

Article

A Review of Vessel Traffic Services Systems Operating in Poland in Terms of Their Compliance with International Legislation

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Abstract: Vessel Traffic Services (VTS) systems are complex systems facilitating decision-making processes and integrating technical infrastructure, aiming to ensure the safety of ship traffic and marine environment protection in indicated water areas. Such services are offered in Poland in selected regions. These systems operate based on guidelines established by the International Maritime Organization (IMO) and European Parliament; therefore, they should be constantly developed and adjusted to current regulations. The aim of this article is to review and assess the adjustment of VTS systems operating in Poland to current selected regulations introduced by the IMO and European Parliament. A comparative analysis and evaluation of three VTS systems operated in Poland was carried out. In addition, the impact of VTS systems on the development of the trans-European transport network was examined. It was stated that the investigated VTS systems' current adjustment to analyzed regulations is different depending on the systems' configuration and possessed infrastructure, parameters of fairways, traffic regulations and other criteria. Based on the achieved research results, recommendations to improve the VTS systems in Poland were proposed. The research outcomes may be interesting for the managers of maritime administrations, ports' authorities, and other decision-makers responsible for safe navigation and traffic management.



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Keywords: vessel traffic services; decision-making processes; maritime transport; traffic management

1. Introduction

Vessel Traffic Services (VTS) systems are dedicated to the monitoring and control of vessel traffic in indicated water areas [1]. The need to establish VTS systems is highlighted in the International Convention for the Safety of Life at Sea (SOLAS) [2]. Usage of these systems contributes, e.g., to the enhancement of safety of life at sea, navigation efficiency and the marine environment protection against the possible adverse effects of maritime traffic [2].

VTS systems are introduced by maritime administrations for several reasons, including [1] observed increased vessel traffic, navigation of vessels carrying dangerous cargoes, the significant impact of hydrometeorological conditions on vessel safety, navigation in narrow passages, fairways integrated with complex port structures with imposed routing patterns, the need to protect the marine environment, etc.

Maritime administrations usually prioritize the issues related to navigation safety and the protection of the marine environment within the conducted activities. Maritime administrations may establish a VTS system when, in their opinion, such services are

justified, considering the traffic volume or risk degree in the operated area [2]. Key benefits of implementing VTS include the following [3]:

- identification and monitoring of vessels;
- strategic vessel traffic planning;
- vessel traffic management;
- provision of information that can influence vessel traffic and assist in decision-making;
- support of navigational safety of ships by providing relevant navigational information;
- supporting related activities such as pilotage;
- search and rescue, maritime security, law enforcement, etc.

Nowadays, a great attention is paid to the development of efficient, sustainable and safe transport systems [4–6]. VTS systems are extremely important components of modern transport systems. They make it possible to not only to improve operational efficiency and reduce costs of ships service in set water areas, but also to increase safety, better manage risks and improve the quality of services provided [7–9].

According to the Act of 21 March 1991 on Sea Areas of the Republic of Poland and the Maritime Administration [10], vessel traffic monitoring and control is one of the four pillars of Polish maritime administrations' activities. Currently, three VTS systems are operated by maritime authorities in the area of Polish territorial waters (Figure 1) [7–9]:

- VTS Zatoka Gdańska;
- VTS Ławica Słupska;
- VTS Świnoujście-Szczecin.

