Analysis of Modern Port Technologies Based on Literature Review

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ABSTRACT: Modern technologies provide the optimization, the management, and the automation of the port operation and the logistics processes, hence they create an effective advance which strengthens the port's position among the maritime communities. If it is not enough, they also improve the integration of governing bodies to standardize and harmonize the reporting formalities. Ports have been especially challenged during the COVID - 19 pandemic. The port enterprises, which had dynamically introduced innovative solutions, have maintained their position on the market. This means that innovation is the only way to maintain a high position in the international economy. The aim of the study is to present a review of port technologies, which is based on literature. The article was written in accordance with the method of literature analysis.

1 INTRODUCTION

Modern seaports have a significant role in the competitiveness of each country in terms of globalization. It is worth mentioning that globalization is a process of technological changes. Technological changes have been taking place in the international economy for many years. Newer and newer port technologies have been introduced to the market. As it is shown by the statistics, the reason of their introduction is the rapidly developing containerization. Ports have grown to play a very important role in supply chains [62]. Furthermore, the efficiency and safety of the cargo flows highly depend on the related information flows [17]. Therefore, in order to increase the profitability and importance of the port in the global economy, it is necessary to implement the latest IT systems. Modern technologies provide the optimization, the management, and the automation of the port operation and the logistics processes, hence they create an effective advance which strengthens the port's position among the maritime communities. If it is not enough, they also improve the integration of governing bodies to standardize and harmonize the reporting formalities. Ports have been especially challenged during the COVID - 19 pandemic. The port enterprises, which had dynamically introduced innovative solutions, have maintained their position on the market. This means that innovation is the only way to maintain a high position in the international economy.

The aim of the study is to present a review of port technologies, which is based on literature. The article was written in accordance with the method of literature analysis.

In the introductory part of the paper, the reasonableness and the purpose of applying modern technologies are described. Also the necessity of examining them with the use of literature analysis, is explained there. Moreover, the introduction will help readers to gain a general knowledge of the topic. The second chapter, entitled "Methods and Models", describes the method, which was used. In this part, sixty-five scientific publications, concerning the issue, were analyzed, and particular observations, based on the research conducted by individual experts, were presented. Furthermore, in this chapter the technologies and their practical application, based on case studies, were described. The innovative solutions, characterized in this chapter, have been grouped into two main parts: a) Internet of Things (IoT), b) Artificial Intelligence (AI) and Big Data. While IoT concerns devices that interact with the Internet, AI makes devices learn from their data. Both systems are considered to change the current port into the smart port in the most quickly way. In each part, the most popular and modern systems, which operate in ports or which are currently being implemented, have been selected. The final part of the article "Results and Discussion" presents the effects of the research, which were obtained from popular websites and academic publications. What is more, also the problems encountered during introduction of modern solutions were discussed in the paper. The aforementioned part confirms the reasonableness of implementing innovative systems in seaports in order to improve their functionality.

2 METHODOLOGY

The research method used in the publication is the method of literature analysis. According to Webster and Watson, the full review concerns relevant literature about analyzed subject and is not limited to neither one research methodology, nor one set of journals, nor one geographic area [69]. When creating this article, the following databases were mainly used: Scopus, Web of Science, Google Scholar, Research Gate, IEEE Xplore, Science Direct, and information obtained from the Croatian Standards Institute. The above-mentioned research bases are the leading research portals. They enable to identify the required articles from various sources, e.g. publications in indexed journals, academic conferences, publications in international monographs, dissertations, opinions of professional associations, etc. The literature has been analyzed mainly in order to find keywords (or combination of keywords): smart port, big data, artificial intelligence (AI), internet of things (IoT), port, smart port technologies in English. Ninety most relevant scientific articles, mainly in English, have been analyzed. Each of them was initially examined in terms of: style, compliance with the topic of the paper and attractiveness among the competing publications. The articles which did not meet the above requirements were rejected. The aforementioned

criteria were fulfilled by sixty-five articles, which were subsequently used during the analysis.

3 RESULTS

This chapter presents the results of literature research concerning modern technologies used in seaports. The current state of knowledge about particular innovative port systems was examined, as well as experts' predictions of future innovative solutions were indicated.

