessels with dangerous cargo reporting (Šorović *et al.,* 2023a). Another important platform is the Sea Traffic Management(STM), launched in the Baltic region for optimization of safety, efficiency, and environmental aspects in maritime transport (Šorović *et al.,* 2023b). Also, special attention should be paid to maritime transport chain data flow resilience in terms of ensuring cybersecurity. Maritime shipping companies and terminals were exposed to cyber attacks that caused prolonged outages or disruptions in timely freight distribution (Maatsch, Jović, *et al.,* 2022; Ntshangase and Bauk, 2024). To achieve better interconnectivity and efficiency of maritime surveillance, data sharing and safety response, the harmonization of Vessel Traffic System (VTS) services and training on these platforms is necessary for all maritime transport involved agencies (Šorović *et al.,* 2023c).

The relevant institution in the maritime regulations area is the International Port Community System Association (IPCSA), which plays a very important role in shipping and port logistics concerning the PCS of users. This organization is competent in developing and supporting initiatives for trade facilitation and greater transparency in supply chain and logistics flows. The IPCSA prioritizes new emerging technologies with maritime applications, such as Blockchain Bill of Lading, a logistic visibility task force, and Network of Trusted Networks(Paladin *et al.,* 2024; Jaiman *et al.,* 2022). In accordance with the mentioned, there was a justified need for the creation of a PCS, as a neutral platform for electronic data sharing and exchanging, related to cargo, amongst all parties involved in this process (Bezić *et al.,* 2011). Thanks to the harmonization between PCS and MSW, the most important goal has been reached: the elimination of data duplication. In such a manner, once entered data is visible to all seaport system stakeholders, developing more structured and functionalbusiness operations. Also, PCS aids port stakeholders in reducing logistics costs, facilitating faster cargo delivery, boosting economic growth, and reducing externalities like pollution and harmful emissions (Tijan *et al.,* 2012; 2018). In the last decade[1], the European Union (EU) has put an effort into creating the European MSW(EMSW) to completely harmonize the interfaces that ship operators can use to deliver necessary data throughout the EU. The EMSW aims to standardize the data required for port management to ensure all relevant stakeholders have access to the submitted information openly. The national MSW and EMSW need to be synchronized and completely unified with the PCS to enhance business processes. All the parties engaged in running a certain port cluster share and aggregate data through the PCS. Many nations have highly developed PCS systems in place of their underdeveloped national MSW, which is quite varied. Unlike the national MSW, there isn't a universally applicable, standardized PCS model for all ports. Since each PCS is unique, because every nation has unique laws, each port community creates its own PCS based on its requirements. Every PCS should connect over the national MSW interface to prevent data duplication and expedite business procedures (Kapidani *et al.,* 2015; Tijan *et al.,* 2019; Jović *et al.,* 2022).

Another important concept are the smart containers on blockchain, the area that is still in its infancy and under-researched, but relevant for further development and full introduction of blockchain in maritime container transport. The number of academic articles on the subject is quite limited. However, we have found several relevant manuscripts. The white paper (UNECE, n.d.) gives an overview of the perspectives of smart containers in the context of IoT, big data, data pipelines, and blockchain technology (Fig. 1).

With regards to blockchain, Iakushkin *et al.* (2019) paper deals with the architecture of the system for tracking and tracing(T&T) smart containers using blockchain, while the data on the location and status of the smart containers are recorded on the

[1] Since June 2015, parties engaged in maritime trade and transportation within the EU have been required by law to submit information and documents through an electronic SW to comply with reporting requirements. Individual data items should only be submitted once (Directive 2010/65/EU of the European Parliament and of the Council, 2010). The agreement between the EC and the European Parliament and Council about the implementation of the EMSW, which is anticipated to come into effect in 2025, was signed at the beginning of 2019, and well received by the maritime sector, including the European maritime ports.

permissioned blockchain, Hyperledger Iroha, e.g. Elmay *et al.* (2022) present data and documentation flows in container transport in unimodal and multimodal logistics, using the InterPlanetary File System and the Ethereum. Baygin *et al.* (2022) demonstrate blockchain-based smart containers T&T by UHF RFID chips. In this case, Solidity language was used, and different experiments were performed with Ganache, Truffle, and Metamask blockchain platforms. Furthermore, the Meyer *et al.* (2019) article gives a framework for blockchain interoperability in T&T smart containers in the Physical Internet (PI) environment. Bauk *et al.* (2023) developed a prototype for T&T smart container based on Raspberry Pi and Python, and plan to extend this project towards data integration of smart container on the blockchain. The impediments on blockchain mainstream implementation in maritime, not only in cargo T&T, as a case study, are considered in Bauk and Ntshangase (2023). The structure of related data, events, document flow, and network participants' relations will be the subject of further research in this domain.

