

**Title:**

*Latest applications and future challenges of integrating Machine Learning models and AI algorithms in Logistics and Shipping, specifically freight container transportation.*

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**Abstract**

In the freight container logistics industry, integration of machine learning (ML) and artificial intelligence (AI) offer the potential to optimize and streamline the entire supply chain. However, there are several challenges to implementing these technologies, including the complexity of the logistics industry, technological stagnation, and the human factor. Supply chains involve multiple parties, different software, and data formats, making integration a significant challenge. Many logistics companies still use legacy software systems and upgrading them can be time-consuming and costly. Resistance to change from paper-based protocols in logistics industry is also a challenge. Despite these challenges, there are promising use cases for ML and AI in the logistics industry. Predicting demand, optimizing routes, and identifying security threats are examples. Therefore, this article explores the current state of ML and AI integration into the freight container logistics industry, as well as identify potential issues and the future direction of the industry.

**Word count:** 4206 words

## **Introduction**

Since the dawn of exploration age, the humanity has faced a crucial task of efficient logistics. Throughout the years this has been the challenge considering the slow advancement in technologies, but since the beginning of the 20<sup>th</sup> century everything has changed with emergence of the term globalisation. Globalisation in the broad term refers to the increasing global interconnectedness between nations, businesses, and economies (PIIE, 2022). In order to maintain this relationship, the countries started trading goods on a large scale, which demanded high efficiency. Since then, the transportation industry has started to innovate their logistics routes for profit maximisation.

For the most time, the logistics upgrades have remained tangible, for example cutting the workforce or finding more efficient route for transport, but everything has changed with emergence of digital technology and the Internet. To this day, this breakthrough has been the greatest revolution in logistics. Digitalisation has allowed for greater transparency and more efficient cost benefit analysis. However, unlike transportation, digital technologies have evolved more rapidly, and nowadays we are seeing the gradual domination of neural algorithms in all spheres. Transportation is not an exception. Machine Learning and AI has started to dominate supply/demand forecasting, warehouse capacity, process optimisation, traffic flow, location prediction and other aspect of freight logistics (Port Technology, 2021).

On the other hand, despite the obvious benefits of ML and AI (PierNext, 2021), there were certain obstacles with integration. It is important to understand that ports are the drivers of global economy, so theoretically, countries where the ports are located would be more willing to invest and develop the maritime infrastructure. However, in the real world, some ports have been more successful in integrating new technologies, such as the ones in Singapore, Rotterdam, UK, Norway, whereby other ports are struggling, such as the ones in Africa or Central Asia (Port Technology, 2021) (Sinay, 2021) (Kaye, 2018) (Illsley, 2017). As a result of this uneven spread of development we can see a formation of bottlenecks in logistics. While some ports are integrating Machine Learning and AI for supply/demand forecasts and efficient routing, other lack funding or even struggle to digitalize their procedures and data. As reported by Off-Shore energy, 80% of world ports are not digitalised (Prevljak, 2021). As mentioned by David Yeo, CEO of Aqua group “The current dynamic reflects the often-messy reality of port operations, which is a blend of high-tech digital and paper-based, manual processes sitting side-by-side” (Prevljak, 2021).

Therefore, this article tends to explore the current state of ML and AI integration into the freight container logistics industry, as well as elaborate thoroughly upon the dwelling issues and the future direction towards which the industry as a whole is heading.

## **Current Integration of ML in freight transportation**

To accomplish the above stated objective multiple articles were scouted and analysed. On one hand we can see a substantial increase in the use of deep learning methods, ensemble approaches, and regression methods over the last several years, and this trend is anticipated to remain due to the growing interest in scientific research. In excess, sixty percent of demand forecasting applications use classic machine learning and ensemble bagging techniques to solve arrival forecasting challenges (Kalliopi, 2022). The research indicated that deep learning approaches are widely used in the optimisation of industrial operations, but ensemble methods, boosting and bagging, are not employed for vehicle routing issues. On the other hand, the performance of ANNs and ensemble learning approaches has been shown to be superior to that of less advanced machine learning techniques. *However, not everything is that simple. Other studies for example by Jonquais (2019) come to completely controversial conclusion. Models having longer transit times and higher total variability, benefit most from the Neural Network's superior performance compared to the baseline models mentioned in the study. On both the models' gate-in and gate-out, the Neural Network does marginally worse compared to the average. The necessity for substantial computing power is another drawback of Neural Network designs. It requires more time and resources to train a Neural Network than any kind of model. Adding additional concealed layers to the model may make it better, but doing so would only provide small improvements in reliability and substantially raise the amount of processing time required to train the model.*