3.1 *Smart solutions based on Internet Of Things*

The Internet of Things (IoT), as defined by IEEE, is a network of items, including sensors and embedded systems, which are connected to the Internet and enable physical objects to collect and exchange data [26]. IoT is used in transport and logistics. It should be highlighted, that development and improvement of information technology throughout the entire logistics process put pressure on port systems, requiring continuous development and technological progress at the appropriate level [32]. In this economic sector, the novelty could optimize the cargo tracking and the process of its delivery. During the ICIST'18 conference, one of the examples of the use of IoT, in order to optimize the container service using RFID, was presented [34]. Addo-Tenkorang and Helo define IoT as "Big Data II", highlighting the fact, that IoT schemas go a step further than Big Data applications, enabling a powerful network which integrates industrial facilities, as well as all kinds of products, via sensors and actuators [1]. The Smart Port concept has attracted the attention of the world's largest ports, e.g. the Port of Hamburg, the Port of Amsterdam, Port Le Havre, etc. since 2010 [36]. The largest seaports have opted for IoT, including innovative technological and digital solutions, to modernize their port infrastructure [6, 59]. As IoT develops, sensors play a key role in measuring the physical properties of objects and converting them into numerical values. Subsequently, the numerical values could be noted by another device or by the user. The above could be confirmed by future projects of various governments, e.g. Industry 4.0 (Germany). In Smart Ports the main role is played by intelligent sensors, wireless devices, and data centers. To collect the necessary data, sensors such as: inertial sensors, ultrasonic sensors, eddy current sensors, radar, lidar, image sensors and readers, RFID tags, etc., are needed [72]. A good example of the use of IoT is the proposal to use the positioning algorithm and the obstacle avoidance algorithm for automated guided vehicles (AGV) in the environment based on laser measurement systems [52]. Another form of benefit from IoT is the suggestion presented by Li and Xu. Li and Xu, in their scientific publication, proposed an innovative positioning project for land vehicles. This positioning is based on a virtual sensor and on an integrated inertial measurement unit [39]. The structure of an automated container terminal is presented below.
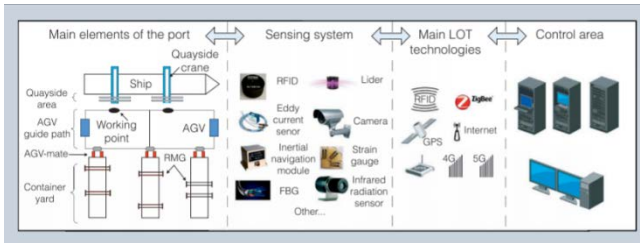
Figure 1. The structure of an automated container terminal [3].

Successful implementation of port processes based on IoT requires strong connection and participation of all stakeholders, as well as competitive companies from supply chain, in order to jointly invest in IoT infrastructure. Burazer claims that it is necessary to invest in the M2M (Machine to Machine) and V2V (Vehicle to Vehicle) models. In order to provide the functioning of both models, the communication via the Internet in one, common, intelligent IoT network, is needed [11, 18]. Properly implemented IoT port processes enable to [32]:

- conduct a full automation of the port terminal;
- reduce operating costs;
- introduce the autonomous vehicles for transporting containers;
- carry out a GPS tracking and cargo management;
- improve the protection of the assets of expensive loads,
- communicate with other vehicles in the supply chain;
- supervise the port / docks live on video;
- take advantage of mobile applications for port workers to increase productivity and improve operations.

The key technologies in the IoT:

6. Sensors

Sensors, are described by Xisong & Gang & Xiujiang & Yuantao & Yisheng as the essential link to make automatic detection and automatic control possible. They could detect, by catching an external signal, physical conditions (such as light, heat, humidity, pressure) or chemical composition (for example smoke), and send them to the top layer of the Internet of Things, using information and communication technology. The sensor responsible for collecting data in the Internet of Things is not only the base for the perception of the real world, but also for IoT services and applications [71]. According to the Heiling's, Ruiz's and VoB's article, a good example of exploitation of sensors is the conversion of paper documents into digital documents with the use of sensors [27].

7. Radio Frequency Identification Devices (RFID)

In accordance with Shi, Tao and VoB, RFID is a technology which is growing rapidly as costs decrease and benefits are recognized. The fundamental advantage of RFID in a port / terminal application is that this is the technology of "automatic" data collection [61]. Kadir and other authors of the publication described the purpose of the RFID system. Its task is to shorten the waiting queue of trucks, to reduce the number of operators from eight to four, to improve containers security, and to facilitate online container tracking [35]. Sensors play an important role in the automation of each application. They estimate and process the collected data in order to detect physical changes [58].

8. Wireless Sensor Network (WSN)

The use of Wirless Sensor Network has been widely presented in the scientific journal IEEE. WSN, has been described as a wireless sensor network in a form of a set of spatially dispersed, autonomous sensors. They cooperate in order to monitor the physical or environmental quantities of the objects being of interest to them [2]. WSN is used in maritime operations, e.g. container monitoring. According to the researchers from the University of Guilan, thanks to wireless sensor networks, it is possible to monitor online containers that transport more than 90 percent of the world's non-bulk cargo, located at the ships and seaport areas, [54].

9. Machine to Machine (M2M)

According to Chen and Li, Machine to Machine is a new communication technology. In 2012, an article on M2M was published, in which the system was presented as a large number of "smart devices", which can autonomously communicate with each other, and make joint decisions without direct human intervention [14]. Live data provided by M2M applications, are increasingly considered as a prerequisite for the digital port of the future.

10. Cyber-physical systems (CPS)

Cyber-physical systems (CPS) are used to automate seaport equipment. These systems are able to connect physical devices with the virtual world.

