AIS Data for Building a Transport Maritime Network: A Pilot Study in the Strait of Messina (Italy)

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Abstract. The maritime transport of goods enables economic exchanges at a global level. Containership, sea routes, port systems and relative performances (e.g. times and costs) influence the quality and quantity of these exchanges. For these reasons, it is necessary to develop quantitative methods for evaluating the main performances of maritime container services. At the same time, ICT (e.g. Automatic Identification System, AIS) enable the acquisition and collection of information and data for supporting Transport Simulation Models (TSM), useful for calculating the performances. In this context, this paper presents a method for building a supply transport network model of container maritime services. The method is based on the acquisition and elaboration of data deriving from the AIS. The supply model allows the calculation of indicators for evaluating the main performance of containership services at the international level. The proposed method is applied to developing a pilot study of maritime containership services in a portion of the Mediterranean Sea. The results of the pilot consist of the representation of a transport network obtained from the available AIS data. The obtained results show the main potentialities of the proposed method for developing TSM from the fed by the AIS data. The method and results obtained are of potential interest to public and private decision-makers and takers involved in the maritime transport sector.

Keywords: TSM · maritime transport · AIS data · containerships · big data · sustainability

1 Introduction

Maritime transport plays a relevant role because it enables economic exchanges at a global level. Containership, sea routes port systems and relative performances (e.g. times and costs) influence the quality and quantity of these exchanges. For these reasons, it is necessary to develop quantitative methods for evaluating the main performances of maritime container services.

This research focuses on the Transport System Models (TSMs) supported by data deriving Information and Communication Technologies (ICTs). The good use of transport supply maritime networks has great potential for evaluating the performances of

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container lines. This implies the necessity to adapt the existing modelling approaches to the maritime sector by using the potentialities offered by ICT [1]. With the correct use of small and big data, by considering their volume, velocity and variety, the consolidated formalizations can be enhanced to improve the modelling representation of the maritime networks. In other contexts, the combination of different sources is experimented to support the implementation of TSM, about supply, demand [2, 3] and their interactions for measuring performances [4].

This paper focuses on the potentialities offered by the Automatic Identification System (AIS) used in different research fields of interest in the maritime industry. This paper focuses on the use of AIS data to extract maritime transport networks. The works available on this topic propose different methodologies to extract maritime transport networks by elaborating AIS data [5]. However, there is a limited use of AIS data for building transport supply network models. This paper explores the possibility of using AIS data for implementing the graph approach generally adopted in terrestrial transport systems [6]. With this aim, the paper offers the following research contributions:

- an overview of methods and models to build a maritime transport network, starting from the acquisition and elaboration of AIS data with a specific focus on the containership sector;
- an approach to formalize maritime transport supply modelling according to TSM;
- a first pilot for building a network in a specific case study.

The paper represents the first step of a wide research aimed at analyzing intermodal transport at the global level and transport network performances that influence economic exchanges.

After this introduction, the paper has four sections. Section 2 recalls the main approaches available in the literature for building a maritime transport network by using the AIS data. Section 3 proposes a TSM approach for building maritime transport supply models empowered using AIS data. Section 4 describes the main results obtained by the pilot study relative to the study area. Section 5 discusses the results with final remarks and further developments of the research.

2 The Use of AIS Data for Maritime Transport Networks

Scientific literature presents works about the AIS characteristics (Sect. 2.1), the possible applications for building maritime transport networks (Sect. 2.2) and calculating transport performances (Sect. 2.3).

2.1 AIS Data Characteristics

According to the International Maritime Organization (IMO) rules, ships must be equipped with an Automatic Identification System (AIS), shipborne monitoring that provides ship voyage and navigational status information. AIS provides updated information about vessels information in different times. The information and data can be classified on [7]:

- static, by considering the structural data about the ships (e.g. ship name, characteristics and international identification); collected data regards physical and functional information about the ships (e.g. capacity);
- dynamic, by considering the registered data about the movements (e.g. spatiotemporal positions) and navigation status of the ships; collected data regards the historical and real-time vessel sailing information (e.g. speed) referred to different time intervals.

There are different commercial platforms (e.g. AISHub, Elane, ExactEarth, FleetMon, IHS Markit, and Marine Traffic) that collect and provide AIS data that can be available in a row or elaborated formats.