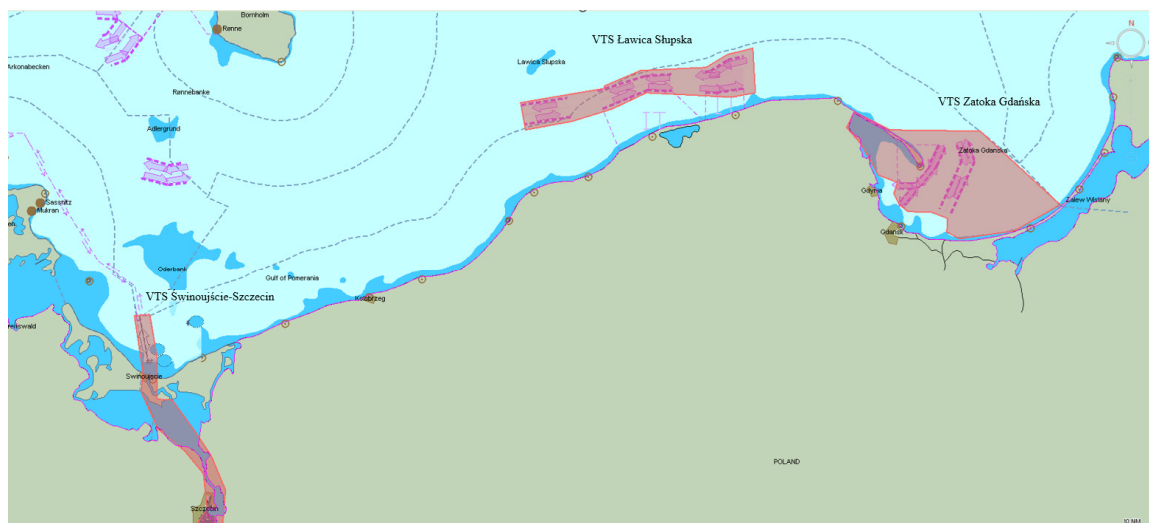


Figure 1. Areas of responsibility of the VTS systems operated in Poland (our own elaboration based on [11]).

As a rule, VTS systems were created based on services previously provided by harbor masters' duty services for vessel traffic and order management in the port. VTS Świnoujście-Szczecin was established in 2000 in accordance with the guidelines [1,2], followed by VTS Zatoka Gdańska (year 2003) and VTS Ławica Słupska (year 2010). Even though the main objective of VTS activity deals with improving navigation safety and the marine environment protection, the organization of the above-mentioned systems, their architecture and realized functions are different.

Polish VTS systems do not form a unified, common system. Each system performs a local function, offering services within a selected area of responsibility. As a part of the National Maritime Safety System (NMSS) project completed in 2015 [12], the technical infrastructure of VTS systems was replaced and unified (hardware-wise). The NMSS project

was a joint venture between maritime authorities to comprehensively modernize technical infrastructure, including the VTS systems. A common network of Automatic Identification System (AIS) receivers was also created [2], ensuring the reception of data sent by vessels in the entire area of responsibility of the Polish maritime administration.

Each system was created considering the possibility to apply specific services offered [1]:

- An Information Service is provided by broadcasting information at fixed times and intervals or when deemed necessary by the VTS system or at the request of a vessel and may include, for example, reports on the position, identity and intentions of other traffic participants, waterway conditions, weather, hazards, or other factors that may affect the vessel movement;
- A Navigational Assistance Service is particularly important in difficult navigational or meteorological conditions or in the event of faults or deficiencies. This service is normally provided at the request of a vessel or by the VTS system when deemed necessary;
- A Traffic Organization Service refers to the operational management of traffic and planning of vessel movements to prevent congestion and the occurrence of dangerous situations and is particularly important during periods of heavy traffic or when the movement of special transport means may affect the traffic of other ships. This service may also include the establishment and operation of a traffic clearance system or VTS system nautical plans or both, regarding traffic priorities, space allocation, mandatory reporting in the VTS system area, routes to be followed, speed limits to be observed or other appropriate measures when deemed necessary.

VTS systems in Poland offer a task-specific set of services (Table 1).

Table 1. Services offered by VTS systems in Poland (our own elaboration based on [1]).

