Using Automatic Identification System Data in Vessel Route Prediction and Seaport Operations

Russell Montiel, Enrique Alejandro; Klunk, Ruven Felix; Tijan, Edvard; Jović, Marija

Source / Izvornik: **Pomorski zbornik, 2021, 61, 45 - 56**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

https://doi.org/10.18048/2021.61.04.

ISSN 0554-6397
UDK: 004.032.26
Review article
Received: 10th September 2021.

Enrique Alejandro Russell Montiel
E-mail: erussellmontiel@gmail.com
Ruven Felix Klunk
E-mail: ruvenk@outlook.com
Jade University of Applied Sciences, Faculty of Maritime and Logistic Studies, Weserstr. 52, 26931 Elsfleth, Germany
Edvard Tijan
E-mail: edvard.tijan@pfri.uniri.hr
University of Rijeka, Faculty of Maritime Studies, Studentska ulica 2, 51000 Rijeka, Croatia
Marija Jović
E-mail: jovic@isl.org
Institute of Shipping Economics and Logistics, Universitätsallee 11, 28359 Bremen, Germany

Using Automatic Identification System Data in Vessel Route Prediction and Seaport Operations

Abstract

In this paper, the authors perform a comprehensive literature review on the use of data obtained from the Automatic Identification System, with an emphasis on vessel route prediction and seaport operations. The usage of Automatic Identification System vessel's position data in the vessel route prediction and seaport operations has been analyzed, to prove that Automatic Identification System data has a large potential to improve the efficiency of maritime transport. The authors concluded that proper vessel route prediction and route planning can improve voyage safety and reduce unnecessary costs. Furthermore, AIS can provide port authorities with early warnings, allowing them to take preemptive action to avoid possible congestions and unnecessary costs.

Keywords: Automatic Identification System data, vessel route prediction, seaport operations

1. Introduction

Maritime transportation has a great social, environmental, political, and economic impact worldwide, as the most important mean of transportation of goods and passengers [1] with the largest share of goods in the world, with 80% of the volume and 70% of the value of total cargo [2]as well as by a need to fulfill sustainability requirements that are expressed by social opinion and formal regulations. There is a potential to relieve this pressure through integration of a dry port, as a seaport's inland interface, in the supply chain. Therefore, this paper aims to explain how a supply chain can benefit or enhance its outcomes of cost, responsiveness, security, environmental performance, resilience, and innovation, by the integration of a dry port. The data for this case study is collected through interviews and site visits from the privately owned Skaraborg dry port, Sweden; and the study is limited to the actors of the transport system involved in the development and operations of the dry port integrated setup. The results show that the six supply chain outcomes (cost, responsiveness, security, environmental performance, resilience, and innovation. The security of ports, shipping routes, and ships is extremely essential to establish and maintain international trade [3].

In the maritime transport, the communication between ships and the land (ports and marine surveillance centers) is of extreme importance. The implementation of Automatic Identification System (AIS) real-time systems is extremely important in the maritime transport, as they provide important information about ships [4], such as position, course, speed, characteristics, and can also reveal the environmental impact of ships [5]. The effective information exchange between ships, ships, and ports, and ships and marine surveillance centers through the AIS system allows improved management of maritime traffic, reduced costs arising from unnecessary waiting in ports, reduced risks of collisions between ships, etc. [6]. Furthermore, real-time data may enable improved quality of services, reduced human errors (that may increase costs), and increased safety of ships. This collected data is of extreme importance today and can assist in a decision-making process [7]. This information can contribute to the safety of ships in their navigation but also of ports, and can improve maritime traffic management.

The rapid growth of data in the market is a challenge for the maritime industry, therefore stakeholders (such as shipping companies, port authorities, etc.) have to look for an effective and fast solution to manage these data in real-time, to react promptly to the constant changes produced by the demanding requirements of customers [8].

The authors will analyze the use of AIS data in vessel route prediction and seaport operations. The research problem stems from the insufficient use of the readily available AIS data, which may lead to increased costs, delays, and risks in the maritime transport chain. This paper presents a review of research papers dealing with the topic of AIS data being used for improved route prediction and optimization of seaport operations to reduce undesirable events, such as collisions, congestions, delays, which consequently lead to unnecessary costs.