More details about AIS data and relative application are reported in [8].

2.2 AIS Data for Building Maritime Transport Networks

Different frameworks and methodologies for building maritime traffic networks by using AIS data are available in the literature [9]. The proposed approaches regard the extraction of maritime transport networks from AIS data.

A great part of the scientific works available in literature regards the automated extraction of maritime networks from AIS data [5, 9]. Several of these studies are based on geospatial clustering techniques aimed at grouping a set of objects identified by geographic and temporal positions. The elements belong to the same cluster with different criteria, for instance, the degree of similarity measured by spatial, temporal and non-spatial attributes [10]. Lee et al. [11] propose a clustering algorithm aimed at identifying maritime routes starting from the ship trajectory pattern. The method is based on a spatial clustering methodology (DBSCAN) performed to identify the waypoints of vessels that are connected to the individuated routes. Similar patterns constitute the result of a kernel density estimation analysis (KDE), becoming a cluster that represents a specific maritime route.

Yan et al. [12] propose a method based on the graph theory for extracting maritime routes. AIS massive data are used for reconstructing the historical spatiotemporal positions of a ship and relative trajectories [13], where each ship trip is represented as "stop-waypoint-stop" trip object. The result is a directed maritime traffic graph where nodes and links allow the extraction of the shipping routes.

The maritime transport network extractions from AIS data are used for different applications. The more common application is to the identification of previous trajectories, or paths taken by a vessel, obtained elaborating data about the vessel's positions in space and time. Ship trajectories obtained from the historical AIS data can be elaborated for automatic route analysis and the extraction of the maritime shipping network. Some authors used AIS data to analyze the influence of COVID-19 Pandemic, on international container liner ports [13]. The maritime network allows analysts to evaluate the transportation efficiency of the supply chain at a global level [14]. The possible evolution of this common application concerns vessel trajectory prediction and sailing optimization by modifying speed to enhance energy efficiency [15]. In other applications, AIS data are useful for estimating externalities, for instance, the estimation of gas emissions deriving from maritime transport lines. The elaborations apply "bottom-up" methods that use static (e.g. power engine) and dynamic (e.g. kinematics characteristics) information of

vessels. This approach is more accurate concerning the "top-down" methods based, for instance, on fuel consumption or fuel-based emission factors. Other AIS data applications regard maritime safety, concerning the possibility of supporting the avoidance of vessel collisions [16].

In synthesis, according to Yan et al. [12], the methods for extracting maritime transport networks can be classified into:

- grid-based methods, based on a reorganization of the original data by grid index; by counting the traffic data in each element of the grid, it is possible to individuate the maritime traffic characteristics (e.g. nodes); this method is simple, but it is not suitable for large areas;
- vector-based method, based on the elaboration of data for representing maritime routes as a combination of points and segments needed for individuating the main traffic patterns in large regions; one representative method is the Traffic Route Extraction and Anomaly Detection (TREAD) proposed by Pallotta et al. [17];
- statistics-based method, based on statistical modelling for individuating the ship maritime traffic patterns from data; spatial and temporal cluster analysis is commonly used in the methods belonging to this class; for instance, ship tracks are grouped into different line clusters for individuating the main patterns of maritime traffic Yan et al. [12].

2.3 AIS Data for Calculating Transport Network Performances

Maritime transport networks allow the calculation of performances relative to different aspects of the maritime sector.

Ducruet [18] proposes a critical review of different studies on maritime flows and networks producing more insights about the possible evolutions of maritime network analysis, in geography and other sciences. The main evolutions regard three issues: the managerial implications of maritime flows from a business point of view; maritime flows and networks as markers and vectors of wider geo-economic structures and dynamics; maritime networks as parts of territories and chained systems, similar to urban or regional networks. The results of the review show the necessity to cover other scientific fields (e.g. complex network analysis).

Kanrak et al. [19] review the principal applications of the network theory and models in the maritime sector. The focus is on the methods of calculations of indicators (e.g. centrality, density, degree distribution, …), of the maritime transport networks, where ports are nodes linked by shipping services. The implementation of the existing theories and models of network analysis in the maritime sector requires further investigations.