VTS System	Main Objective	Offered Services
VTS Zatoka Gdańska	To ensure the safety of navigation for vessels calling at ports located on the coast of the Gulf of Gdańsk. The operation of this VTS system is based on a ship reporting system and a virtual network of shipping lanes called the Traffic Separation Schemes (TSS) [2], the purpose of which is the safe distribution of ship traffic to ports in Gdynia, Gdańsk.	• Information Service • Navigational Assistance Service • Traffic Organization Service
VTS Słupska Ławica	To model ship traffic in the area of the central coast of Poland in such a way as to protect the valuable sea areas of Słupska Ławica and, at the same time, ensure the safety of navigation for ships operating in this area. The operation of this VTS system is based on the TSS.	• Information Service
VTS Świnoujście-Szczecin	To ensure the safety of navigation for vessels calling at ports located in the lower section of the Oder River. The operation of this VTS system is based on a ship reporting system and a system of recommended shipping routes.	• Information Service • Traffic Organization Service

It should be noted that VTS systems operating in Poland differ in terms of functions and particular characteristics that should be adjusted to the current regulations introduced by the International Maritime Organization (IMO) and European Parliament [1,2,13]. VTS systems development is a complicated decision-making process. Therefore, it is reasonable to analyze in detail the individual features of these systems.

This article aims to review and assess the adjustment of VTS systems operating in Poland to current selected regulations introduced by IMO and European Parliament. The VTS systems operating in the area of Polish territorial waters were characterized and compared. Particular attention was paid to the adjustment of these systems to the Resolution A.1158(32) Guidelines for Vessel Traffic Services [13], Regulation No 1315/2013 of the European Parliament and of the Council on Union guidelines for the development of the trans-European transport network (TEN-T) in the European Union (EU) [14]. The novelty of the presented research deals with conducting a comparative analysis of the VTS systems operating in Poland, as well as assessment of the VTS systems' impact on the trans-European transport network development. Recommendations to improve the VTS systems operated in Poland were proposed.

This article includes Section 2, where the literature review results are presented. The methodology used to conduct the research is described in Section 3. The research results are presented in Section 4, where the effects of the comparative analysis of the VTS systems are shown. The discussion of the achieved results is shown in Section 5. In order to summarize the research results, recommendations to improve the operation of the VTS systems were developed and conclusions were drawn (Section 6).

2. Literature Review

In the current literature much attention has been paid to the safety of navigation [15,16]. Traffic with high-frequency services have been analyzed [17], as well as an approach to documenting arbitrary data from different entities in a trustworthy way has been proposed [18].

The need to apply comprehensive systems facilitating safe and sustainable navigation has been highlighted in the available literature [19,20]. These systems are primarily intended to have a preventive effect. Therefore, their operation is mainly oriented towards identifying factors that could pose a risk in the future [21]. Moreover, these systems should enable efficient navigation for vessels in designated areas [22]. Within these areas sensors systems may be used [23], as well as radar distance measurement systems may be applied [24]. The progress of intelligent systems, their role in modern vessels traffic and impacts on port operations have been highlighted [25].

In order to successfully support the growing digital and autonomous marine traffic, the fairways should be upgraded and modernized. Therefore, the development of the Smart Fairways concept has been considered [26]. Moreover, Çağlayan and Aymelek proposed an integrated multi-criteria decision support model for sustainable ship queuing policy application via a VTS system [27].

In the available studies, the role of the human factor in the assurance of maritime traffic safety has been highlighted [28,29]. VTS system operators should possess appropriate qualifications [30]. A rule-based maritime traffic situation complex network approach has been examined to enhance situation awareness by VTS system operators [31]. The proper operation of VTS systems is heavily influenced by cooperation with allied services providers, which has been the subject of available research [32]. The cooperation of tugboats and pilots has been analyzed in terms of delays of vessels calling at the port of Rotterdam [33]. Bottlenecks were found along the lines of cooperation and organization of these services. A similar issue was addressed by Arslan and Nas [34] who discussed the re-

relationship between a VTS system, master and cooperating pilot. Malagoli et al. [35] studied human–machine cooperation and made an attempt to measure the VTS system operator’s workload. Moreover, attention was paid to the need to establish effective teamwork and implement adequate safety leadership on ships, increasing safety in general and improving marine environment protection [36], as well as working conditions on ships [37].