3.2 *Smart solutions based on artificial intelligence and big data*

Big data and artificial intelligence (AI) are essential elements of data-driven decision making process in most industries [40]. Big Data and Artificial Intelligence have gained considerable attention in recent years, thanks to numerous scientific publications [4]. According to Frank's, Big Data means large amounts of data. Scientists has been creating newer and newer techniques for analyzing large data sets [23]. According to scientists, the number of researches on Big Data and AI use, has increased significantly since 2012. Following this trend, new business models has been developed [48]. Maritime operations which have made use of large data sets and artificial intelligence, could influence the economic and environmental aspects of maritime activities [57]. Thanks to artificial intelligence and Big Data, the maritime industry is transforming into a more productive and optimal one [27]. In reference to verified bibliography, AI and Big Data could be divided into clusters: digitization, applications of big data from AIS, and energy efficiency [49].

Cluster of digitization - it focuses on the use of digital technologies in shipping. As a result, there is a new digital business and hence newer methods of generating income. During the literature analysis, it could be noticed that there is a trend which indicates that among the modern technological systems, the Port Community System is the most popular.

Cluster of applications of big data from AIS - they have been described mainly by literature reviews. The

pioneers in this studies are: Wang, Yang Sidibe, and Shu [49]. Wang and others claim in their publication, that proper visualization of maritime traffic could improve the safety of maritime transport [22, 67].

Cluster of energy efficiency - it concentrates on improving energy efficiency in maritime transport using artificial intelligence and big data. Most of the research in this cluster focus on optimizing ship speed, according to Lee's and Yan's 2018 publication. The others pay attention to route planning. Brouer, Karsten, and Pisinger analyzed a new scenario for optimizing the shipping network in 2017 [10].

The key technologies of artificial intelligence and big data

1. Port Community System

   In reliance on Srour, van Oosterhout, van Baalen, and Zuidwijk statements, the Port Community System could be defined as holistic, geographically limited, information centers in global supply chains, which primarily serve the interests of a heterogeneous collective of companies related to ports [63]. The exploitation and the purpose of this system has been presented for example by Long. Long in his publication claims that the development and implementation of Port Community Systems are important factors contributing to effectiveness of cargo flow across international borders [42].

2. Applications of big data from AIS

   At the IEEE conference, scientists demonstrated the use of big data from AIS. The AIS system was originally created as a navigational safety system to support vessel traffic in ports [44]. Currently, according to Pallott, Vespe, and Bryan, AIS data could also be used for route prediction [50].

3. Multi-agent systems (MAS)

   MAS, was created to improve cooperation between terminal managers, customers and carriers through information connections [41]. Itmi and others in their publication described the use of MAS in terms of solving allocation problems, for example with transport of containers from the quay to the yard [31]. The MAS architecture offered the integration of heterogeneous information from multiple operations in a terminal configuration to create a centralized and structured dispatch system [5].

4. Artificial neural network

   Already in 1999, the automatic character recognition system (CRS) was tested. This system aimed to identify container numbers on the basis of various distortions [38]. In 2012, in the academic article published by Shetty and other, the character recognition system was detailed in the context of the supply chain [60].

5. AGV

   The AGV (automated guided vehicle) system was described in detail in 2013 by Fazlollahtabar and Saidi-Mehrabad. The authors present the use of automated guided carts in reloading systems, such as container terminals [20]. According to Gotting, the use of AGVs will benefit in environments with recurring transport patterns. The examples of such environments are: distribution, transshipment and transportation systems [25].

6. Autonomous Robots

   According to Stavrou et al., automation could improve efficiency of logistics. The authors are developing a method for assigning containers to robots. They use mixed integers for linear programming [64]. Bouge described in his publication the use of an autonomous underwater vehicle – the AUV type. This vehicle is designed to inspect hulls of ships and underwater infrastructure to monitor port security [7, 8]. A model of autonomous ships for moving containers from a ship to a shipyard, was presented in the article by Yuan et al., published in 2010 [73].

7. Algorithms

   In 2009, Salido et al. described in their publication an intelligent model for containers stacking [56]. Park et al. in 2010 described how to re-select containers by practicing a dynamic genetic algorithm, and also proposed a sequencing parameter to take into consideration that there could be multiple tiers or stacks of containers stored at the yard [51]. In 2007, Preston and Kozan investigated mathematical modeling and optimization using a genetic algorithm in order to transfer export containers from warehouse to moored ships. Their implementation of the model and optimization algorithms is able to cope with big problems which arise from operations on the quayside [37].

8. Smart grid

   Smart grid is an intelligent energy grid. This network in ports is designed to power terminals and warehouses by means of wind turbines or photovoltaics. Çağatay Iris et al. described smart grid in their publication. According to them, this is the mathematical analysis aiming to configure and design an intelligent network, what is the advantageous research direction [30].