2. Automatic Identification System data

The Automatic Identification System (AIS) is an autonomous and continuous system for data exchange operating on the Very High Frequency band (VHF) of the maritime mobile frequency spectrum [9]. Introduced by the International Maritime

Organization (IMO) in 2002, AIS enables commercial vessels to identify each other, avoid accidents, and receive information about the surrounding environment [10]. The AIS system enables real-time data exchange on passenger ships and cargo ships of over 300 tons or more on international voyages. The AIS system provides real-time information including the vessel's position, current speed, course, rate of turn, and the estimated time of arrival at the destination port [11]. Figure 1 shows the AIS information divided into static information, dynamic information, voyage-related information, and short safety-related messages.

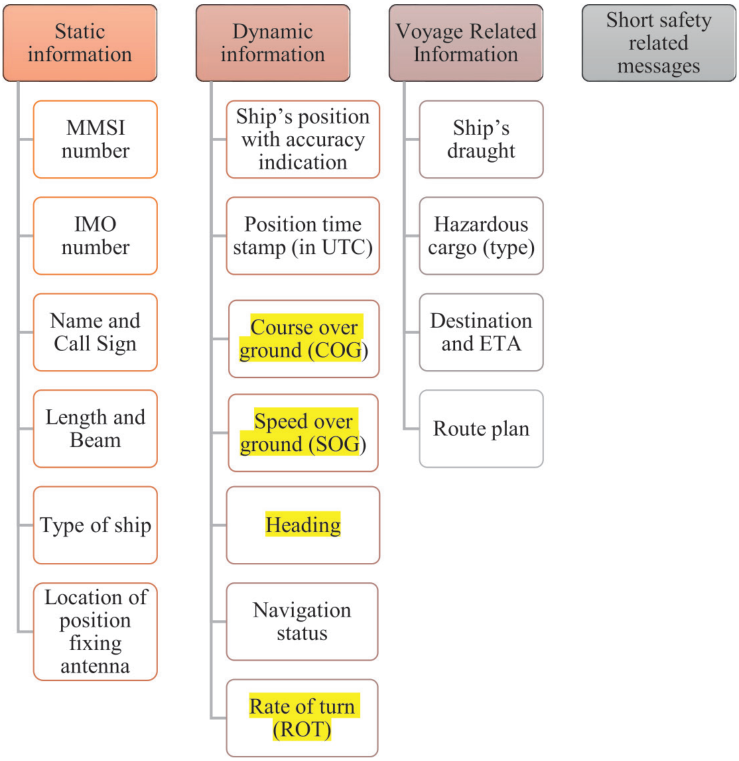

Figure 1 – AIS ship information [12], [11], [13], [14]

Ship static information (transmitted every 6 minutes and on request [13]) include MMSI number, IMO number, name and call sign etc. Ship dynamic information (depends on speed and course alteration [13]) includes ship's position with accuracy indication, course over ground etc. Voyage-related information (transmitted every 6 minutes, when data is amended, or on request [13]) includes ship's draught, destination and ETA, etc. Among them, ship dynamic data is the main source of ship speed and position longitude and latitude data [15]. Short safety-related messages are addressed to one or many destinations or all stations in the area. This content could be related to missing buoys, iceberg sightings, etc. [13].

AIS is mainly used to locate the position of nearby vessels via GPS for collision avoidance [16]. According to [17], through the AIS, it is possible to enhance the quality of maritime traffic surveillance by providing correct and real-time data on ships that may be in danger of collision. AIS enables monitoring of the movement of ships through onboard transceivers, terrestrial, or satellite base stations. The AIS can improve the safety of ports as well (the AIS system's GPS feature helps the vessel with specific procedures like entering a port) [16]. The AIS prevents collisions, helps ships chart and alter their routes whenever and wherever necessary, and helps the authorities to enforce maritime laws [18]. Furthermore, Lechtenberg et al. [19] claim that AIS can be used to identify anomalies in the routes of vessels that deviate from identified route patterns.

AIS technology can be integrated into other maritime systems, e.g. Electronic Chart Display and Information System (ECDIS) [20], a computer-based navigation system that complies with IMO regulations and can be used as an alternative to paper navigation charts. ECDIS includes electronic navigational charts and integrates position information from the GPS and other navigational sensors or systems, such as AIS, radar, and fathometer [21]. ECDIS uses the positioning system to track the position of the ship autonomously, with high information updating ability and provides efficient route information [20]. The AIS information of different ships can improve the safety of ships' navigation, and the AIS information can be displayed on the ECDIS screen [20].