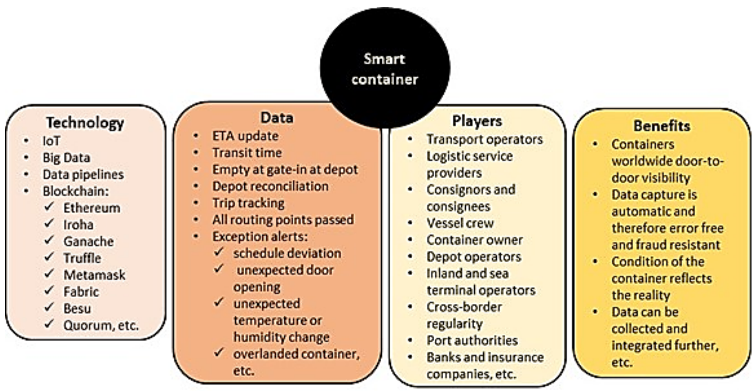

Figure 1: Smart container technology, data, players, and benefits
Source: Own research.

3 Research design

This paper is based on exploratory desktop analyses of the IMO and UN regulations and standards for data exchange and trade facilitation. Based on the same research principles, the paper provides a comprehensive presentation of the unified MSW platform. This manuscript also includes a case study, which is based on the latest research results from the ePIcenter project. The case study is focused on Transporeon solution and Synchromodal optimization model.

4 Mandatory IMO and UN regulations on data sharing

The IMO as the world's top institution for the establishment of general regulations and provisions for every aspect of global maritime affairs, through its working groups and together with the UN institutions, constitutes, updates, discusses, adopts, and finally publishes the regulations and documents applied in every member state countries. One of these working groups is the Expert Group on Data Harmonization (EGDH), which significantly contributed to setting and advancing the system of data sharing and electronic business regulation. Its core documents is the "Compendium on Facilitation and Electronic Business", a reference manual for creating and harmonizing the systems needed to support the transmission, receipt, and response of information required for the arrival, stay, and departure of the ship, persons, and cargo via electronic data exchange (IMO, EGDH 3/20/1, 2020). To include e-business solutions beyond those related to the "Convention on Facilitation of International Maritime Traffic" (FAL Convention), the formal document FAL 42 is extended to address port logistics operational data for digital exchange between the port and the ship (IMO, FAL 42/8, 2018). However, the major barriers to adopting FAL requirements for electronic data exchange are the following (IMO, Facilitation Committee, FAL 45/5, 2021):

- Multi-stakeholder interests in port communities and established practices should enable the reuse and data sharing, to make electronic reporting and clearance of vessels, cargo, crew, and passengers efficient.
- The legal framework is a barrier as it can depend on competing and/or overlapping public administrations.

Herewith, the IMO Data Set (DS) is constructed to identify all the data elements for reporting information and the IMO Reference Data Model (RDM) for the underlying hierarchical data structure used in electronic data exchange. The IMO DS combined with the IMO RDM promotes harmonization used for electronic business from the World Customs Organization, the UN Economic Commission for Europe, and the International Organization for Standardization (ISO) TC 8. It is proved that data harmonization contributed to the MSW concept implementation, which is a high-level priority of the IMO. This process increased international trade efficiency, by simplifying communications among stakeholders in an electronic information environment that promotes accountability, transparency, informed decision-making, and interoperability (ePIcenter D1.7, 2022).

Apart from mandatory IMO regulations related to data sharing and reporting, there are multiple international data standards in use in maritime trade. Among many of these protocols, the two most relevant ones are UN/EDIFACT and Extensive Markup Language (XML).

The top UN institution, the UN Centre for Trade Facilitation and Electronic Business (UN/CEFACT), is responsible for the launching, development, and governance of communication standards in the world trade business (UNECE/CEFACT, 2013; 2017). The UN/CEFACT improves the ability of business, trade, and administrative organizations to exchange products and relevant services effectively. The UN/EDIFACT and related standards, are used for establishing the MSW and other electronic platforms, containing the following prepositions (UNECE/CEFACT, 2011; 2020):

1. involvement of relevant trade and transport stakeholders;
2. standardized information and formalized documents;
3. single entry point in fulfilling regulatory requirements, and
4. single submission of the data.

The XML is a commonly used in electronic messaging, particularly in administrations, but the UN/EDIFACT messages are still widely used. The XML has extensive support in common office automation tools and off-the-shelf or public-domain computer software. The advantage is that an information system that adopts the XML format for Electronic Data Interchange (EDI) is relatively simple compared with traditional EDI systems that adopt a UN/EDIFACT format. However, creating new variants of XML has led to many different and partly competing standards, which apply to ship clearance, although the use of XML for this purpose is not widely implemented. Some relatively well-known examples are PortNet in Finland; the Electronic Notice of Arrival/Departure (eNOA/D) system by the USA Coast Guard and SafeSeaNet (SSN) – EMSA in Europe (IMO, FAL 42/8).