4 DISCUSSION

The problems encountered during the implementation of modern port technologies were discussed, in reference to bibliography and on the example of case studies. The discussion covers also the legitimacy of implementing innovative systems in seaports [53], in order to improve their functionality. In accordance with a detailed review of sixty-five publications, the article identifies the most popular port technologies from the last few years.

Cerulli et al. described the advantages of using sensors and laser scanners in seaports. The new Qianwan Container Terminal (QQCTN) in China uses laser scanners, sensors and various positioning gauges to handle containers in the port. Their implementation has reduced the number of workers needed to reload one ship in the port from 60 to 9. Terminal operating costs have decreased by 70%. Efficiency has been improved by 30% [13]. Wireless sensors "Waspmote" were created by the company "Liblium" for use in logistics management in ports and shipping. The effects of their application were presented by Rezapour and other authors, in the publication on the use of WSN in seaports. In their opinion, the WSN system enables to increase the safety of employees and goods [9]. Another advantage is smart container management [54].

At the seaport of Hamburg, the largest seaport in Germany, the HPA links the seaport with the technological port. They base their activities on three pillars: infrastructure, traffic and trade [55]. According to Cullinane & Song & Ji & Wang, the Internet of Things has helped to develop a system in which trade and traffic flow improved significantly and allowed the port of Hamburg to become one of the strongest ports in the world [15]. In a publication from 2020, Moros-Daza and other authors presented the concept of the Port Community System development from 1982 until the present moment - to the so-called "fourth wave". The German PCS system is called DAKOSY and, as the authors claim, it has strengthened the position of the port among the competitors [47]. However, Tsamboulas and Ballis notice problems with the implementation of the PCS system. They consider the system to be very expensive, requiring dedication of time and effort to be skillfully implemented. Another issue is to find solutions to the needs of all stakeholders, who operate in the port [66]. Not only Germany has this system. Many seaports such as Rotterdam, Amsterdam, Antwerp, Zeebrugge, Wilhelmshaven, Bremerhaven, and others have implemented PCS [65]. In 2018, an article by Meyer-Larsen and Müller was published. It focused on the problems arising during the adoption of this system. Scientists suggest that effective cyber attacks against this system could lead to enormous problems in the functioning of the ports [19, 28], significant delays in the transport and, in extreme cases, even stoppage [43].

According to Gordon et al., these are the IoT system and innovations that make the port of Singapore a world-class transshipment center [24].

In 2011, Siror, Huanye, and Dong explained in their research the importance of the RFID system using the example of the port of Kilindini, which is one of the world's busiest logistics hubs [21]. On the example of Mombasa, this system provides automatic acquisition and tracking of containers, transport vehicles and goods under supervision of synchronized data exchange between the port, shipyards, warehouses, customs authorities, and freight forwarders [70].

Scientists, in their latest studies, have predicted that in a few years' time around 200 ports in the world will be automated [3]. Orive and co-authors of the publication released in 2020, emphasize the importance of automated ports all over the world. They prepared the list which presents the largest ports in the world which are fully or partly automated. These ports mainly use as cargo handling equipment: ARMG, C-ARMG, ASC, ARTG, AGV [12]. These are inter alia:

- ECT Europa Container Terminal—Rotterdam. Euromax terminal
- ECT Europa Container Terminal –Rotterdam. Delta Terminal
- DP World—Amberes Antwerp Gateway
- Global Container Terminal—New York/New Jersey. Global Terminals
- Xiamen International Port Corp—Xiamen. Halcang + Fuijang
- Shanghai International Port Group—Shanghai. Yangshan

According to UNCTAD reviews, containerization is constantly growing. UNCTAD expects that this growth will continue in the coming years. In reference to those reviews, the introduction of automation of operations and equipment in subsequent ports is inevitable [74]. Douaioui et al. affirm that the automated equipment of the port reduces the energy costs of automated vehicles and optimizes routes. As a result, the number of energy-intensive vehicles used in the port terminal is optimized [16]. Automation is associated with the risk of a cyber attack. According to Wang and co-authors, it can lead to remote control of computer systems. Cyber risk management is essential [68]. In 2019, an article was published in which the author gives the example of the Kenya Ports Authority (KPA), which had automated processes such as time management and payroll functions [46]. Scientists from the University of Rijeka emphasize the importance of digitization in ports, pointing out the joint forces of shipowners Maersk and IBM as an example. These were them, who developed a solution called "Tradelens". It aims to digitize global trade [33].

5 SUMMARY

After a careful literature analysis, it could be concluded that the next generation ports will use automation, electrification and smart energy management systems [30]. The Internet of Things technology provides smart solutions to storage and monitoring of data at the port. Modern remote sensing technologies, such as RFID for identification and location, cameras and built-in computer vision algorithms, could contribute to safer and shorter handling time in comparison to classic container terminals. However, despite the significant advantages of innovative solutions, there are also difficulties. One of them is the expensiveness of this facilities. Furthermore, the noticeable drawback is its vulnerability to cyber attacks, which may occur more frequently in case of digitization. The example of this is the Maersk shipowner, therefore it is so important to remember about proper security of systems. According to many marine accident investigations, the vast majority of maritime casualties are due to or related to human error [29]. Hence it is necessary to introduce modern port technologies to port systems. Kaizer, Modzelewska and Borowski believe information technologies in logistics allow us to optimize the flow of goods and if a port wants to stay ahead of the competition, it must invest in information technology [45].