A detailed analysis of the implementation of the new resolution (so-called VTS Guidance) was performed in the literature [38]. The available analyses concern the increase in the efficiency and safety of navigation resulting from the human factor and the impact of new regulations on increasing navigation safety. The factors influencing maritime accidents, which have a significant impact on decision-making processes, were analyzed by Fan et al. [39]. The Bayesian Networks method was used to assess this impact in the research process. The economic impact of actions taken by a VTS system was discussed by Luling et al. [40], where the possible consequences of erroneous decisions and their financial effects were considered.

The configuration and parameters of dedicated shipping routes have a key impact on a VTS systems’ functioning [41]. Each system uses information that may refer to the navigation plans and navigation alerts, weather information, marine traffic management and other factors [42]. The information distortion impacts the decision-making process and may lead to the occurrence of undesirable situations [43].

The significance of VTS system implementation is expressed primarily in unique traffic rules, as well as restrictions and limitations in navigation within certain areas. For example, specific traffic rules were introduced in the area covered by the Świnoujście–Szczecin VTS system [44]. While ensuring compliance with traffic efficiency regulations, a detailed analysis of ship traffic and flow, traffic patterns, queuing, etc. is needed. These issues were examined in the number of publications [45–47]. Available research is based mainly on the statistical analysis of data obtained from the AIS system. Attention is paid to the need to implement new decision support technologies for VTS system operators [48,49]. New technologies should be based on the analysis of large amounts of data and supported by artificial intelligence [50,51].

The conducted literature analysis revealed that the adaptation of VTS systems operating in Poland to current international legislation [13,14] had not yet been analyzed in detail. Therefore, conducting a comparative analysis of these systems and evaluating the degree to which these requirements are met is needed.

3. Research Methodology

The methodology applied to carry out the research is presented in Figure 2.

To carry out the research, the data were collected from the available literature and the specifications of individual VTS systems operated in Poland were examined. Three VTS systems, including VTS Zatoka Gdańska, VTS Ławica Słupska, VTS Świnoujście–Szczecin, were reviewed and compared.

In order to conduct the research, materials from official websites were used and the internal documents of particular VTS systems were analyzed.

The criteria for VTS comparative analysis were identified, including:

1. System location;
2. Organization of the system;
3. Technical infrastructure;
4. Traffic management;
5. Risks related to vessel traffic in the area covered by the system;
6. Traffic management functions in relation to the implementation of Regulation (EU) No 1315/2013 [14];