The traditional applications concern the route design or navigation planning to support navigators by considering weather conditions such as wind or sea currents. Other applications regard the calculation of energy consumption concerning the maritime route and then its planning for increasing efficiency [20].

Some authors analyzed the competition between roll on–roll off (ro–ro) and lift on–lift off (lo–lo) services inside the Short Sea Shipping (SSS), regarding the Mediterranean Sea [21, 22]. Sometimes, these maritime network services offer a possible alternative to terrestrial transport producing relevant impacts on social, economic and environmental sustainability. Then, it is necessary to analyze maritime passenger transport to evaluate

the centrality of the national maritime services networks [23]. In other research contexts, approaches based on maritime networks support investment decisions aimed at increasing reliability and resiliency in a port system for facing the effects of multiple disaster scenarios [24].

A limited quantity of research applies classical analysis approaches adopted for transport systems. For instance, Kang et al. [25] study the speed-density relationships that characterize ship traffic. The final aim is to estimate the fundamental diagram of ship traffic in the Singapore Strait by elaborating AIS data.

In synthesis, the performances obtained from elaborations of AIS data and maritime network can regard:

- a macro level by using the aggregated AIS data, relative to the entire network; for instance Liu et al. [9] adopt a data-driven approach for individuating ship patterns, grouping different ship paths in relation to similar travel characteristics such as origin and destination areas;
- a micro level by using disaggregated AIS data, relative to a specific element of the network (e.g. port performances or route congestion); for instance, Russo et al. [26] study the ports' performances respecting to the seaside with the support of AIS data for calibrating calculating port's performance indicators at country level.

From the reviewed literature, it emerges that there are different approaches to building maritime transport networks from AIS data. These networks are used in some scientific fields for performing different applications. However, there is a limited quantity of works that combine AIS data with TSM approaches. The following section proposes a possible TSM approach empowered by the use of AIS data.

3 Modeling Maritime Transport Networks with a TSM Approach

AIS data can be used for building a maritime transport network adapting existing TSM approaches. This paper focuses on the transport supply modeling.

According to Russo [27] a transport supply model can be classified in:

- analytic, in which transport system is represented in aggregate form;
- topologic, in which the infrastructures and services are represented in a similar way as the services are in the real situation with an expansion in time; topologic model is composed by two macro models:
  - network model that comprehends two elements: models of connections among points (graph approach); cost functions for links and nodes;
  - system relationships (models of relationships in transport system).

In this paper we refer to the network approach used widely in literature to simulate a transportation system. Section 3.1 describes the main elements of a maritime transport graph. Section 3.2 illustrates the maritime transport network topology, recalling the main issues related to the simulation of maritime transport services.

3.1 Maritime Transport Topology

A great part of the methods available in the literature is based on the graph concept. A generic graph G comprehends two related sets: the set of nodes, named N and the set of links or a couple of nodes belonging to N, named L:

$$G = (N, L) \tag{1}$$

In the context of TSM the graph representing a transport network is oriented, then the links have a direction the couple of nodes are ordered. A generic link that connects a couple of nodes can be identified with the indexes used for the initial and final nodes (i, j) or with a unique index where:

$$(i, j) \neq (j, i) \tag{2}$$

In the case of the maritime transport network:

- the nodes represent the specific points in the maritime space of the vessel's maritime routes (ports or maritime crossroads); in the set of nodes, ports (or port systems) are considered centroids, where the trips vessel start or end;
- the oriented links connect two generic nodes representing a movement of the ships along the predefined maritime routes, sometimes called "maritime roads".

The methods proposed in the literature and recalled in Sect. 2 can be adapted to build a topology (nodes, links and routes) according to the TSM approach. The obtained graph represents the maritime links and paths that connect two generic ports. The generic port can be represented in an aggregate way, with a single node. For analysis aimed at measuring the port performances, it is necessary to represent the port in a disaggregate way, to consider all phases that characterize the outflows and inflow operations from and to a specific port.