REFERENCES

1. Addo-Tenkorang, R., Helo, P.T.: Big data applications in operations/supply-chain management: A literature review. Computers & Industrial Engineering. 101, 528–543 (2016). https://doi.org/10.1016/j.cie.2016.09.023.
2. Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., Cayirci, E.: A survey on sensor networks. IEEE Communications Magazine. 40, 8, 102–114 (2002). https://doi.org/10.1109/MCOM.2002.1024422.

3. Alho, T.: Latest Automation Technology Developments for Ports and Terminals. In: Proceedings of the ANESCO Automation Coference. , Madrid, Spain (2019).

4. d'Amore, M., Baggio, R., Valdani, E.: A Practical Approach to Big Data in Tourism: A Low Cost Raspberry Pi Cluster. In: Tussyadiah, I. and Inversini, A. (eds.) Information and Communication Technologies in Tourism 2015. pp. 169–181 Springer International Publishing, Cham (2015). https://doi.org/10.1007/978-3-319-14343-9_13.

5. Anwar, M., Casalichio, E., Henesey, L.: Digitalization in Container Port Logistics: A Literature Review. Presented at the 27th Annual Conference of the International Association of Maritime Economists (IAME) , Athens, Greece June 25 (2019).

6. Belfkih, A., Duvallet, C., Sadeg, B.: The Internet of Things for Smart Ports Application to the Port of Le Havre. In: Proceedings of IPaSPort 2017. , Normandie University, Le Havre, France (2017).

7. Blokus, A., Dziula, P.: Safety Analysis of Interdependent Critical Infrastructure Networks. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 13, 4, 781–787 (2019). https://doi.org/10.12716/1001.13.04.10.

8. Bogue, R.: Underwater robots: a review of technologies and applications. Industrial Robot: An International Journal. 42, 3, 186–191 (2015). https://doi.org/10.1108/IR-01-2015-0010.

9. Bojic, F., Karin, I., Juricevic, I., Cipcic, M.: Design and Application of an Automated Smart Buoy in Increasing Navigation Safety and Environmental Standards in Ports. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 15, 2, 373–380 (2021). https://doi.org/10.12716/1001.15.02.14.

10. Brouer, B.D., Karsten, C.V., Pisinger, D.: Optimization in liner shipping. 4OR. 15, 1, 1–35 (2017). https://doi.org/10.1007/s10288-017-0342-6.

11. Burazer, B.: Normizacija u procesu kreiranja „pametnih gradova", https://www.hzn.hr/UserDocsImages/pdf/Normizacija%20u%20procesu%20kreiranja%20pametnih%20gradova.pdf, last accessed 2021/06/30.

12. Camarero Orive, A., Santiago, J.I., Corral, M.M., González-Cancelas, N.: Strategic Analysis of the Automation of Container Port Terminals through BOT (Business Observation Tool). Logistics. 4, 1, (2020). https://doi.org/10.3390/logistics4010003.

13. Cerulli, R., Raiconi, A., Voß, S. eds: Computational Logistics: 9th International Conference, ICCL 2018, Vietri sul Mare, Italy, October 1–3, 2018, Proceedings. Springer International Publishing https://www.springer.com/gp/book/9783030008970 (2018). https://doi.org/10.1007/978-3-030-00898-7.

14. Chen, M., Wan, J., Li, F.: Machine-to-Machine Communications: Architectures, Standards and Applications. KSII Transactions on Internet and Information Systems. 6, 2, 480–497 (2012). https://doi.org/10.3837/tiis.2012.02.002.

15. Cullinane, K., Song, D.-W., Ji, P., Wang, T.-F.: An Application of DEA Windows Analysis to Container Port Production Efficiency. Review of Network Economics. 3, 2, (2004). https://doi.org/10.2202/1446-9022.1050.

16. Douaioui, K., Fri, M., Mabrouki, C., Semma, E.A.: Smart port: Design and perspectives. In: 2018 4th International Conference on Logistics Operations Management (GOL). pp. 1–6 (2018). https://doi.org/10.1109/GOL.2018.8378099.

17. Dziula, P., Kolowrocki, K., Soszynska-Budny, J.: Maritime Transportation System Safety - Modeling and Identification. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 7, 2, 169–175 (2013). https://doi.org/10.12716/1001.07.02.02.

18. Dziula, P., Pas, J.: Low Frequency Electromagnetic Interferences Impact on Transport Security Systems Used in Wide Transport Areas. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 12, 2, 251–258 (2018). https://doi.org/10.12716/1001.12.02.04.