Regarding the national MSW, international standards for implementing the system interface are UN/EDIFACT, the WCO data model, and the ISO standard on electronic port clearance - ISO 28005. To ensure information reporting regardless of the standards, the interoperability between the messaging systems implemented by the national MSWs is essential. The exchange of information through SSN requires that the digital format of the messages be used within national SafeSeaNet systems, following Directive 2002/59/EC. Also, EU member states shall comply with the harmonized XML messages and the technical standards developed for exchanging information through SSN (EC, DG MOVE, 2015).

4.1 Maritime Single Window

To comply with national and international legislation and to complete ship reporting requirements for entering or leaving ports, parties who are participating in maritime transport now, must produce and submit a substantial amount of documentation. The document submission (paper and/or electronic form) to various authorities is required. This procedure takes a lot of time and places a significant administrative burden on the business community and governments (Economic Commission for Europe, 2005). Because of that, the idea of a MSW has been presented as an important concept in reducing trade costs and delays. Also, it is a platform for better cooperation and information sharing between many government departments engaged in foreign commerce, through a single-entry point, without data duplication (Kapidani and Kočan, 2015). Furthermore, under the specified level of authentication and authorization, it is ensured that the entered data is immediately visible in other systems (Tijan *et al.,* 2018; Jović *et al.,* 2022). In the maritime industry, this requirement for automated and standardized reporting procedures is critical, since it has affected the effectiveness and safety of maritime transport (Kapidani and Kočan, 2015).

To tackle the aforementioned issue, the UN/CEFACT advises the implementation of a Single Window (SW), which is described as a "facility that allows parties involved in trade and transport to provide standardized information and documents through a single entry point to fulfill all import, export and transit-related regulatory requirements" (Ibid.). Hence, the IMO and more precisely, its FAL Convention plays a significant part in easier data exchange in maritime transport, as well as among other issues related to the uniformity in formalities and precise procedures. Following that, the IMO arrived with standardized forms – IMO FAL Forms, to simplify the formalities, and procedures and integrate the documents that are demanded to be sent to the authorities. Thus, every contracting country of the IMO FAL Convention is in the obligation to be involved in electronic information exchange between ports and ships. This mandatory requirement came into force on April 8th, 2019. In that manner, the Convention stimulates the data use of a SW to allow a submission of all required information related to the arrival, stay, and departure of ships, persons, and cargo, via a single portal, without data duplication (Kapidani et al., 2020).

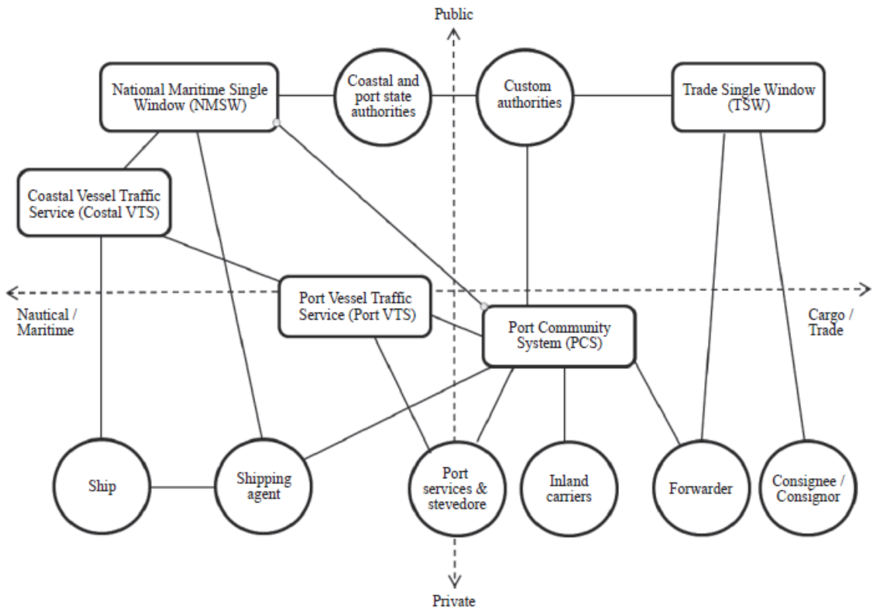

Figure 2: Model of MNSW environment

Source: Kapidani et al., 2020.

The MNSW (Fig. 2) is closely defined as a location, where all data about the maritime environment are entered once and made available to different parties (Tijan *et al.,* 2018). Its emphasis is on the information related to vessels, rather than the information regarding trade and cargo. As the authority operating the SW for ship clearance, the national MSW shall, at the very least, handle the vessel's IMO FAL data, which contains general safety and security information on the cargo being transported. Additionally, the national MSW must be designed to handle reporting requirements arising from international legislation to which the particular country has acceded at both, the regional and global levels.