*Talking about machine learning techniques, to better understand the penetration of ML and AI in marine logistics it is crucial to look over three main Machine Learning approaches. These approaches are Supervised Learning (most common approach where the input and output data is known and the steps towards solution are found), Unsupervised Learning (only input data is known, no output data points) and Reinforcement Learning (similar to supervised but has training data set and sequence of dependent decisions) (Akyuz, 2019). Implementation of all the of the named learning approaches has been widely explored in two papers by Akyuz (2019) and Thangalakshmi (2021). On one hand, both authors draw various examples of ML and AI implementation in the maritime logistics in Port /Ship /Fuel /Route Optimisation, Obstacle avoidance, Maintenance and Repair forecasting, but nevertheless both authors come to the same conclusion. Despite there is rise of ML and AI implementation in maritime logistics, it is still in the elementary stage of development. Both papers only overview the ML and AI development and do not dive deep into the cause of the issue, but Akyuz (2019) includes in his paper a table of AI pros and cons in marine logistics, which can be seen below.*

**Table 3. Pros and Cons of AI - Maritime Sector [15]**

| <b>Artificial Intelligence – Maritime Sector</b> |                                          |
|--------------------------------------------------|------------------------------------------|
| <b>Pros</b>                                      | <b>Cons</b>                              |
| Cutting-edge Analytics                           | Reduced data-quality                     |
| Computerised Processes/Equipment                 | Dearth of proper info                    |
| Safety/Value-added Security                      | Panic of occupation replacement          |
| Direction/path optimization                      | Absence of perfect approach              |
| Performance guessing                             | Make over into trade is a lengthy course |
| Cost cutbacks                                    |                                          |
| Boosting maintenance                             |                                          |

*This table is a visual representation of current marine sector from the AI perspective. On the left-hand sight, we can see that there are obvious benefits to the sphere, but on the right-hand sight we can see the pulling back factors. Two of these “con” factors, specifically “reduced data quality” and “panic of occupation replacement” will be particularly important for understanding the broader picture later in the review.*

*Maritime logistics sector is not only about ports, but also about vessels. Good example here is the Suez Canal incident, whereby one ship has cause billions of dollar losses. Could that have been prevented with use of AI algorithms? Previously, the main focus of the paper lied in terms of port operations, but for proper representation it is also crucial to analyse how ML and AI have been integrated in the freight vessel transportation and management. In most papers, vessels transportation and management is only covered briefly, as a part of a major marine logistics topic, albeit there is one paper by Park (2023) that not only explores the topic of vessels, but also applies the algorithms on real world geographical location, specifically gulf of South Korea. The implementation of Vessel Data Lakehouse for VMS and a working example of the resulting system are the primary topics of this study. The components of the Vessel Data Lakehouse are the Vessel Data Lake, the Vessel Data Warehouse Model, the Vessel Application Services, and the Extraction and Ingestion layer. Each of these levels plays an intermediary role, allowing data to flow through it and be processed. The author then applies the Vessel Data Lakehouse methodology to actual datasets that have been imported. In this work, the author imports data using the Impala SQL language. The end result is an ML/AI model capable of effectively managing the vast bulk of vessel data. Experiments conducted with about 34 GB of data from AIS and VPSS revealed that the Data Lakehouse had a 92.95% greater mean request reply rate than the relational database (Park, 2023). Nevertheless, consumers are currently unable to tap into every opportunity of this information ecosystem due to the present difficulties in developing large-scale maritime information services. From a technological standpoint, these difficulties are rooted in the vast quantity of data and the inherent diversity of marine-based data sources.*