Data on vessel movements in offshore waters or areas isolated from ports and shorelines are often incomplete or missing. In this respect, a satellite-derived automatic identification system was developed to collect and process vessel transmissions beyond the reach of land-based receiving stations [22]. ExactEarth, a provider of global maritime vessel data for ship tracking solutions, developed an AIS microsatellite system (exactAIS), which enables tracking of over 200,000 vessels in real-time with no delays, and acts based on accurate and actionable data (thus simplifying decision-making, even in highly congested maritime traffic areas [23]. Figure 2 shows two images differentiating the standard AIS signals, where 23 ships are located, and the exactAIS signals supported by satellite signals with 253 ships.

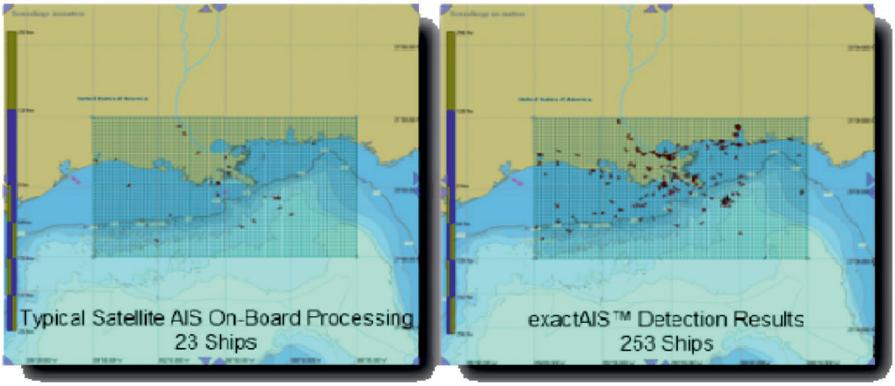

Figure 2 - The difference between standard AIS signals (left) and satellite exactAIS signals (right) [24]

AIS data collection and its use with satellite signals have had a great impact on maritime transport as the data have been used for traffic management, risk management, marine accident investigation, and many others [25]. The analysis of the routes of ocean-going vessels with the use of AIS satellite data is also of great importance for the protection of the environment, since it is possible to estimate air pollutant emissions from ships, and thus attempt to reduce emissions [25].

However, due to the increased usage of the AIS and the rise in maritime traffic, in congested waters, the system is already overloaded. Given the danger that this overload can present for the main AIS mission (collision avoidance), the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and several national maritime authorities have started the work on the VHF Data Exchange System (VDES). Rather than an evolution of AIS, VDES is a communications system encompassing different subsystems of communications, one of them being the AIS [26], [27]. New techniques providing higher data rates than those used for the AIS are a core element of VDES. The VDES could have a significant positive impact on the provision of maritime information services, such as maritime safety information, general data communications at high data rates, locating, vessel traffic management, satellite communications, etc. [28].

3. Methodology

The purpose of the literature review was to research the theoretical foundations of the Automatic Identification System for vessel route prediction and optimizing seaport operations. The authors started with the inclusion criteria by using a combination of keywords “Automatic Identification System AND vessel route prediction” and

"Automatic Identification System AND optimizing seaport operations", and alternative keywords "Automatic Identification System AND prediction" and "Automatic Identification System AND seaport" (title, abstract and keywords). ResearchGate, Google Scholar, Semantic Scholar, IEEE Xplore, Springer, ORBIS plus, Elsevier, ScienceDirect, Scopus, TRID, HRČAK, MDPI, Datenbank-Infosystem (DBIS) and Taylor & Francis Online were used for this purpose. The search for articles was conducted with no time limitations and mostly included journal articles and conference papers.

4. Using AIS data for Vessel route prediction

The prediction of routes lays still in the hand of the crew onboard and is managed according to their own experience or the experience of pilots when it comes to canals or port entrances [29]. Human decisions regarding the navigational route are prone to errors, especially when the navigational environment is complex and difficult to overview [30], [31]. Furthermore, an efficient model for better vessel route prediction may be a challenging task because AIS data usually have certain shortcomings, such as low data quality, highly irregular time intervals between messages, poor data integrity, and because of route diversity (different types of vessel, different geographical contexts and different maneuvering statues) [32].