7. Possibilities of implementing the IMO Resolution Guidelines A.1158(32) [13].

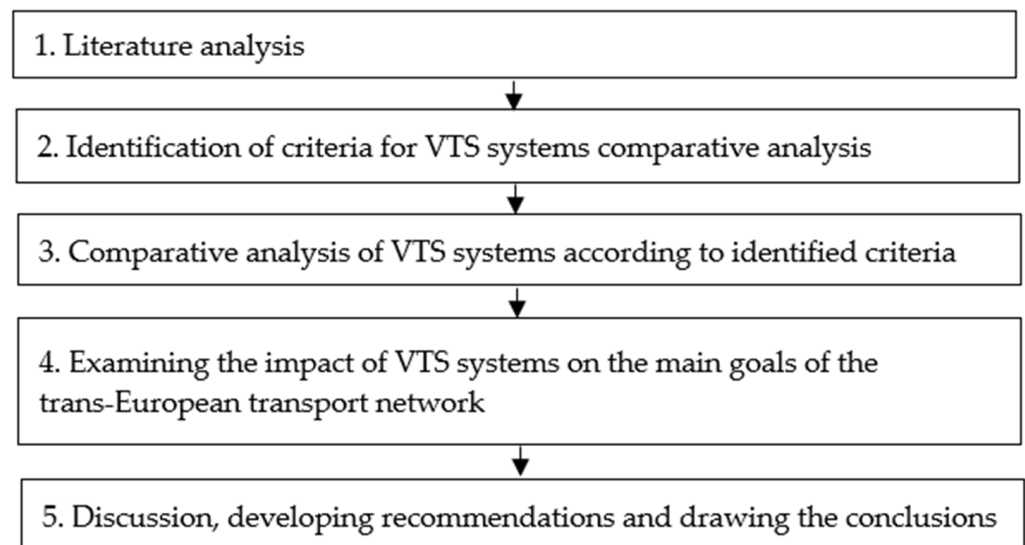


Figure 2. Research methodology.

The above mentioned criteria were identified considering the literature review result and the authors' experience in the operation of VTS systems, addressing both technical and organizational aspects. Criteria 6 and 7 refer to the purpose of the undertaken research and the need to assess the adjustment of VTS systems operating in Poland to the two current selected regulations introduced by the IMO [13] and European Parliament [14]. The assessment of these criteria allowed us to show the importance of VTS systems operating in Poland in relation to TEN-T development.

A comparative analysis of the VTS systems according to identified criteria was performed. An expert method was used to determine the impact of VTS systems operating in Poland on the implementation of individual TEN-T tasks. The authors were the experts and provided the assessments based on their knowledge and practical experience. Experienced VTS managers from each of the analyzed VTS systems shared the data and information (one person per VTS system).

The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) Waterway Risk Assessment Program (IWRAP MK II) was applied to assess the probability of the occurrence of undesirable situations on selected parts of the analyzed fairways. The IWRAP MK II software includes the development of a waterway model and the geometry of the relevant routes and uses data on traffic volume and composition, waterway bathymetry and other factors. Once the model is defined, IWRAP MK II calculates the expected annual average number of collisions and groundings.

The impact of VTS systems on the development of the trans-European transport network was examined. Moreover, a discussion was carried out, focusing on the level of difficulty to implement the provisions of the regulations introduced by the IMO [13] and European Parliament [14]. Then, recommendations to improve VTS systems were formulated and conclusions were drawn.

4. Results

4.1. The VTS Systems' Locations

VTS systems located in Poland operate in designated areas (Figure 1).

The VTS Zatoka Gdańska system supports all vessels operating in the Gulf of Gdańsk area after crossing the so-called "reporting line". All ships in this area should use TSS Zatoka Gdańska [2,7,52,53].

The VTS Ławica Słupska system services all ships sailing in the central part of the Polish coast and the Słupsk Bank. Ships are obliged to use TSS Ławica Słupska. This VTS system is located entirely within the area of Polish territorial waters [8].

The VTS Świnoujście–Szczecin system services ships over 20 m long entering this VTS system's area, as designated by reporting lines. Vessel traffic in the area covered by the VTS Świnoujście–Szczecin system takes place mainly on a section of the “natural” fairway delineated in the Pomeranian Bay and an “artificial” fairway, dredged in the Oder riverbed [9,11,54].

A comparison of the VTS systems taking into account their location is presented in Table 2.

Table 2. Comparison of the VTS systems in Poland according to the criterion system location (our own elaboration based on [55,56]).

Name of VTS System	Reporting System?	TSS?	Location	Surroundings	Types of Traffic Served	Annual Average Number of Ships Served *
VTS Zatoka Gdańska	YES	YES	Internal sea waters, territorial sea waters	Adjacent border and territorial waters of the Russian Federation	Regular SOLAS vessels, auxiliary ships of harbor shipping, local passenger vessels	8775 (regular SOLAS vessels)
VTS Ławica Słupska	NO	YES	Territorial sea waters	Territorial sea of the Polish Republic	Regular SOLAS vessels, auxiliary ships of harbor shipping, local passenger vessels, fishing vessels	3600 (regular SOLAS vessels)
VTS Świnoujście–Szczecin	YES	NO	Internal sea waters, territorial sea waters	Adjacent border and territorial waters of the German Republic	Regular SOLAS vessels, auxiliary ships of harbor shipping, local passenger vessels, inland water vessels, internal port traffic	10132 (regular SOLAS vessels) + 7000 inland water vessels

* Data are given as the average for 2018–2022.