Adopting the TSM approach, the topology can be represented with the following analytical elements [6, 28]:

$\boldsymbol{\Delta}$ the link–path incidence matrix that has a number of rows equal to the number of links and a number of columns equal to the number of paths; the generic element assumes value 1 if the link belongs to the path, 0 otherwise;

$\mathbf{c_A}$ the vector of additive link generalized costs (e.g. travel times), with dimension equal to the number of present links in the maritime network;

$\mathbf{g_{NA}}$ the vector of no additive path generalized costs (e.g. equipment costs), with dimension equal to the number of available paths in the maritime network;

$\mathbf{g_A}$ the vector of additive path generalized costs (e.g. naviagation times between two ports), with dimension equal to the number of available paths in the maritime network;

$\mathbf{f}$ the vector of link flows (e.g. number of ships/day), with dimension equal to the number of available links in the maritime network;

$\mathbf{h}$ the vector of path flows (e.g. number of ships/day), with a dimension equal to the number of available paths in the maritime network.

With these elements, it is possible to express analytically the topology of a maritime transport network, with the two following relationships.

The relationships between link and path generalized costs:

$$\mathbf{g} = \mathbf{g_A} + \mathbf{g_{NA}} = \boldsymbol{\Delta}^{\mathrm{T}} \Delta \mathbf{c_A} + \mathbf{g_{NA}} \tag{3}$$

The relationships between link and path flows:

$$\mathbf{f} = \Delta \mathbf{h} \tag{4}$$

The maritime transport network is completed by associating a cost function to each link:

$$\mathbf{c} = \gamma(\mathbf{f}) \tag{5}$$

where

$\gamma(\cdot)$ is the vector of the link–cost flow functions.

Note that the level of aggregation of the network depends on the aims of the analysis. Moreover, in most cases, it is necessary to disaggregate the nodes representing a port with specific nodes, links and cost functions for taking into account all the phases connected to the entry and exit manoeuvres (see [27]).

3.2 Maritime Transport Services

The graph approach, generally applied to simulate services for passenger terrestrial transport, comprehends two different approaches (see [6, 29, 30]):

- the frequency-based approach usually represents high frequency; the characteristic element of the system is the line, defined as a path used by transport means with fixed frequency; the service is simulated by nodes and links representing the stops and the line segments;
- the schedule-based approach usually represents low frequency and high regularity services; the characteristic element of the system is the run, defined as a path used by vehicles with explicit representation of time (diachronic network); for every stop a temporal axis is made on which the nodes represent the arrival and departure time of the run at the stop.

A great part of the works available in the literature represent maritime transport services by means of supply models that usually apply the frequency-based approach.

In the supply model, there is a network of infrastructures consisting of ports (nodes) and routes (links). Each port can be represented by a set of nodes and links with cost functions relative to times, costs. Each route is represented by a sequence of links for each service. This representation doesn't allow the analysis in detail of different runs flows or variations in service times. There are some simulations of variations in maritime service times [27, 31–33].

The use of AIS data empowers the application of the schedule-based approach because it is possible to have information about each ship's travel in space and time. However, the literature presents a limited quantity of works that adopt the schedule-based approach for representing maritime transport networks.

4 A Pilot Study

The pilot study regards maritime transport in the Strait of Messina in the South of Italy. With a spatial extension of about three kilometres, the Strait divides the Sicily region with the continental Italian territories. The included maritime stretch serves the connections in two perpendicular directions:

- the Sicily – Calabria direction enables the connections of people and freights mobility between Sicily and continent territories; this is possible employing maritime transport services (e.g. ro-ro and high speed) that connect two ports in the Sicilian coast (Messina and Tremestieri) and two ports in Calabrian cost (Reggio Calabria and Villa San Giovanni);
- the Tyrrhenian – Ionian enabling the connections between the Tyrrhenian Sea and the Ionian Sea, within the central Mediterranean; in this direction, there is the navigation of different kinds of ships (bulk, container, ro-ro, …) that cross the Mediterranean Sea and relative ports; one of the main port near to the strait is the Gioia Tauro port that plays transhipment and gateway functions in container trades at global level.