19. Erstad, E., Ostnes, R., Lund, M.S.: An Operational Approach to Maritime Cyber Resilience. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 15, 1, 27–34 (2021). https://doi.org/10.12716/1001.15.01.01.

20. Fazlollahtabar, H., Saidi-Mehrabad, M.: Methodologies to Optimize Automated Guided Vehicle Scheduling and Routing Problems: A Review Study. Journal of Intelligent & Robotic Systems. 77, 3, 525–545 (2015). https://doi.org/10.1007/s10846-013-0003-8.

21. Ferretti, M., Schiavone, F.: Internet of Things and business processes redesign in seaports. The case of Hamburg. Business Process Management Journal. 22, 2, (2016). https://doi.org/10.1108/BPMJ-05-2015-0079.

22. Formela, K., Neumann, T., Weintrit, A.: Overview of Definitions of Maritime Safety, Safety at Sea, Navigational Safety and Safety in General. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 13, 2, 285–290 (2019). https://doi.org/10.12716/1001.13.02.03.

23. Franks, B.: Taming The Big Data Tidal Wave: Finding Opportunities in Huge Data Streams with Advanced Analytics | Wiley. Wiley https://www.wiley.com/en-us/Taming+The+Big+Data+Tidal+Wave%3A+Finding+Opportunities+in+Huge+Data+Streams+with+Advanced+Analytics-p-9781118208786 (2012).

24. Gordon, J.R.M., Lee, P.-M., Lucas, H.C.: A resource-based view of competitive advantage at the Port of Singapore. The Journal of Strategic Information Systems. 14, 1, 69–86 (2005). https://doi.org/10.1016/j.jsis.2004.10.001.

25. Gotting, H.H.: Automation and Steering of Vehicles in ports. Port Technology International. 10, 101–111 (2000).

26. Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M.: Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems. 29, 7, 1645–1660 (2013). https://doi.org/10.1016/j.future.2013.01.010.

27. Heilig, L., Lalla-Ruiz, E., Voß, S.: Digital transformation in maritime ports: analysis and a game theoretic framework. NETNOMICS: Economic Research and Electronic Networking. 18, 2, 227–254 (2017). https://doi.org/10.1007/s11066-017-9122-x.

28. Hemminghaus, C., Bauer, J., Padilla, E.: BRAT: A BRidge Attack Tool for Cyber Security Assessments of Maritime Systems. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 15, 1, 35–44 (2021). https://doi.org/10.12716/1001.15.01.02.

29. Hornauer, S., Hahn, A., Blaich, M., Reuter, J.: Trajectory Planning with Negotiation for Maritime Collision Avoidance. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 9, 3, 335–341 (2015). https://doi.org/10.12716/1001.09.03.05.

30. Iris, Ç., Lam, J.S.L.: A review of energy efficiency in ports: Operational strategies, technologies and energy management systems. Renewable and Sustainable Energy Reviews. 112, 170–182 (2019). https://doi.org/10.1016/j.rser.2019.04.069.

31. Itmi, M., Morel, D., Pecuchet, J.-P., Serin, F., Villefranche, L.: Eco-problem solving for containers stacking. In: 1995 IEEE International Conference on Systems, Man and Cybernetics. Intelligent Systems for the 21st Century. pp. 3810–3815 (1995). https://doi.org/10.1109/ICSMC.1995.538382.

32. Jardas, M., Dundović, Č., Gulić, M., Ivanić, K.: The Role of Internet of Things on the Development of Ports as a Holder in the Supply Chain. Pomorski zbornik. 54, 1, 61–73 (2018). https://doi.org/10.18048/2018.54.05.

33. Jović, M., Filipović, M., Tijan, E., Jardas, M.: A Review of Blockchain Technology Implementation in Shipping

Industry. Pomorstvo. 33, 2, 140–148 (2019). https://doi.org/10.31217/p.33.2.3.

34. Kadir, E.A., Irie, H., Rosa, S.L.: Intelligent System in Container Terminal for Speed-up Handling Process. In: Proceedings of the International Conference on Intelligent Science and Technology. pp. 56–61 Association for Computing Machinery, New York, NY, USA (2018). https://doi.org/10.1145/3233740.3233743.

35. Kadir, E.A., Rosa, S.L., Gunawan, H.: Application of RFID technology and e-seal in container terminal process. In: 2016 4th International Conference on Information and Communication Technology (ICoICT). pp. 1–6 (2016). https://doi.org/10.1109/ICoICT.2016.7571926.

36. Karas, A.: Smart Port as a Key to the Future Development of Modern Ports. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 14, 1, 27–31 (2020). https://doi.org/10.12716/1001.14.01.01.

37. Kozan, E., Preston, P.: Mathematical modelling of container transfers and storage locations at seaport terminals. In: Kim, K.H. and Günther, H.-O. (eds.) Container Terminals and Cargo Systems: Design, Operations Management, and Logistics Control Issues. pp. 87–105 Springer Berlin Heidelberg, Berlin, Heidelberg (2007). https://doi.org/10.1007/978-3-540-49550-5_5.