The information on the ship clearance that is mandated by national law should also be covered by the national MSW (Kapidani *et al.,* 2020). However, numerous entries of the same data, in several different applications, have caused errors that frequently happen during repetitive data input, which are resulting in complications in official procedures. Hereby, data duplication still occurs through electronic and paper methods.

5 The ePIcenter project recent results

The latest developments of technological progress and global transport community requirements are directed towards more efficient transport digitalized solutions. Following the international regulations and initiatives, the ePIcenter project aims to create multilayered advanced platforms for transport effectiveness, increasing the optimization of resources, Physical Internet (PI) implementation, and development of eco-friendly and AI-supported toolsets and concepts in transport and logistics. In this regard, here has been conducted huge research considering the recent trends development of IT in providing sustainable, resilient and synchronized transport solutions. As a result of research made within the ePIcenter project, here are presented the most important features and tools for implementation of the "ePI-Link" demonstrator. This demonstrator shows the platforms for an integrated network of global transport partners and freight flows to efficiently connect ports, terminals, and shipping companies.

5.1 Transporeon: Multimodal visibility

As part of the ePI-Link demonstrator results, the industrial partners AB InBev and Den Hartogh Logistics wanted to increase visibility in their multimodal transport flows. Transporeon (Trimble Company) further developed and integrated their multimodal visibility solution with the aim to obtain better estimated and actual data and be able to distribute that information based on a *need-to-know* basis such that the logistics management process can be triggered when needed. The development centered around three main achievements:

1. Consolidation of multiple data sources. In a context where individual data sources are fragmented (only covering part of the multimodal transport chain and part of the shipments) and prone to inaccuracies and delays, all available data sources need to be combined through an extensive process of data cleansing, normalization, and prioritization. Integrating deep sea terminal data was achieved within the project. As a result, we could eliminate blind spots and make information available at an earlier point in time.

2. Predicting estimated time of arrival (ETA). Shippers and 3PLs need to go through a constant cycle of planning, monitoring, and adjusting their shipments. To support this, it is essential to have reliable data on the estimated time of arrival (ETA) at a port of discharge and the final destination. Transporeon developed a layered model to predict such ETAs in which information was combined on multimodal combinations of transport services, transshipments, service loop structures, and real-time movements. Through smart combinations of transit time statistics and dynamic prioritization of data sources, an improvement was achieved in the completeness, accuracy, and latency of ETA information (Fig. 3).

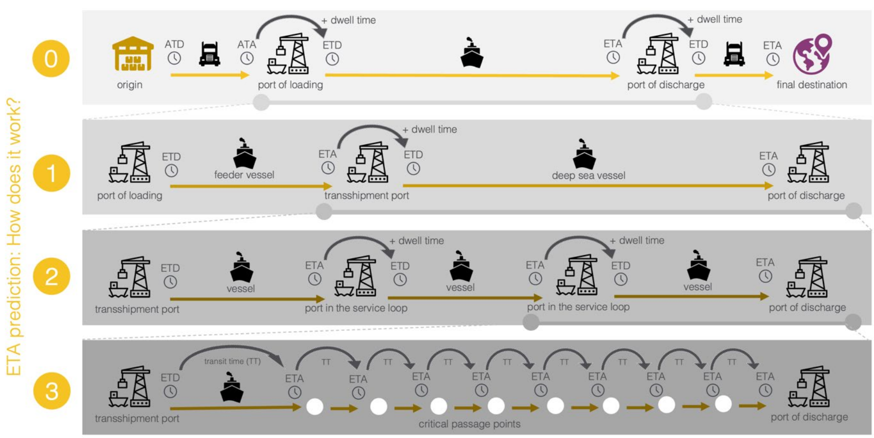

Figure 3: The ETA prediction module within Transporeon solution
Source: Own research.

3. The SW interface for multimodality. All relevant information was integrated into a single control tower, combining main haulage (ocean) and pre-/on-carriage into a comprehensive view that supported both carrier haulage and merchant haulage scenarios. All modalities and milestones were integrated into a seamless end-to-end process. In addition, key functionalities were added to support usability like monitoring of detention & demurrage charges, configurable notifications and widgets, integrated carbon footprint calculations, and management reporting (Fig. 4).

The impact of these developments is situated mainly in higher transparency and more proactive information provisioning towards control towers and thereby enabling them to timely plan on-carriage transportation. This in turn creates potential savings on demurrage costs and the ability to better assess options for more sustainable non-road transport alternatives for on-carriage.