Maritime routes have very similar and replicating patterns in which vessels move through the waters. These spatial patterns are reflecting the current maritime traffic characteristics such as planning policies or maneuvering behaviors [33]. The prediction field of vessel routes covers different concepts: direction, speed, registered locations, and statistical analysis to identify routes [34]. By taking the ship's routes and cumulating them into movement behavior points (turning, departure, entry, and stops) and segments (traces formed in a period), the revealed information can be used to find systematic patterns [34], [35]. However, these methods are highly complex and are not considering the semantic information about the ship's motions or other moving objects [36]. According to [37], through analyzing the attributes of the AIS data such as latitude and longitude, it is possible to mine the vessel motion patterns.

A method proposed by Zhaojin Yan combines the semantic routes and the graph theory to address the extraction and expression of maritime traffic routes. The semantic approach is enhanced through the implementation with large amounts of AIS data [38]. The advantage of this method is that it can filter much more data than the clustering [39] and grid-based [40] methods.

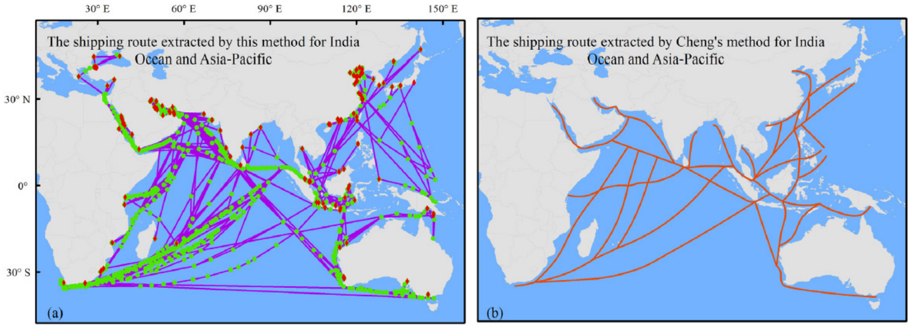

Figure 3: Comparison of different methods to extract maritime traffic routes. (a) the maritime traffic routes in the Indian Ocean and Asia-Pacific region extracted by Yan's method [38]. (b) the maritime traffic routes in the Indian Ocean and Asia-Pacific region extracted by Cheng's method [40]

By comparing the extraction results of maritime traffic routes in the Indian Ocean and Asia-Pacific region in Fig. 3a and 3b, it is observed that 4251 routes extracted by Yan's method is about 70 times more than 59 routes extracted by Cheng's method [40], who used a grid-based method. Also, for the Persian Gulf, Red Sea, Indian Ocean, and the South China Sea, the route density extracted by Yan's method is higher than that of Cheng's method. In this respect, it is possible to statistically identify and analyze busy routes and areas [38], which may serve as a basis for route prediction.

Proper vessel route prediction and route planning can not only enhance the safety of a voyage but can also simplify route planning in terms of time and traffic density.

To get the optimal route for a specific vessel, it is necessary to analyze data in a more detailed way. This leads to another issue, that not all the AIS data can be used for all ships, as not all vessels are operating in the same way nor have the same characteristics (size, draught, etc.) [35]. The data rather must be separated according to the vessel's needs and can then generate different routes for the ships [41].

By using combined algorithms and methods along with the geographical data and ship data, an optimized route could be offered, which could then prevent human errors that could cause casualties, economic losses, or an environmental crisis [42]. Furthermore, the movement of goods from their origin to the desired destination may incur unnecessary costs, which depend on the route taken and the occurring conditions [43]. The choice of the optimal route is therefore an important point of the reduction of unnecessary costs and the mitigation of unwanted economic impacts.

Another key point of route prediction is the prevention of collisions. A good prediction of upcoming and unforeseen events can be of great assistance to the maneuvering of the ship. The navigation in port areas and narrow passages are more likely to cause ship accidents [44]. Numerous assistance systems exist, such as GPS, radar, digital maps, and other systems that provide information about the environment.

However, so far it has proven to be difficult to use all this available information and to combine them into one collision warning system. As of now most sources act individually and must be observed and evaluated by the responsible ships or onshore crew. A simple combining approach such as the one used for the route prediction would be changing the shipping navigation significantly [45].

This data may also be used for autonomous vessels by creating the route generation system, which would mine the AIS data and work in cooperation with the control systems to ensure the needed safety [46]. The system would then act as a predictor to certain routes with a time horizon of about 30 minutes. Problematic route patterns that occur from surrounding vessels can therefore be prevented by proactive maneuvering [47]. However, regarding autonomous vessels and AIS, it is necessary to consider vulnerabilities and pitfalls that can occur due to relying on AIS data such as spoofing [48], [49], [50] or cybersecurity.