38. Lee, J.C.M.: Automatic character recognition for moving and stationary vehicles and containers in real-life images. In: IJCNN'99. International Joint Conference on Neural Networks. Proceedings. pp. 2824–2828 (1999). https://doi.org/10.1109/IJCNN.1999.833530.

39. Li, X., Xu, Q.: A Reliable Fusion Positioning Strategy for Land Vehicles in GPS-Denied Environments Based on Low-Cost Sensors. IEEE Transactions on Industrial Electronics. 64, 4, 3205–3215 (2017). https://doi.org/10.1109/TIE.2016.2637306.

40. Liang, T.-P., Liu, Y.-H.: Research Landscape of Business Intelligence and Big Data analytics: A bibliometrics study. Expert Systems with Applications. 111, 2–10 (2018). https://doi.org/10.1016/j.eswa.2018.05.018.

41. Lokuge, P., Alahakoon, D.: Improving the adaptability in automated vessel scheduling in container ports using intelligent software agents. European Journal of Operational Research. 177, 3, 1985–2015 (2007). https://doi.org/10.1016/j.ejor.2005.12.016.

42. Long, A.: Port Community Systems. World Customs Journal. 3, 1, 63–67 (2009).

43. Meyer-Larsen, N., Müller, R.: Enhancing the Cybersecurity of Port Community Systems. In: Freitag, M., Kotzab, H., and Pannek, J. (eds.) Dynamics in Logistics. pp. 318–323 Springer International Publishing, Cham (2018).

44. Millefiori, L.M., Zissis, D., Cazzanti, L., Arcieri, G.: A distributed approach to estimating sea port operational regions from lots of AIS data. In: 2016 IEEE International Conference on Big Data (Big Data). pp. 1627–1632 (2016). https://doi.org/10.1109/BigData.2016.7840774.

45. Modzelewska, M., Borowski, R., Kaizer, A.: Przegląd trendów IT w zarządzaniu sieciami dostaw, które decydują o współczesnej przewadze rynkowej. Prace Wydziału Nawigacyjnego Akademii Morskiej w Gdyni. Z. 32, (2017). https://doi.org/10.12716/1002.32.06.

46. Molavi, A., Lim, G.J., Race, B.: A framework for building a smart port and smart port index. International Journal of Sustainable Transportation. 14, 9, 686–700 (2020). https://doi.org/10.1080/15568318.2019.1610919.

47. Moros-Daza, A., Amaya-Mier, R., Paternina-Arboleda, C.: Port Community Systems: A structured literature review. Transportation Research Part A: Policy and Practice. 133, 27–46 (2020). https://doi.org/10.1016/j.tra.2019.12.021.

48. Munim, Z.H.: Autonomous ships: a review, innovative applications and future maritime business models. Supply Chain Forum: An International Journal. 20, 4, 266–279 (2019). https://doi.org/10.1080/16258312.2019.1631714.

49. Munim, Z.H., Dushenko, M., Jimenez, V.J., Shakil, M.H., Imset, M.: Big data and artificial intelligence in the maritime industry: a bibliometric review and future research directions. null. 47, 5, 577–597 (2020). https://doi.org/10.1080/03088839.2020.1788731.

50. Pallotta, G., Vespe, M., Bryan, K.: Vessel Pattern Knowledge Discovery from AIS Data: A Framework for Anomaly Detection and Route Prediction. Entropy. 15, 6, (2013). https://doi.org/10.3390/e15062218.

51. Park, T., Kim, J., Ryu, K.R.: Iterative Replanning using Genetic Algorithms for Remarshaling in a Container Terminal. Presented at the Artificial Intelligence and Applications (2010). https://doi.org/10.2316/P.2010.674-120.

52. Pratama, P.S., Nguyen, T.H., Kim, H.K., Kim, D.H., Kim, S.B.: Positioning and obstacle avoidance of automatic guided vehicle in partially known environment. International Journal of Control, Automation and Systems. 14, 6, 1572–1581 (2016). https://doi.org/10.1007/s12555-014-0553-y.

53. Przybylowski, A.: Global Trends Shaping Life Quality in Agglomerations with Particular Emphasis on Mobility in Seaport Agglomerations. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 13, 3, 615–620 (2019). https://doi.org/10.12716/1001.13.03.18.

54. Rezapour, T.Y., Atani, R.E., Abolghasemi, M.S.: Secure positioning for shipping containers in ports and terminals using WSN. In: 2014 11th International ISC Conference on Information Security and Cryptology. pp. 10–14 (2014). https://doi.org/10.1109/ISCISC.2014.6994014.

55. Safa, P., Weeks, K., Safa, M., Zelbst, P.: How Digitalization and IoT Can Improve the Operations of Panama Canal. Journal of Business and Management Sciences. 7, 3, 140–146 (2019).