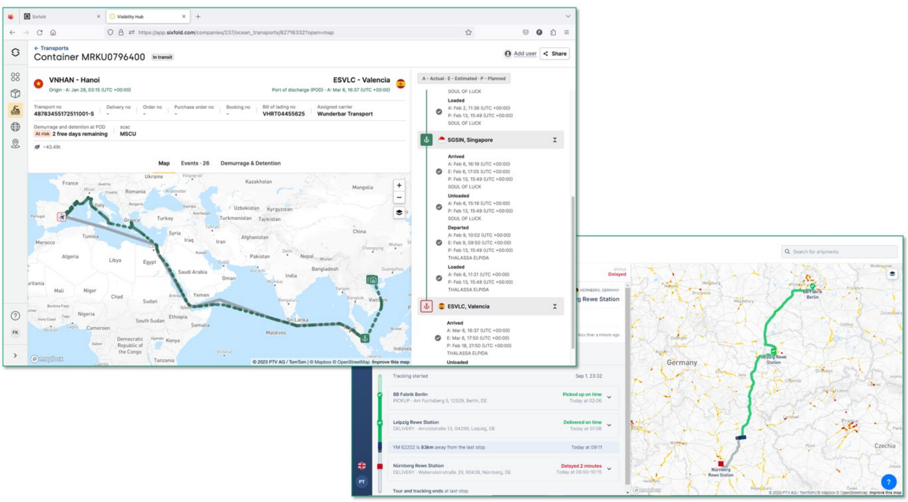

Figure 4: The SW interface for multimodality within Transporeon solution
Source: Own research.

5.2 MJC²: Synchromodality optimization

Synchromodality refers to the ability to dynamically route and re-route freight through a multimodal network, automatically changing and updating the route in response to disruptions, using sophisticated AI-based algorithms. As any transport planner will attest, the size and complexity of modern logistics operations mean that this is a very challenging computational problem. The European TEN-T network itself is very large, as illustrated by the European Commission's infographic (Fig. 5).

At each node, there are multiple modes, routes, and service providers to consider, each with its own constraints, costs, and benefits. Extending this picture to contemplate multiple international routes and options (ocean and rail) increases the scale and complexity. Optimizing freight routing in a network of this nature is extremely challenging: in many cases it can be shown that there are millions of possible options for a single container, so for a large organization managing 1000s of such movements the optimization problem is vast.

Network in numbers (2021)	Total
Rail network length	119.078 km
Road network length	108.597 km
Inland waterways network length	15.451 km
Number of maritime ports	282
Number of inland ports	229
Number of 'maritime & inland' ports	40
Number of airports	317
Number of urban nodes	424
Number of rail-road terminals	251

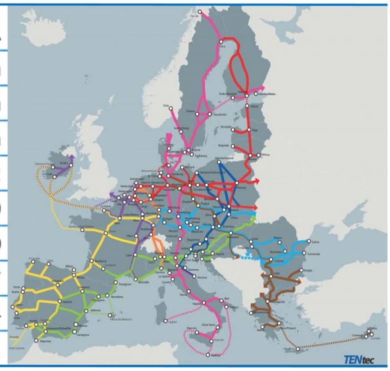

Figure 5: European TEN-T network components
Source: transport.ec.europa.eu

Within the results of the ePIcenter project, the participating MJC² company has developed innovative multimodal optimization algorithms that enable synchromodal logistics planning in large complex networks and international freight transport operations. The core innovation is a very powerful optimization engine that can dynamically allocate and route 1000s of container movements in seconds. Apart from the intrinsic speed of the optimization process, a flexible multi-layered approach has been developed that can accurately model operational rules and constraints, ensuring that outputs are feasible and aligned with business processes and expectations.

The research of new multimodal logistics algorithms to facilitate synchromodal planning, developing entirely new optimization techniques to tackle this very challenging logistics scheduling problem, has been thoroughly conducted for this purpose. There are both short- and long-term benefits. The results and solutions developed, which are ahead of the current state-of-the-art, can be applied to today's logistics networks, creating major cost savings for the companies involved, while reducing congestion and GHG emissions.

The approach has been proven in real-world scenarios, optimizing complex networks and transport operations, and showing how logistics operations can reduce fuel usage and driver workload through new optimization solutions. Longer-term, these innovations take a significant step toward the PI paradigm. The concept is based on an analogy with the way data flows through the Internet in the form of "packets". In the proposed PI world freight would be moved around an open logistics network in intelligent π-containers, which are automatically routed between nodes (warehouses, ports, terminals) by synchromodal algorithms. The ePIcenter synchromodal algorithms can be used for the automated decision-making needed at each node in the logistics chain. These algorithms also allow companies to deal with uncertainty and disruption in the supply chain in a much faster and more efficient way. They absorb information received from real-time tracking and visibility solutions and automatically find new, optimized logistics plans and transport resource schedules.