5. Optimizing seaport operations by using AIS data

As companies in the maritime transport sector have to continuously improve their performance, the optimization of their current services over their competitors is a key element. The AIS data can be used to cross analyze vessel traffic behavior, port performances, or for strategic decisions [11]. A classification company DNV GL (Norske Veritas, Norway and Germanischer Lloyd, Germany) proposes to use the collected data for business intelligence and use the knowledge for strategic decisions. Improved decisions can be made based on AIS data in combination with other data sources and technologies, such as Big Data [51].

AbuAlhaol et al. [52] analyzed the possibility to indicate port congestion based on static and dynamic AIS data. Spatial complexity, spatial density, and time criticality were chosen as warning indicators. The gained static and dynamic messages from the AIS databases are correlated with each other and filtered afterward according to ship types, speed, and navigational conditions. With the aggregation of filtered data, three geospatial algorithms are applied to calculate the convex area, geohash area, and vessel average proximity. This calculation is then leading to the determination of the density, complexity, and time criticality in the selected port area during a time period.

As a direct answer to the problem (indication of possible congestion), the data could then be presented to a pre-warning system. This system would then provide an early warning to the port authorities which could then take the right actions to address the congestion. Some steps that can be taken in response are [52]:

1. The adjustment between ships locations, to change the density of arriving vessels
2. Let ships drop their anchors away from the traffic area
3. Increase the speed of port operations such as loading and unloading

Other approaches to address port congestions also exist, such as the analytical approach from Zhang et al. [53] to see the spatiotemporal characteristics of ship traffic in the port of Singapore. They used the AIS data to visualize the patterns of ships and discovered several hotspots where ships move faster and variate vastly in their maneuvering. The discovery of these areas is key to target possible congestion indicators and consequences, such as collisions. It is therefore the interest of all parties to find the source for the occurrence of hotspots and divert the vessels to ease the situation. It is of great importance for every port to measure the variable characteristics in port operations and ship's behavior in the wider port area to ensure safety and security [54].

6. Conclusion

In maritime transport, numerous stakeholders (such as ship owners, insurance companies, maritime logistics companies, agents, etc.) are interested in optimizing their business processes, consequently reducing costs and minimizing the risks. AIS data can be used in process optimization, such as route prediction, harmonization of ship departure and arrival times, improvement of port operations, etc.

The AIS sends and receives data in real-time, which can improve and facilitate the safety management of ships at sea and in seaports. For example, the ExactAIS system, based on AIS data and satellite signals, helps to better obtain data and recognition of ships in a given area in real-time, thus enabling maritime authorities to have better control of large maritime traffic areas. AIS data can also assist in vessel route predictions, which can therefore add value to maritime transport, making it safer.

Proper vessel route prediction and route planning can improve voyage safety, while also making it easier to plan routes in terms of time and traffic density. For example, with Yan´s method (which, among others, includes the semantic approach enhanced through the implementation with large amounts of AIS data), it is possible to statistically identify and analyze busy routes and areas, which may serve as a basis for route prediction. It is important to conduct a more extensive analysis of data to determine the best route for a certain vessel. However, not all AIS data can be used for all vessels because each vessel differs according to various features such as size, draught, etc. An optimized route might be identified by combining different algorithms and methods with geographical data and ship data, which could thus eliminate human errors that could result in casualties, economic losses, etc. In this respect, it can be concluded that selecting the best route is very important for reducing unnecessary costs or mitigating negative economic consequences. Another important aspect of route prediction is collision avoidance. A proper forecast of undesirable events can largely assist in ship maneuvering.

AIS can provide port authorities an early warning which can help them to take measures to prevent possible congestion, consequently leading to cost reduction. In other words, it is possible to optimize and automate the port operations and to improve decision-making in unexpected situations. One of the ways to forecast port congestion is based on static and dynamic AIS data.

Another approach is visualizing the patterns of ships using AIS data, in order to discover hotspots where e.g. ships variate vastly in their maneuvering. The identification of these areas is essential for identifying potential congestion indicators and consequences (e.g., collisions), which can also directly or indirectly affect the seaport operations. However, despite the numerous opportunities that AIS provides, AIS has numerous vulnerabilities, which means that further research is needed to ensure that AIS data can be used, without negative consequences. This research has shown that it is still too early to discuss more advanced use of AIS data, but with the development of new digital technologies, AIS data risks and vulnerabilities could be minimized.