This configuration generates relevant maritime traffic flows between high-frequency services performed by ships that enable the different functions along the above directions. The intersection between the routes of different kinds of ships produces potential impacts in terms of congestion and safety. For instance, in 2007, there was a collision between a passenger hydrofoil navigating between Reggio Calabria and Messina ports and a containership navigating between Tyrrhenian and Ionian seas. As a result of the incident, in 2007 the International Maritime Organization (IMO) Assembly adopted the "IMO with SN.1/Circ.279 on 12 June 2009" resolution. This implies the introduction of a "roundabout-type" Traffic Separation Scheme (TSS), graphically represented in Fig. 1. After the resolution, the navigation in Strait of Messina is constrained to follow specific regulations and maritime way, controlled by the Vessel Traffic Services (VTS) that is a monitoring system that control the strait providing information messages to ships, such as spatiotemporal positions of vessels.

The introduced elements demonstrate the relevance of the pilot study and the necessity to follow the movement of ships in the study area. Starting from the AIS data collected in relation to a sub set of ships navigating the Strait of Messina (Sect. 4.1), a schematic representation of the maritime network is obtained (Sect. 4.2).

4.1 The Collected AIS Data

The pilot study case starts from the individuation of the maritime area in the Strait of Messina. The area comprehends the four ports located in the coastal area of Calabria and Sicily regions. The area constitutes the input for selecting AIS data from the "marinetraffic" platform. A sub-set of ships that perform the two described functions are selected. A sample of spatiotemporal positions relative to the temporal period from 28 January 2024 to 4 February 2024 is selected. The monitored ships and relative services are reported in Table 1 where are indicated: the monitored day (date), the travel time measured as the difference between arrival and departure times in the ports and final and initial times

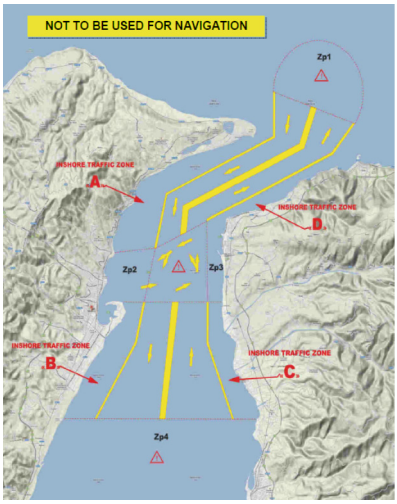

Fig. 1. Maritime traffic separation scheme (source [34]).

in the study area, the maximum and minimum speed, the main function and relative shipping services.

4.2 The Schematic Maritime Network

The collected data are mapped and ordered in a GIS by considering the spatiotemporal position of each monitored ship in the study area. The tracks of the ships were drawn by joining the points in space. It is possible to verify that the monitored ships follow the indications provided by the IMO resolution, navigating along the roundabout. It is necessary to consider the errors of GPS points in the space. By the intersections between the monitored routes, it is possible to individuate the main nodes in the maritime transport network including the ports and the maritime positions. After, it is possible to individuate the links that connect the nodes. The cost functions can be calibrated by observing the spatiotemporal profiles of each service.

Figure 2 represents the obtained schematic network in the strait of Messina. From this representation it is possible to define the analytical network topology of a transport subnetwork in relation to the prescriptive IMO regulation and relative "roundabout-type" TSS. Table 2 reports the links – paths incidence matrix ($\mathbf{\Delta}$) that represents the topology.

Table 1. Monitored ship services in the Strait of Messina

Direction	Ship Name	Date	Travel time in the area (minutes)	Speed (knots)		Service
				min	max	
Sicily–Calabria	Trinacria	28/01/2024	32	0.7	11.3	freigth Ro Ro
	Enotria	31/01/2024	53	0.6	12.7	freigth Ro Ro
	Giano	01/02/2024	44	0.1	11.3	freigth Ro Ro
	ALE M	03/02/2024	28	0.7	26.7	passenger High Speed
	Zancle	01/02/2024	28	0.8	11.8	mix Ro Ro
Tyrrenian–Ionian	Konet	01/02/2024	150	13.2	15.1	containership
	MSC Amanda	01/02/2024	160	10.8	15.1	containership