To sum up, it should be mentioned that considering the location of each VTS system, the vessel traffic served is different. It consists of ships involved in international shipping, so-called regular SOLAS vessels, as well as port traffic ships, such as passenger vessels, inland barges, etc. The types of served vessels impact the VTS systems services and decision-making processes performed by the operators of these systems.

4.2. Organization of the VTS Systems

The organization of the operation of each VTS system also differs.

The VTS Zatoka Gdańska system's management authority is located in Gdynia and provides 24-h service by 12 operators who work in four teams; services are provided in 12-h shifts [55].

The management authority of the VTS Ławica Słupska system is situated in Ustka and provides full-time service by 12 operators working in four teams; services are also provided in 12-h shifts [55].

The VTS Świnoujście–Szczecin system’s management is divided into two sub-centers: the VTS Świnoujście Centre and the VTS Szczecin Centre (Figure 3). Thirteen operators are employed in each center and the staff is divided into four teams. Operators perform services in 12-h shifts [56]. Each center serves an assigned area of responsibility. A comparison of the VTS systems taking into account the organization and configuration of each system is presented in Table 3.

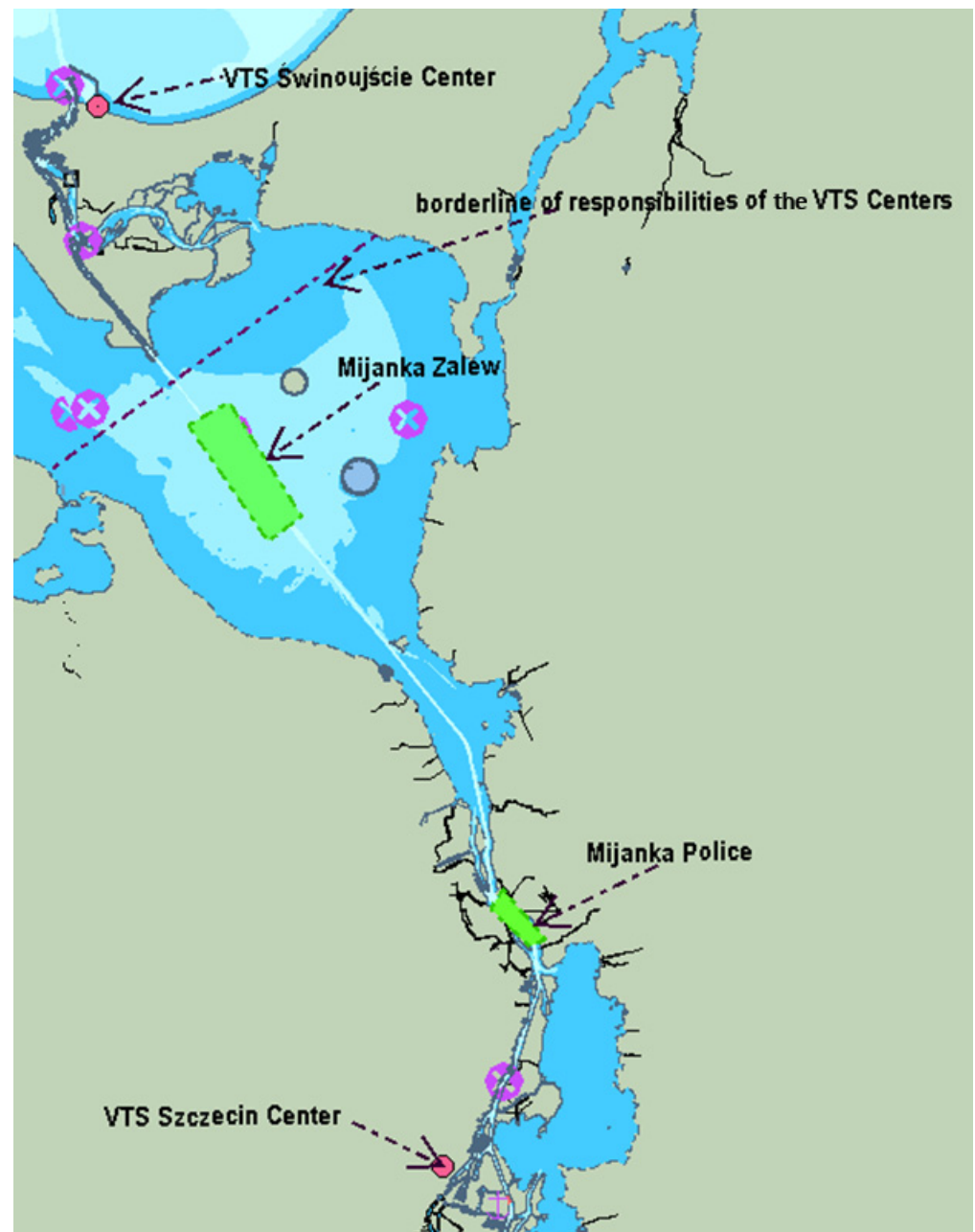


Figure 3. Areas of responsibility of the VTS Centers in Szczecin and Świnoujście (our own elaboration based on [11]), where “Mijanka Zalew” and “Mijanka Police” are places indicated within Świnoujście–Szczecin Fairway where ships may pass each other and purple circles represent map components.

Table 3. Comparison of the VTS systems in Poland according to the criterion organization of the system (own elaboration based on [55,56]).

Name of VTS	Selected Decision-Making Participants	Selected Allied Services	Number of VTS Centers	Types of Services Provided	Selected Traffic Management Approaches