5.3 Smart containers

An important goal of the project ePIcenter is the research of introduction of smart containers in the operation and this investigation resulted in many positive findings. Statistics show that there are approximately 65 million cargo containers in use worldwide today (TheShip, n.d.). Only 5.6% of them are equipped with telematics devices to record and transmit their number, position, status, and the condition of the cargo inside in real-time. This percentage is increasing, and it is expected that by 2027, 30% of containers in use will be chipped (TGL, n.d.). These so-called smart containers help manage the supply chain, provide up-to-the-minute T&T, and predict arrival times. They save time, reduce paperwork and human error, prevent loss and theft, increase visibility, accountability, and more (BOXPORT, n.d.; Kollman, n.d.). Freight container T&T is important for the optimal use of empty containers, storage, filling, (un)loading, manipulation, transport, transshipment, delivery, etc., but also for monitoring and controlling the conditions inside. This is extremely important when dealing with dangerous, perishable, and high-specific value cargoes, such as nuclear waste, pharmaceuticals, food, animals, plants, flowers, treasures, etc. In such circumstances, it is advisable to T&T each container separately, in parallel with the physical conditions inside, including the condition of the cargo itself (Bauk *et al.*, 2023).

However, this is much easier to achieve on land than at sea. There are many reasons for this: the Internet at sea is not as stable and fast as on land, due to the movement of the sea surface, occlusion by waves, usually harsh weather conditions, the 'urban canyon' effect, multipath fading, etc. In addition, whereas overland containers are usually lined up one after the other along the route, containers shipped by sea are loaded in huge blocks while being exposed to electromagnetic fields from electronic equipment and machinery on board. Containers transported by sea are placed side by side on several levels in the ship's hull and on board. This makes it difficult to access and collect data.

The situation is less complex, for example, in the maritime transport of radioactive cargo. Ships built for this purpose can carry only about twenty specially designed containers, called casks or drums (WNTI, 2021; PNTL, 2021). Although it is much easier to T&T containers in this arrangement, to the best of our knowledge, information on the status of the casks is sent manually by the officer on watch (OoW) to the main control center on shore, rather than automatically in real-time (Bauk, 2020). Further research is therefore needed.

6 Conclusion

In the global environment, harmonization in data and information sharing with common structures, contributes to higher interoperability, creating communities with common values and shared goals. In maritime transport field, the stakeholders are mostly the agencies, administrative institutions, ports, or regional/international consortiums. Harmonization and interoperability tend to leverage technology, minimize administrative burdens, reduce paperwork, and facilitate the application of PCS, MSW, blockchain, smart containers and ETA prediction tools in the maritime sector. In general, ship reporting procedures include electronic transmission of sensitive, private, and proprietary information, ship location/destination, cargo types/amounts, passenger names and identity, and security/safety-related information (IMO, Facilitation Committee, FAL 44). Therefore, the paper gives a broad literature review and discusses the most important regulations from IMO/IPCSA/UN organizations that indicate mandatory documentation for ship reporting, data harmonization, exchange, and facilitation of global maritime trade. These significantly shape the recent trends in the development of technical solutions for big data management and integration. Among these, MNSW and PCS play a crucial role together with other initiatives for the development of algorithm toolsets and AI-supported modules for transport data-sharing platforms optimization.

The case study was conducted over the innovative research project ePIcenter, considering the platforms and modules features (Transporeon, Syncrhomodal optimization and smart containers on blockchain) deployed for trial Enhanced Physical Internet-enabled Global-European Network with aim to increase efficiency and reduce transport challenges. The solutions resulted with provision of optimal technical capabilities and decision support for maritime and intermodal supply chain management participants. Furthermore, as final results are new resilience strategies for global operations and the ePIcenter technology. At least, this concept would allow businesses to develop more robust operations and contingency strategies to mitigate the impact of future disruptions in maritime and intermodal transport.

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References

Ahmad, S., Abidin, S., Omar, N. (2011). Data Sharing in Networked Environments: Organization, Platforms and Issues. In *Proc. 5th WSEAS int. conf. on ICT*, pp. 207-213.

Bauk, S. (2020). Modelling Radioactive Materials Tracking in Sea Transportation by RFID Technology. TransNav – International Journal on Maritime Navigation and Safety of Sea Transportation, Vol. 14, No. 4, pp. 1009-1014.

Bauk, S., Ntshangase, L.H. (2023). Blockchain Implementation Barriers in Maritime: A Case Study based on ISM and MICMAC Techniques. *Journal of Maritime Research*. Vol. 20, No. 3, 2023, pp. 72-80; https://www.jmr.unican.es/index.php/jmr/article/view/736/766

Bauk, S., Radulovic, A., Dzankic, R. (2023). Physical Computing in a Freight Container Tracking: An Experiment. In the *Proceedings of the 12th Mediterranean Conference on Embedded Computing* (MECO'2023), Montenegro, doi: 10.1109/MECO58584.2023.10155008.