This research is based solely on the literature review and as such offers only an initial overview of possible use of AIS data in route prediction and optimizing seaport operations, which is also the main limitation of the paper. Future research will be focused on the possibilities of using AIS data in combination with disruptive digital technologies.

References

1. Naletina, D. & Perkov, E. (2017) The economic importance of maritime shipping with special reference on Croatia. In *Book of Proceedings 19th International Scientific Conference on Economic and Social Development*, 09-10 February 2017, Melbourne, Australija. pp. 248–257.
2. Khaslavskaya, A. & Roso, V. (2019) Outcome-Driven Supply Chain Perspectives on Dry Ports. *Sustainability*. 11 (5), 1492. Available from: https://www.mdpi.com/2071-1050/11/5/1492 [Accessed 20th October 2021].
3. Dui, H.; Zheng, X. & Wu, S. (2021) Resilience analysis of maritime transportation systems based on importance measures. *Reliab. Eng. Syst. Saf.* 209. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0951832021000296 [Accessed 20th October 2021].
4. Ermakova, T., Fabian, B., Bender, B. & Klimek, K. (2018) Web Tracking - A Literature Review on the State of Research. In *Proceedings of the 51st Hawaii International Conference on System Sciences*. pp. 4732-4741.
5. Tetreault, B. J. (2005) Use of the Automatic Identification System (AIS) for Maritime Domain Awareness (MDA). In *Oceans 2005: Washington DC,* 17-23 September 2005.
6. Rajabi, A., Saryazdi, A. K., Belfkih, A., Duvallet, C. (2018) Towards Smart Port : An Application of AIS Data. In *2018 IEEE 20th International Conference on High Performance Computing and Communications; IEEE 16th International Conference on Smart City; IEEE 4th International Conference on Data Science and Systems (HPCC/SmartCity/DSS)*, 28-30 June 2018, Exeter, England. pp. 1414-1421.
7. Suresh, J. (2014) "Bird's eye view on 'big data management,'. In *2014 Conference on IT in Business, Industry and Government,* CSIBIG 2014*,* 8-9 March 2014 *Indore, India.*
8. Dissanayake, G. N. (2020) *A Study on Real-Time Database Technology and Its Applications*. Available from: https://thekeep.eiu.edu/cgi/viewcontent.cgi?article=5823&context=theses Accessed 16th October 2021].
9. Kos, S., Vojković, L. & Brčić, D. (2014) Development of AIS and its influence on marine traffic control. In *8 Proceedings of the 8th Annual Baška GNSS Conference*, 7-9 May 2014, Baška, Croatia. pp. 47–68.
10. AISHub *Free AIS vessel tracking | AIS data exchange | JSON/XML ship positions*. Available from: https://www.aishub.net/ [Accessed 16th November 2021]