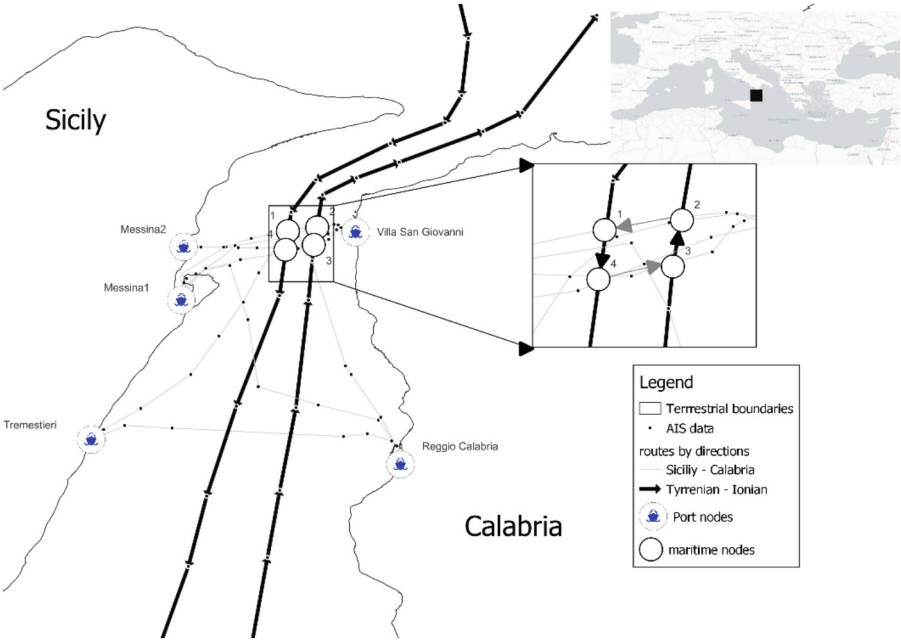

Fig. 2. Maritime transport network in the Strait of Messina.

Table 2. Links – paths incidence matrix of the roundabout in the strait of Messina ($\boldsymbol{\Delta}$)

Links	Paths			
	Calabria-Sicily	Sicily-Calabria	Tyrrenian-Ionian	Ionian-Tyrrenian
1–4	1	0	1	0
4–3	0	1	0	0
3–2	0	1	0	1
2–1	1	0	0	0

5 Discussion and Final Remarks

The maritime transport sector deserves particular attention as it allows the mobility of people and the exchange of goods at different territorial scales. Maritime navigation includes different infrastructures and services that allow the performance of different functions.

Recently, also thanks to the potential offered by emerging ICT technologies, the maritime phenomenon can be studied by using large data and information on the characteristics of ships, travel times and maritime itineraries followed. This information contributes to face the growing complexity of maritime transport networks. This paper focused on the potential of AIS data, now available in large quantities for different types of maritime traffic.

This paper presents some limitations regarding the literature and the experimentations. By considering these two limits, two research directions can be investigated in future developments.

The first development concerns the scientific literature. The main methodologies for extracting maritime transport networks from AIS data processing were analyzed. Several techniques based on statistical and geographical methods are available. However, based on the documents analyzed, there is a limited combined use of the TSM approach and existing techniques. The use of TSMs would allow for further applications especially connected to the development of implemented future scenarios and therefore to carry out a priori assessments of the effects produced by the plan actions. It is necessary to extend the research conduct, considering the growing interest in various disciplines regarding the maritime sector.

The second research direction concerns the development of a pilot study to build a maritime transport network in the area of the Strait of Messina. The area is particularly complex as it is crossed by various components of maritime traffic connected to different mobility components (people and goods). The study was carried out using a limited amount of AIS data referring to a limited sample of ships crossing the area. The obtained results are limited but at the same time encouraging. It is necessary to extend the findings in space and time to understand the further dynamics underlying the phenomenon. In particular, it is necessary to develop the potential of AIS data and the development of demand, supply and interaction models in transport systems.