Overviewing ML and AI approaches is always a must, but there are also countless case studies applied on real-life ports (Kretschmann, 2021), one of them is the port of Gibraltar, which is considered a Smart Port (Moscoso, 2016). The research about this port has focused upon applying Freight flow prediction techniques. Freight flow prediction is an essential decision-making technique in port operations and might enhance the quality of service in various global ports. In terms of Gibraltar port, Artificial Neural Networks and Support Vector Machines for Regression performed the forecast. In terms of the seven-day-ahead forecast, both techniques performed admirably. In addition, it has been shown that SVR might be a useful method in freight flow forecasting difficulties, specifically for predicting vegetable Roll-on/Roll-off movements through the Strait of Gibraltar somewhat better than ANN models do. Taking this into account we can estimate that in other Smart Ports, similar models can be applied and tested.

*Another study looks more in depth in terms of interconnectedness of various ports, specifically China and Vietnam ports (Hu, 2020). The authors look at the commercial and financial*

*consequences of vessel traffic across two sovereign maritime systems. Considering that China is experiencing a slowdown in growth while the Vietnamese economy and commerce are flourishing, the shipping network of movements connecting China and Vietnam is shown as a typical instance. The flow patterns and volumes are calculated and analysed using networking and flow analysing techniques, based on data from the last five years of reciprocal interaction among Vietnam and China. The dynamic cargo movements that stand in for supply networks between the two nations are analysed using marine convection. The strength and trends of shipping commerce between the two nations are analysed using maritime variation. In the context of China's Belt and Road Initiative, we start seeing and thinking about these two things in a new light. A comprehensive framework is used to create convection and instability networks and associated metrics. As a result, the suggested technique may be used in the study of relations in any kind of network, not only those linked together by flows.*

Apart from traditional transportation of goods from point A to point B, Machine Learning has even penetrated the undervalued spheres of logistics, such as Reverse Logistics (Lickert, 2021). Reverse Logistics is a term referred to the process of returning the product back to the initial destination (Jenkins, 2021). Unlike, traditional transportation, reverse logistics is a hard penetrable sphere, therefore research for now is mainly focused upon identifying the criteria which can be used for actual ML learning applications. There is also a demand for further research in this field, as selected criteria are too rigid and yet to be polished.

*After looking into both paper and real-life implementation of ML and AI in freight logistics, we can see that most of the Machine Learning concepts, such as Regression models, Decision trees, SVM, Neural Networks etc are only being tested to find the best fit for aspects of logistics such as demand forecasting, arrival time prediction, route optimisation etc. What is more, some areas of cargo transportation, specifically Reverse Logistics are yet to be properly tested with ML models. When reviewing the real-world implementation of ML in logistics, another problem arises. In most cases the datasets are either trial, meaning they have been imported from ports' data warehouse, but non-representative of the real situation in the port, or completely simulated (Araujo, 2021). Finding a study that truly applies ML in real-life port infrastructure is a challenging task. This is mainly due to several issues, for example data privacy and leakage concerns, as well as ports' simple inability to adopt such algorithms. The main reason for that will be explored in depth further in the paper. Another challenge is finding examples of ML integration in Vessel management for exactly the same reasons.*

With that being said, we can see that although there is a leap of development in the ML integration in ports, the symbiosis is far from complete. The development paper came to the same conclusion and this paper, despite trying to challenge that conclusion, was not able to do so. There are certainly ports that went ahead of others, such as the one in Rotterdam (Witschge, 2019), and implemented ML in its management, but as research indicates, Rotterdam and similar ports are exceptions, and a lot of ML algorithms are only being tested on paper or sample data. Yet, it is forecasted that in 5 years there will be a significant growth of real implementation of ML in ports infrastructure.

### **What are the issues with integration of ML in freight logistics?**

Despite many examples of ML and AI integration into freight transportation were listed previously, it is important to remember that as of 2021, only 20% of ports were digitalised, meaning only they can be impacted by the significant boost of efficiency as a result of ML integration (Prevljak, 2021). But what about the other 80%? What are the current challenges they facing and is the gap in development that big?