11. Tu, E., Zhang, G., Rachmawati, L., Rajabally, E., Huang, G.-B. (2018) Exploiting AIS Data for Intelligent Maritime Navigation: A Comprehensive Survey From Data to Methodology. *IEEE Trans. Intell. Transp. Syst.* 19 (5), 1559–1582.
12. Serry, A. (2016) *The Automatic Identification System (AIS): A Data Source for Studying Maritime Traffic*. Available from: https://hal.archives-ouvertes.fr/hal-01724104/document [Accessed 16th October 2021].
13. MarineInsight (2020) *Automatic Identification System (AIS): Integrating and Identifying Marine Communication Channels*. Available from: https://www.marineinsight.com/marine-navigation/automatic-identification-system-ais-integrating-and-identifying-marine-communication-channels/ [Accessed 16th November 2021]
14. Ylitalo, J., Hänninen, M., Kujala, P. (2008) *Accident Probabilities in Selected Areas of the Gulf of Finland*. Available from: https://research.aalto.fi/en/publications/accident-probabilities-in-selected-areas-of-the-gulf-of-finland. [Accessed 16th November 2021].
15. Shuang, S., Yan, C. & Jinsong, Z. (2020) Trajectory Outlier Detection Algorithm for ship AISData based on Dynamic Differential Threshold. In *Journal of Physics: Conference Series*.
16. Chao, H.-C., Wu, H.-T., & Tseng, F.-H. (2021) AIS Meets IoT: A Network Security Mechanism of Sustainable Marine Resource Based on Edge Computing. *Sustainability*. 13 (6). Available from: https://www.mdpi.com/2071-1050/13/6/3048 [Accessed 16th November 2021].
17. Harati-Mokhtari, A., Wall, A., Brooks, P. & Wang, J. (2007) Automatic Identification System (AIS): Data Reliability and Human Error Implications. *J. Navig.* 60 (3), 373–389.
18. MarineInsight (2021) *The Importance of Vessel Tracking System*. Available from: https://www.marineinsight.com/marine-safety/the-importance-of-vessel-tracking-system/ [Accessed 16th November 2021].
19. Lechtenberg, S., de Siqueira Brag, D. & Hellingrath, B. (2019) *Automatic identification system (AIS) data based ship-supply forecasting*. Available from: https://www.econstor.eu/handle/10419/209386 [Accessed 16th November 2021].
20. Hao, Y., Zheng, P. & Han, Z. (2021) Automatic generation of water route based on AIS big data and ECDIS. *Arab. J. Geosci.* 14, 533. Available from: https://link.springer.com/content/pdf/10.1007/s12517-021-06930-w.pdf [Accessed 16th November 2021].
21. Martek Marine (2012) *What is ECDIS?*. Available from: https://www.martek-marine.com/ship-performance/ecdis-charts/ [Accessed 16th November 2021].
22. Metcalfe, K. *et al.* (2018) Using satellite AIS to improve our understanding of shipping and fill gaps in ocean observation data to support marine spatial planning. *J. Appl. Ecol.* 55 (4), 1834–1845.
23. ExactEarth (2021) *exactAIS*. Available from: https://www.exactearth.com/product-exactais[Accessed 18th November 2021].
24. Miler R. K. & Bujak, A. (2013) exactEarthSatellite - AIS as One of the Most Advanced Shipping Monitoring Systems. In *13th International Conference on Transport Systems Telematics*. pp. 330–337.
25. Šakan, D., Rudan, I., Žuškin, S. & Brčić, D. (2018) Near real-time S-AIS: Recent developments and implementation possibilities for global maritime stakeholders *Pomorstvo*. 32 (2), 211–218.
26. Lázaro, F., Raulefs, R., Wang, W., Clazzer, F., Plass, S. (2019) VHF Data Exchange System (VDES): an enabling technology for maritime communications, *CEAS Sp. J.* 11 (1), 55–63.
27. IALA (2019) *VDES FAQ*. Available from: https://www.iala-aism.org/technical/connectivity/vdes-vhf-data-exchange-system/ [Accessed 18th October 2019].
28. Valčić, S., Žuškin, S. & Brčić, D. (2018) VHF Maritime Mobile Band - A New System to Declutter AIS Channels. *Sea Technol.* 59 (7), 24–27.
29. Silveira, P., Teixeira, Â. P. & Soares, C. G. (2019) AIS Based Shipping Routes Using the Dijkstra Algorithm. *Int. J. Mar. Navig. Saf. Sea Transp.*13 (3), 565–571.
30. Wiegmann, D. A. & Shappell, S. A. (2017) *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System*. London: Taylor and Francis.
31. Kim, H.-T., Na, S. & Ha, W.-H. (2011) A Case Study of Marine Accident Investigation and Analysis with Focus on Human Error. *J. Ergon. Soc. Korea*. 30 (1), 137–150.
32. Tu, E., Zhang, G., Mao, S., Rachmawati, L., Huang, G.-B. (2020) Modeling Historical AIS Data For Vessel Path Prediction: A Comprehensive Treatment. Available from: https://arxiv.org/abs/2001.01592 [Accessed 18th October 2021]