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References

1. Russo, F., Musolino, G.: The role of emerging ICT in the ports: increasing utilities according to shared decisions. Front. Future Transp. **2**, 722812 (2021). https://doi.org/10.3389/ffutr.2021.722812
2. Croce, M., Rindone, V.: Transport system models and big data: zoning and graph building with traditional surveys, FCD and GIS. ISPRS Int. J. Geo-Inf. **8**, 187 (2019). https://doi.org/10.3390/ijgi8040187
3. Alonso, B., Musolino, G., Rindone, C., Vitetta, A.: Estimation of a fundamental diagram with heterogeneous data sources: experimentation in the city of Santander. ISPRS Int. J. Geo-Inf. **12**, 418 (2023). https://doi.org/10.3390/ijgi12100418
4. Croce, A.I., Musolino, G., Rindone, C., Vitetta, A.: Energy consumption of electric vehicles: models' estimation using big data (FCD). Transp. Res. Procedia **47**, 211–218 (2020). https://doi.org/10.1016/j.trpro.2020.03.091
5. Filipiak, D., Węcel, K., Stróżyna, M., Michalak, M., Abramowicz, W.: Extracting maritime traffic networks from AIS data using evolutionary algorithm. Bus. Inf. Syst. Eng. **62**, 435–450 (2020). https://doi.org/10.1007/s12599-020-00661-0
6. Cascetta, E.: Transportation Systems Engineering Theory and Methods. Springer, New York (2013). https://doi.org/10.1007/978-1-4757-6873-2
7. Yan, R., Wang, S., Zhen, L., Laporte, G.: Emerging approaches applied to maritime transport research: past and future. Commun. Transp. Res. **1**, 100011 (2021). https://doi.org/10.1016/j.commtr.2021.100011
8. Yang, D., Wu, L., Wang, S., Jia, H., Li, K.X.: How big data enriches maritime research – a critical review of Automatic Identification System (AIS) data applications. Transp. Rev. **39**, 755–773 (2019). https://doi.org/10.1080/01441647.2019.1649315
9. Liu, Z., Gao, H., Zhang, M., Yan, R., Liu, J.: A data mining method to extract traffic network for maritime transport management. Ocean Coast. Manag. **239**, 106622 (2023). https://doi.org/10.1016/j.ocecoaman.2023.106622
10. Murgante, B., Borruso, G.: Analyzing migration phenomena with spatial autocorrelation techniques. In: Murgante, B., et al. (eds.) ICCSA 2012. LNCS, vol. 7334, pp. 670–685. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-31075-1_50
11. Lee, J.-S., Lee, H.-T., Cho, I.-S.: Maritime traffic route detection framework based on statistical density analysis from AIS data using a clustering algorithm. IEEE Access. **10**, 23355–23366 (2022). https://doi.org/10.1109/ACCESS.2022.3154363
12. Yan, Z., et al.: Exploring AIS data for intelligent maritime routes extraction. Appl. Ocean Res. **101**, 102271 (2020). https://doi.org/10.1016/j.apor.2020.102271
13. Graser, A., Dragaschnig, M., Widhalm, P., Koller, H., Brandle, N.: Exploratory trajectory analysis for massive historical AIS datasets. In: 2020 21st IEEE International Conference on Mobile Data Management (MDM), pp. 252–257. IEEE, Versailles, France (2020). https://doi.org/10.1109/MDM48529.2020.00059