Baygin, M., Yaman, O., Baygin, N., Karakose, M. (2022). A blockchain-based approach to smart cargo transportation using UHF RFID, Expert Systems with Applications, Vol 188, 116030, https://doi.org/10.1016/j.eswa.2021.116030.

Bezić H., Tijan E., Aksentijević S. (2011). Port Community Systems – Economic Feasibility Evaluation. *Review of Contemporary Entrepreneurship, Business, and Economic Issues*. J. J. Strossmayer University of Osijek, No. 2/2011 pp. 247-256.

BOXXPORT GmbH (n.d.). What are Smart Containers? Available online: https://www.youtube.com/watch?v=6YtNAYtHBlA (accessed on 01/03/2024).

Directive 2010/65/EU of the European Parliament and Council on reporting formalities for ships arriving and departing from ports of the Member States, Strasbourg, 20/10/ 2010.

Economic Commission for Europe, United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT). (2005). Recommendation and Guidelines on establishing a Single Window to enhance the efficient exchange of information between trade and government. *Recommendation No. 33*, United Nations New York and Geneva.

Elmay, F.K., et al. (2022). Blockchain-Based Traceability for Shipping Containers in Unimodal and Multimodal Logistics. *IEEE Access*, vol. 10, pp. 133539-133556, doi: 10.1109/ACCESS.2022.3231689.

ePIcenter project deliverable. (2022). D1.7 Final Review of EU/Global Initiatives Policies and Standards Impacting ePIcenter. Public report within Project GA No. 861584.

European Commission, DG MOVE, Directorate D - Logistics, maritime & land transport and passenger rights, D.1 - Maritime transport & logistics, National Single Window Guidelines, Final version, Bruxelles, 17/04/2015.

Iakushkin, O., Selivanov, D., Pavlova, E., Korkhov, V. (2019). Architecture of a Smart Container Using Blockchain Technology. In: Misra, S., et al. Computational Science and Its Applications – ICCSA 2019. Lecture Notes in Computer Science, vol 11620. Springer, Cham. https://doi.org/10.1007/978-3-030-24296-1_42.

IMO, Expert Group on Data Harmonization. (2020). EGDH 3/20/1, Any Other Business, Modelling progress update following EGDH 2, Submitted by UNECE, WCO, ISO.

IMO, Facilitation Committee. (2020). FAL 44/WP.5, Review and Revision of the IMO Compendium on Facilitation and Electronic Business (Item 6), Developing Guidance for Authentication, Integrity and Confidentiality of Content for Exchange via MSW (Item 7).

IMO, FAL 42/8, Update the Guidelines for Setting up a Single Window System in Maritime Transport, 5th March 2018.

Jaiman, V., Pernice, L., Urovi, V. (2022). User incentives for blockchain-based data sharing platforms. *PLoS ONE* Vol. 17, No.4: e0266624. https://doi.org/10.1371/journal.pone.0266624.

Jović, M., Tijan, E., Brčić, D., Pucihar, A. (2022). Digitalization in Maritime Transport and Seaports: Bibliometric, Content and Thematic Analysis. *J. Mar. Sci. Eng.* Vol. 10, No. 486., pp. 1 -24.

Kapidani, N., Kočan, E. (2015). Implementation of National Maritime Single Window in Montenegro. *23rd Telecommunications Forum Telfor (TELFOR).*

Kapidani, N., Tijan, E., Jović, M., Kočan, E. (2020). National Maritime Single Window – Cost-Benefit Analysis of Monetengro Case Study. *Promet – Traffic & Transportation*, Vol. 32, No. 4, pp.543-557.

Kirstein, L. (2018). Information Sharing for Efficient Maritime Logistics. *OECD/The International Transport Forum.*

Kollman, J. (n.d.) Smart containers key to improved supply chains. Available online: https://www.ingwb.com/progress/insights-sustainable-transformation/smart-containers-key-to-improved-supply-chains (accessed on 01/03/2024).

Lind, M., Michailides, M., Ward, R. Watson, R. (2021). *Maritime Informatics*. Springer, 2021.

Lind, M., Ward, R., Bergmann, M., Haraldson, S., Zerem, A. (2020). Digitalizing the port call process. *Transport and Trade Facilitation Series No 13, UNCTAD.*

Maatsch, S., Jović, M., Jungen, H., Müller, R. (2022). Position paper: Resilience of maritime transport chains. https://island.isl.org/sites/default/files/2023-09/Position_paper_ Resilience_of_maritime_transport _chains_0.pdf (accessed Dec. 12, 2023).

Meyer, T., et al. (2019). Blockchain technology enabling the Physical Internet: A synergetic application framework. In *Computers & Industrial Engineering*, Vol.136, pp. 5-17, https://doi.org/10.1016/j.cie.2019.07.006.