33. Xiao, Z., Fu, X., Zhang, L. & Goh, R. S. M. (2020) Traffic Pattern Mining and Forecasting Technologies in Maritime Traffic Service Networks: A Comprehensive Survey. *IEEE Trans. Intell. Transp. Syst.* 21 (5), 1796–1825.
34. Bautista-Sánchez, R., Barbosa-Santillan, L. I., & Sánchez-Escobar, J. J. (2021) Method for Select Best AIS Data in Prediction Vessel Movements and Route Estimation. *Appl. Sci.* 11 (5).
35. Xiao, F., Ligteringen, H., van Gulijk, C. & Ale, B. (2015) Comparison study on AIS data of ship traffic behavior. *Ocean Eng.* 95, 84–93.
36. Sheng, P. & Yin, J. (2018) Extracting Shipping Route Patterns by Trajectory Clustering Model Based on Automatic Identification System Data. *Sustainability*. 10 (7).
37. Deng, F., Guo, S., Deng, Y., Chu, H., Zhu, Q. & Sun, F. (2014) Vessel track information mining using AIS data. In *2014 International Conference on Multisensor Fusion and Information Integration for Intelligent Systems (MFI)*. pp. 1–6.
38. Yan, Z. *et al.* (2020) Exploring AIS data for intelligent maritime routes extraction. *Appl. Ocean Res.* vol. 101, 10227.
39. Wang, J., Li, M., Liu, Y., Zhang, H., Zou, W. & Cheng, L. (2014) Safety assessment of shipping routes in the South China Sea based on the fuzzy analytic hierarchy process. *Saf. Sci.* 62, 46–57.
40. Cheng, L., Yan, Z., Xiao, Y., Chen, Y., Zhang, F. & Li, M. (2019) Using big data to track marine oil transportation along the 21st-century Maritime Silk Road. *Sci. China Technol. Sci.* 62 (4), 677–686.
41. He, Y. K., Zhang, D., Zhang, J., Zhang, M. Y. & Li, T. W. (2019) Ship Route Planning Using Historical Trajectories Derived from AIS Data. *TransNav Int. J. Mar. Navig. Saf. Sea Transp.* 13 (1), 69–76.
42. Knapp, S. & Franses, P. H. (2010) Comprehensive Review of the Maritime Safety Regimes: Present Status and Recommendations for Improvements. *Transp. Rev.* 30 (2), 241–270.
43. Notteboom, T. E. & Vernimmen, B. (2009) The effect of high fuel costs on liner service configuration in container shipping. *J. Transp. Geogr.*17 (5), 325–337.
44. Fang, Z., Yu, H., Ke, R., Shaw, S.-L. & Peng, G. (2019) Automatic Identification System-Based Approach for Assessing the Near-Miss Collision Risk Dynamics of Ships in Ports. *IEEE Trans. Intell. Transp. Syst.* 20 (2), 534–543.
45. Trzuskowsky, A., Hoelper, C. & Abel, D. (2016) ANCHOR: Navigation, Routing and Collision Warning during Operations in Harbors. *IFAC-PapersOnLine*. 49 (23), 220–225. Available from: https://ur.booksc.eu/book/63844118/72a3c0 [Accessed 20th October 2021].
46. Xu, H., Rong, H. & Soares, C. G. (2019) Use of AIS data for guidance and control of path-following autonomous vessels. *Ocean Eng.* 194.
47. Hexeberg, S., Flaten, A. L., Eriksen, B.-O. H. & Brekke, E. F. (2017) AIS-based vessel trajectory prediction. In *2017 20th International Conference on Information Fusion (Fusion)*. pp. 1–8.
48. Zhang, T., Zhao, S., Cheng, B. & Chen, J. (2020) Detection of AIS Closing Behavior and MMSI Spoofing Behavior of Ships Based on Spatiotemporal Data. *Remote Sens.*12 (4).
49. Androjna, A., Perkovič, M., Pavic, I. & Mišković, J. (2021) AIS Data Vulnerability Indicated by a Spoofing Case-Study. *Appl. Sci.* 11 (11).
50. Karim, A., Utama, S. & Arifin, M. A. (2021) Algorithms for detecting vessel spoofing of space-based AIS data. In *AIP Conference Proceedings 2366, 060006 (2021)*.
51. DNV (2013) *AIS – Meant for navigational safety, used for business intelligence - DNV*. Available from: https://www.coursehero.com/file/85282804/AISdocx/ [Accessed 20th October 2021].
52. Abualhaol, I., Falcon, R., Abielmona, R. & Petriu, E. (2018) Mining Port Congestion Indicators from Big AIS Data. In *2018 International Joint Conference on Neural Networks,* IJCNN 2018*,* 8-13 July 2018, Rio de Janeiro, Brazil. pp. 1–8.
53. Zhang, L.; Meng, Q. & Fwa, T. F. (2019) Big AIS data based spatial-temporal analyses of ship traffic in Singapore port waters. *Transp. Res. Part E Logist. Transp. Rev.* 129, 287–304.
54. Zhu, F. (2011) Mining ship spatial trajectory patterns from AIS database for maritime surveillance. In *2011 2nd IEEE International Conference on Emergency Management and Management Sciences,* ICEMMS 2011, 8-10 August 2011, Beijing, China. pp. 772–775.