Implementing AI and ML in any industry requires a lot of planning and resources, but before all, the digitalisation of operations and data. Freight logistics is currently experiencing the biggest struggle on that front (Brunila et al., 2021). Digitalisation is a methodological process and cannot be done at once. There are various factors during this process which has to be solved. The first one is systems compatibility, as in order for ML models to learn and work, the systems has to be synced through Industrial Internet of Things (IIoT). Unfortunately, connecting systems is not that easy, as ports and shipping firms computerise their operations in various stages and at variable intervals. This is especially troublesome if the systems' architectures are for integrating technology domains: inoperability presents serious issues that are costly to rebuild and reinstall. This leads to increased expenses and not to the expected efficiency improvements (Brunila et al., 2021). One of the potential solutions is building Ecosystems to optimise operation. However, most of them are private and competing companies in the maritime logistics, instead of sharing data prefer the silo approach. This eventually leads to stagnation in attempts to digitalise ports.

Another issue arises directly from the fact that most ports utilise paper-based protocols. Information storage and warehousing is often a murky problem at ports (Inkinen, 2021). Especially at tiny ports, the whole records management may be taken care of by one individual, and data sources may be dispersed among many databases since they are not linked. Moreover, the preservation of data is not organized, and data styles differ. The data is not necessarily "machine-readable," although it may be stored as PDF documents and map pictures. Information on port infrastructure is often kept by infrastructure businesses rather than the ports themselves. In general, data management offered by several operators are incompatible.

Last but not least, cost planning poses a significant fear on ports' stakeholders (Brunila et al., 2021). Currently, the easiest way of claiming that the port was digitalised is implementing a quick, short-term solution that changes barely anything in daily port operations, but the one that allows the port's management to claim that the first steps of digitalisation were taken (Brunila et al., 2021). The main goal of digitalisation is cost efficiency, and to achieve it, the port's management requires to plan the expenses for innovation integration in long term. Unfortunately, most ports do not follow that path.

Overall, the biggest hurdle towards integration of ML and AI in ports is lack of digitalisation. Digitalisation is time consuming and resource demanding process which possesses a lot of barriers to entry. Some of the barriers have been mentioned above, but other also include cost limitations and shortage of quality labour to facilitate the process of digitalisation (Yildirim,

2022). However, in order to solve the issues, the causes have to be identified. Diving deeper into the topic it can be concluded that the causes are mostly systematic, meaning dictated by the environment. The causes include corruption, lack of collaboration between private and public sectors, slow economic development of the country and increasing price of innovation.

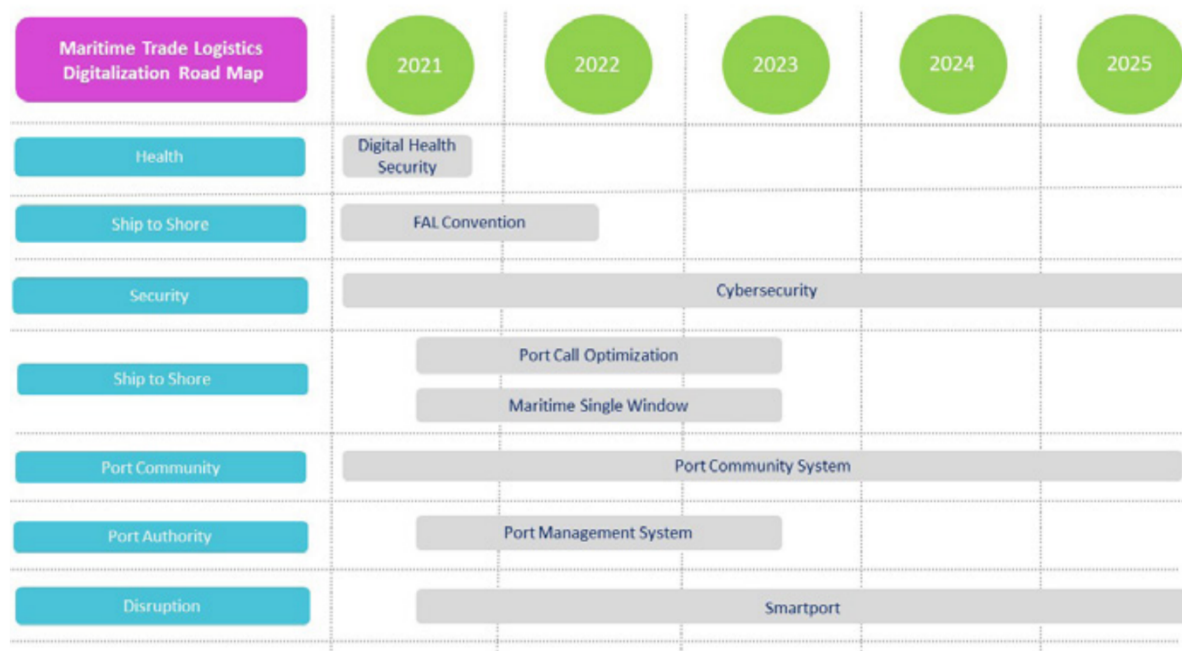
### How to solve the gap in development?