56. Salido, M.A., Sapena, O., Barber, F.: An artificial intelligence planning tool for the container stacking problem. In: 2009 IEEE Conference on Emerging Technologies Factory Automation. pp. 1–4 (2009). https://doi.org/10.1109/ETFA.2009.5347007.

57. Sanchez-Gonzalez, P.-L., Díaz-Gutiérrez, D., Leo, T.J., Núñez-Rivas, L.R.: Toward Digitalization of Maritime Transport? Sensors. 19, 4, (2019). https://doi.org/10.3390/s19040926.

58. Sehrawat, D., Gill, N.S.: Smart Sensors: Analysis of Different Types of IoT Sensors. In: 2019 3rd International Conference on Trends in Electronics and Informatics (ICOEI). pp. 523–528 (2019). https://doi.org/10.1109/ICOEI.2019.8862778.

59. Serry, A., Loubet, L.: Developing the City, Developing the Port: Comparison of the Governance in Medium-size Port-cities in Europe. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation. 13, 3, 607–614 (2019). https://doi.org/10.12716/1001.13.03.17.

60. Shetty, R., Cáceres, R., Pastrana, J., Rabelo, L.: Optical container code recognition and its impact on the maritime supply chain. In: Proceedings of the 2012 Industrial and Systems Engineering Research Conference. pp. 1535–1544 , Orlando, Florida (2012).

61. Shi, X., Tao, D., Voß, S.: RFID Technology and its Application to Port-Based Container Logistics. null. 21, 4, 332–347 (2011). https://doi.org/10.1080/10919392.2011.614202.

62. Skiba, S.: Seaport-City Cooperation On The Example Of The City Of Gdynia. In: Economic and Social Development: Book of Proceedings. pp. 460–467 , Zagreb (2019).

63. Srour, F.J., van Oosterhout, M., van Baalen, P., Zuidwijk, R.: Port Community System Implementation: Lessons Learned from International Scan. Presented at the

Transportation Research Board 87th Annual MeetingTransportation Research Board (2008).

64. Stavrou, D., Timotheou, S., Panayiotou, C.G., Polycarpou, M.M.: Optimizing Container Loading With Autonomous Robots. IEEE Transactions on Automation Science and Engineering. 15, 2, 717–731 (2018). https://doi.org/10.1109/TASE.2017.2679485.

65. Tijan, E., Jović, M., Panjako, A., Žgaljić, D.: The Role of Port Authority in Port Governance and Port Community System Implementation. Sustainability. 13, 5, (2021). https://doi.org/10.3390/su13052795.

66. Tsamboulas, F.J., Ballis, M.: Port Community systems: requirements, functionalities and implementation complications. Presented at the 13th World Conference of Transport Research , Rio de Janeiro, Brazil (2013).

67. Wang, K., Liang, M., Li, Y., Liu, J., Liu, R.W.: Maritime Traffic Data Visualization: A Brief Review. In: 2019 IEEE 4th International Conference on Big Data Analytics (ICBDA). pp. 67–72 (2019). https://doi.org/10.1109/ICBDA.2019.8713227.

68. Wang, S., Wan, J., Li, D., Zhang, C.: Implementing Smart Factory of Industrie 4.0: An Outlook. International Journal of Distributed Sensor Networks. 12, 1, 3159805 (2016). https://doi.org/10.1155/2016/3159805.

69. Webster, J., Watson, R.T.: Analyzing the Past to Prepare for the Future: Writing a Literature Review. MIS Quarterly. 26, 2, xiii–xxiii (2002).

70. Wu, Y., Xiong, X., Gang, X., Nyberg, T.R.: Study on intelligent port under the construction of smart city. In: Proceedings of 2013 IEEE International Conference on Service Operations and Logistics, and Informatics. pp. 175–179 (2013). https://doi.org/10.1109/SOLI.2013.6611405.

71. Xisong, D., Gang, X., Yuantao, L., Xiujiang, G., Yisheng, L.: Intelligent ports based on Internet of Things. In: Proceedings of 2013 IEEE International Conference on Service Operations and Logistics, and Informatics. pp. 292–296 (2013). https://doi.org/10.1109/SOLI.2013.6611428.

72. Yang, Y., Zhong, M., Yao, H., Yu, F., Fu, X., Postolache, O.: Internet of things for smart ports: Technologies and challenges. IEEE Instrumentation Measurement Magazine. 21, 1, 34–43 (2018). https://doi.org/10.1109/MIM.2018.8278808.

73. Yuan, S., Skinner, B.T., Huang, S., Liu, D.K., Dissanayake, G., Lau, H., Pagac, D., Pratley, T.: Mathematical modelling of container transfers for a fleet of autonomous straddle carriers. In: 2010 IEEE International Conference on Robotics and Automation. pp. 1261–1266 (2010). https://doi.org/10.1109/ROBOT.2010.5509706.

74. Review of Maritime Transport, https://unctad.org/system/files/official-document/rmt2013_en.pdf, last accessed 2021/06/30.