14. Wang, X., Wang, W.: Study on the maritime trade pattern and freight index in the post-epidemic era: evidence based on dry bulk market Auto-matic Identification System (AIS) data. Asian J. Shipp. Logist. S2092521223000470 (2024). https://doi.org/10.1016/j.ajsl.2023.09.002
15. Wang, K., et al.: A novel method for joint optimization of the sailing route and speed considering multiple environmental factors for more energy efficient shipping. Ocean Eng. **216**, 107591 (2020). https://doi.org/10.1016/j.oceaneng.2020.107591
16. Yang, Y., Liu, Y., Li, G., Zhang, Z., Liu, Y.: Harnessing the power of Machine learning for AIS data-driven maritime research: a comprehensive review. Transp. Res. Part E Logist. Transp. Rev. **183**, 103426 (2024). https://doi.org/10.1016/j.tre.2024.103426
17. Pallotta, G., Vespe, M., Bryan, K.: Vessel pattern knowledge discovery from AIS data: a framework for anomaly detection and route prediction. Entropy **15**, 2218–2245 (2013). https://doi.org/10.3390/e15062218
18. Ducruet, C.: The geography of maritime networks: a critical review. J. Transp. Geogr. **88**, 102824 (2020). https://doi.org/10.1016/j.jtrangeo.2020.102824
19. Kanrak, M., Nguyen, H.O., Du, Y.: Maritime transport network analysis: a critical review of analytical methods and applications. J. Int. Logist. Trade. **17**, 113–122 (2019). https://doi.org/10.24006/jilt.2019.17.4.113
20. Schøyen, H., Bråthen, S.: Measuring and improving operational energy efficiency in short sea container shipping. Res. Transp. Bus. Manag. **17**, 26–35 (2015). https://doi.org/10.1016/j.rtbm.2015.10.004
21. Russo, F., Musolino, G., Assumma, V.: Competition between ro–ro and lo–lo services in short sea shipping market: the case of Mediterranean countries. Res. Transp. Bus. Manag. **19**, 27–33 (2016). https://doi.org/10.1016/j.rtbm.2016.03.002
22. Russo, F., Musolino, G., Assumma, V.: Ro-ro and lo-lo alternatives between mediterranean countries: factors affecting the service choice. Case Stud. Transp. Policy. **11**, 100960 (2023). https://doi.org/10.1016/j.cstp.2023.100960
23. Russo, A., Campisi, T., Bouhouras, E., Basbas, S., Tesoriere, G.: Sustainable maritime passenger transport: a network analysis approach on a national basis. In: Gervasi, O., et al. (eds.) ICCSA 2023. LNCS, vol. 14109, pp. 195–207. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-37120-2_13
24. Asadabadi, A., Miller-Hooks, E.: Maritime port network resiliency and reliability through co-opetition. Transp. Res. Part E Logist. Transp. Rev. **137**, 101916 (2020). https://doi.org/10.1016/j.tre.2020.101916
25. Kang, L., Meng, Q., Liu, Q.: Fundamental diagram of ship traffic in the Singapore Strait. Ocean Eng. **147**, 340–354 (2018). https://doi.org/10.1016/j.oceaneng.2017.10.051
26. Russo, F., Peda, G., Musolino, G.: Container ports in country systems: calibration of the aggregate function for the time of the ship in port. Int. J. Transp. Dev. Integr. **6**, 415–427 (2022). https://doi.org/10.2495/TDI-V6-N4-415-427
27. Russo, F.: Sistemi di trasporto merci: approcci quantitativi per il supporto alle decisioni di pianificazione strategica tattica ed operativa a scala nazionale. F. Angeli, Milano (2005)
28. Cantarella, G.E.: Dynamics and Stochasticity in Transportation Systems: Tools for Transportation Network Modelling. Elsevier, Amsterdam (2020)
29. Nuzzolo, A., Russo, F., Crisalli, U.: A doubly dynamic schedule-based assignment model for transit networks. Transp. Sci. **35**, 268–285 (2001). https://doi.org/10.1287/trsc.35.3.268.10149
30. Nuzzolo, A., Crisalli, U.: The Schedule-based approach in dynamic transit modelling: a general overview. In: Wilson, N.H.M., Nuzzolo, A. (eds.) Schedule-Based Dynamic Transit Modeling: Theory and Applications. Operations Research/Computer Science Interfaces Series, vol. 28, pp. 1–24. Springer, Boston (2004). https://doi.org/10.1007/978-1-4757-6467-3_1

31. Russo, F., Musolino, G.: State of the art of factors affecting times of ships in container ports: characteristics identification for evaluation of port generations. In: Submitted to the Conference on ICCSA 2024 Computational Science and Its Applications (2024)
32. Polimeni, A., Belcore, O.M.: Ship times in container ports: AIS data for maritime transport and ports applications. In: Submitted to the Conference on ICCSA 2024 Computational Science and Its Applications (2024)
33. Nielsen, O.A.: A large scale stochastic multi-class schedule-based transit model with random coefficients. In: Wilson, N.H.M. and Nuzzolo, A. (eds.) Schedule-Based Dynamic Transit Modeling: Theory and Applications. Operations Research/Computer Science Interfaces Series, vol. 28. pp. 53–77. Springer, Boston (2004). https://doi.org/10.1007/978-1-4757-6467-3_4
34. Ministry of infrastructures and transport Italian coast guard headquarters: MESSINA VTS - "USER'S MANUAL" (2015). https://www.guardiacostiera.gov.it/mezzi-e-tecnologie/Documents/manualiVTS/manualeutentemessina_inglese.pdf

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