*Nevertheless, despite the dwelling issue of digitalisation, it does not mean that there are no solutions to it. In fact, many papers have been exploring and developing immediate, mid-term and long-term solutions to digitalisation. All these solutions vary drastically, therefore, for their better overview, the solutions were split up in General, Technical and Ecosystem Solutions.*

### General Solutions

*Before all ports should establish a long-term Roadmap to Digitalizing their operation, as for example the one proposed by World Bank (2020) below.*

Figure 2.1. Maritime Trade Logistics: Digitalization Road Map



*Roadmaps should be individual for each port, due to the fact that all ports are in different stages of technological development and have various amount of cash on hand. Road Map will not only serve as a vision board, but also set a correct path towards integration into the global logistics chain. It is also important to set up urgent precautions, such as surveillance systems for online medical security and crisis management centres housed inside international organisations. Overall, we want to make sure that cruise ship and ferry staff and passengers are safe in the "new normal" by mandating social distancing and regulating the internal temperatures of port employees.*

*The second phase of digital transformation entails implementing the interim steps necessary to fulfil the prerequisites specified in the IMO (1965) Facilitation (FAL) Convention. The goal of the FAL Convention is to facilitate the digital transfer of data pertaining to the arrival, stay, and departure of vessels, individuals, and freight in an effort to reduce the need for paper documentation and in-person interactions.*

*The nine essential data items for optimising port calls must be discussed at the same time that ports must satisfy the obligatory standards of the FAL Convention. To guarantee docks, fairways, and maritime services at desired ports, port call optimization helps ships to optimise their pace throughout the journey to arrive at the pilot loading point on time. A port's efficiency and demand will improve as a result of these timely arrivals. In addition, ports should begin work to develop and implement a port community network. A port community network is an online database that helps streamline the chain of logistics by collecting data from all links in the supply chain in one place. In order for marine and trade logistics players to reap the benefits of digitalizing those procedures and accompanying apps, there must be consistency between the port community and the port administration networks.*

*General solutions extend further and cover all the aspects of the World Bank's proposed Road Map. Nevertheless, it is crucial to remember that although these solutions are solving the issue of digitalisation, factors such as panic of occupation replacement and lack of cash-flow in ports' balance sheets play a key role in whether the management will eventually start implementing the solutions.*

### *Technical Solutions*

*After analysing general solutions, it is time to discuss more tech driven implementations in port infrastructure that would solve the issue of digitalisation. Tech driven solutions in that sphere can extend to the number of hundred, therefore, instead of looking into all of them, two most promising will be critically evaluated. These are Electronic Wearables, which is basically Internet of Things, and Unmanned Aircraft Systems (UAS).*

*One of the more intriguing instances of digital solutions is now being tested at the Port of Antwerp in Belgium (Verstappen, 2019). The Port of Antwerp has entered into a partnership with a Belgian firm that focuses on developing innovative Internet of Things (IoT) products for the marine industry. The latter's goal is to design the port of the future by aiding in the worldwide digitalization of the port business. A wearable device, similar to the rather professional smartwatches on the market, was created by the firm in 2019; it has a number of security and safety applications tailored to the port environment. The firm implemented a new feature towards the end of February 2020 to enable contact tracking and monitoring of the necessary physical distance between devices. However, the capability of this technology goes even further. One of the most challenging part of port digitalisation has been synchronising the work of employees with the work of the machines. Such wearable devices will not only allow to do that and monitor the health of the employees but will be crucial for in port communication between workers. In addition, port's management will be able to track*