Ntshangase, L. H. and Bauk, S. (2024). Blockchain applications and cybersecurity threats: A review. In *Proceedings of the 28th International Conference on Information Technology (IT)*, Zabljak, Montenegro; https://doi.org/10.1109/IT61232.2024.10475777

Paladin, Z., Bauk, S., Mujalović, R., Kapidani, N., Lukšić, Ž. (2024). Blockchain Technology's Effects on Big Data in Maritime Transportation. In *Proceedings of 28th Information Technologies Conference (IT)*, Zabljak, Montenegro.

PNTL (n.d.). PNTL Ship Tour. Available online: https://www.pntl.co.uk/our-fleet/pntl-ship-tour/ (accessed on 01/03/2024).

Surucu-Balci, E., Çagatay, I., Balci, G. (2023). Digital information maritime supply chains with blockchain and cloud platforms: Supply chain capabilities, barriers, and research opportunities. *Technological Forecasting & Social Change*, No. 198, 122978, pp. 1-16.

Šorović, M., Brčić, D., Frančić, V., Maričević, T., Đurović, Z., Kapidani, N., Lukšić, Ž. (2023a). Integrated information solution as a platform for data exchange in a modernized ADRIREP system. In *22nd International Symposium Infoteh-Jahorina (INFOTEH)*, pp. 1-6.

Šorović, M., Kapidani, N., Lukšić, Ž., Maričević, T., Marušić, Š., Frančić, V., Brčić, D., Strabić, M., Đurović, Z.. (2023b). Towards the Introduction of the Sea Traffic Management System in the Adriatic Sea. In *Proc. 12th MECO Conference*, pp. 610-615.

Šorović, M., Kapidani, N., Lukšić, Ž., Frančić, V., Strabić, M., Brčić, D., Malovrh, A., Đurović, Z., Maričević, T. (2023c). Harmonisation of VTS Training Programs – A Case Study of the Adriatic-Ionian Region. In *3rd International Conference of Maritime Science & Technology - Naše More 2023, Safety, Innovation, Resilience,* Dubrovnik.

TEN-T transport network statistical pocketbook (2021). https://transport.ec.europa.eu/facts-funding/studies-data/eu-transport-figures-statistical-pocketbook/statistical-pocketbook-2021_en (accessed on 6/12/2023)

TGL -Think Global Logistics (n.d.). What are Smart Containers? The Rise of Smart Containers. Available online: https://www.youtube.com/watch?v=-Ry-0HermnE (accessed on 01/03/2024).

TheShip (n.d.). Shipping Containers & Solutions. How Many Shipping Containers Are There in the World? Available online: https://theship.ai/blog/how-many-shipping-containers-are-there-in-the-world/#:~:text=One%20of%20the%20most%20popular,shipping%20containers%20in%20use%20worldwid (accessed on 01/03/2024).

Tijan, E., Agatić, A., Hlača, B. (2012). The Necessity of Port Community System Implementation in the Croatian Seaports. In *Promet – Traffic&Transportation*, Vol. 24, No. 4, pp. 305-315.

Tijan, E., Agatić, A., Jović, M., Aksentijević, S. (2019). Maritime National Single Window—A Prerequisite for Sustainable Seaport Business. In *Sustainability* 2019, Vol. *11, No.*17, p. 4570; https://doi.org/10.3390/su11174570

Tijan, E., Jardas, M., Aksentijević, S., Perić Hadžić, A. (2018). Integrating Maritime National Single Window with Port Community System – Case Study Croatia. *31st Bled eConference – Digital Transformation: Meeting the Challenges Conference Proceedings*, Bled, Slovenia. pp. 1-11.

UNECE (n.d.). Real-time smart container data for supply-chain excellence. Available online: https://unece.org/DAM/cefact/GuidanceMaterials/WhitePapers/WP-SmartContainers_Eng.pdf (accessed on 01/03/2024).

UNECE, UN/CEFACT, Data Simplification and Standardization for International Trade, Recommendation No.34., NY and Geneva, 2013.

UNECE, UN/CEFACT, Recommendation and Guidelines on Establishing a Single Window - To Enhance the Efficient Exchange of International Trade Information Between Trade and Government, Recommendation No.33., Geneva, 2020.

UNECE, UN/CEFACT, Trade and Transport Facilitation Monitoring Mechanism, Recommendation No.42., New York and Geneva 2017.

UNECE/TRADE/C/CEFACT/2011/4, Centre for Trade Facilitation and Electronic Business 17th session, Revision of Recommendation 12: Measures to facilitate maritime transport documents procedures, 2011.

WNTI-World Nuclear Transport Institute (2021). Fact sheet: Quick facts on the transport of Nuclear Fuel Cycle Transport. Available online: https://www.wnti.co.uk/wp-content/uploads/2021/01/Quick-Facts-on-the-Transport-of-Nuclear-Fuel-Cycle-Transport.pdf (accessed on 01/03/2024).