*down the employees from the command centre which will allow them to react and send notifications to devices in a matter of seconds. What is more important here is despite this still being a trial technology, developing such tech is not expensive and will play a crucial role for underdeveloped ports when they will want to digitalise.*

*UAVs are now accessible in several forms, each with its own set of features to better meet the demands of its intended audience. These flying robots are increasingly being used to improve efficiency and reduce the cost of delivering supplies and monitoring the situation on the ground, and they are characterised by significantly lower expenses and greater complexity when contrasted to staff operated apps. Proven uses, such as surveying and visualisation, asset digitisation, building and maintenance monitoring, and incident mitigation, are also seeing a surge of interest. In fact, such use of UAVs is already being implemented in ports, for example in UK (Frąckiewicz, 2023). As mentioned before, these systems are more complex meaning that when implemented the staff training will be required. Also, these systems are useless unless some parts of port operation have already been digitalised. For example, if port already uses unified cloud data storage or a CRM system, then these drones will be of a good use, otherwise, they will serve merely as toys for port employees to play with. In order for UAVs to function properly there should be a unified ecosystem, which will be discussed further.*

### Port Community System

*When it comes to digitalisation Port Community System (PCS) is the most important aspect of it. A port community system (PCS) is an adaptable system that provides all sectors and actors in a port community with capabilities tailored to their requirements (World Bank, 2019). A PCS integrates the processes of imports and exports, transit, reorganisations, dangerous goods, garbage disposal, staff reporting, terminal management, checks, voyage alerts, and data provisioning across sea and air (UAS) transport. Increased effectiveness and rapidity in port procedures, especially via the elimination of paperwork, are the primary advantages delivered by a PCS. The features are designed to simplify procedures by reducing the need for documentation, which may slow down cargo processing. The PCS is an efficient constantly updated system thanks to its reliance on digital data interchange. However, one of the most critical aspects of implementing PCS, which can be a big hurdle, is data stability. Ensuring that all data fed into the PCS is in the same format and easily integrates with each other is the most crucial aspect of it (Srouf, 2008).*

### Conclusion

To sum up, this paper has highlighted the use of Machine Learning algorithms and AI in different aspects of maritime logistics. Therefore, coming back to the initial topic of this article mentioned in the introduction, it can be concluded that although the Machine Learning is being integrated in freight logistics, the progress is not yet significant to claim that symbiosis is complete. Most of the Machine Learning concepts, such as Regression models, Decision trees, SVM, Neural Networks etc are only being tested to find the best fit for aspects of logistics such

as demand forecasting, arrival time prediction, route optimisation etc. Some areas of cargo transportation, specifically Reverse Logistics are yet to be properly tested with ML models.

In addition, we can see that apart from the fact that ML is far from its full capabilities in freight logistics, the capabilities can only be tested in 20% of ports. Majority of ports are significantly lagging behind not only in ML, but also, in simple fact of digitalisation. However, it is critical to note that the development is heading in the right direction.

We can clearly see that in not distant future, big ports will be integrating more AI and ML driven tech, whereby small-midsized ports will be lacking behind due to various reasons, mainly lack of clear Roadmap and funds.

Nevertheless, there is progress towards solving these issues, for example one solution has already been mentioned which is building Ecosystem for port operations, but transparency of these ecosystems is a big question. Another possible solution to solve the issues is legislation. The most successful incentive for the introduction of innovative digital solutions linked to sustainability, safety, and security is legislation. Law successfully reduces some of the disadvantages of opposition to digitalization. Without digital solutions, the current level of emission monitoring and control could not have been attained. Instruments of regulation include jurisdictional and legal decisions, limits, and licences (Kuronen & Tapaninen, 2010). The best example of legislation forcing innovation is EU (Valentin, 2018) (Blomsma, n.d.).

For the further research, there should be more focus towards studying the gap in development that was described in this paper, and how machine learning can be used in a way that all maritime players can win. However, it is also key to remember that solving the issues is less important than dealing with causes of these issues.

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## **Appendix**

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