VTSZatoka Gdańska	1. VTS Zatoka Gdańska Center 2. Gdynia Harbor Master's Office 3. Gdańsk Nowy Port Harbor Master's Office 4. Gdańsk Northern Port Harbor Master's Office.	1. Pilot Station 2. SafeSeaNet 3. Search and Rescue 4. National hydro- meteo service	1	1. Information Services 2. Traffic Organization Services 3. Navigational Assistance Services	1. Assignment of recommended routes 2. Two-way traffic is carried out in dedicated lanes separated by a separation zone 3. The port and coastal traffic takes place in the internal traffic zone
VTS Ławica Słupska	1. VTS Ławica Słupska Center	1. SafeSeaNet 2. Search and Rescue 3. National hydro- meteo service	1	1. Information Services	1. Monitoring of traffic
VTS Świnoujście-Szczecin	1. VTS Świnoujście Center 2. VTS Szczecin Center 3. Świnoujście Harbor Master's Office 4. Szczecin Harbor Master's Office, 5. Port Authority	1. Pilot Station 2. SafeSeaNet 3. Search and Rescue 4. National hydro- meteo service 5. Tug company 6. Botsman company 7. River Information System	2	1. Information Services 2. Traffic Organization Services	1. Planning of two-way and one-way traffic is carried out in one lane of the fairway 2. Passing places are designated for ships to pass each other 3. Port and coastal traffic is carried out in the main fairway

Within each VTS system, the decisions are made considering cooperation between several decision-making participants, e.g., Harbor Masters' Offices located in Szczecin, Świnoujście, Gdańsk or Gdynia, Port Authorities, VTS Centers in Świnoujście, Szczecin or Gdańsk, etc.

It should be noted that analyzed VTS systems have a different number of involved decision-making participants, as well as different number of allied services that impact the organization of decision-making processes. The greater the number of participants involved in the decision-making process, the more complex and time-consuming it becomes.

4.3. Technical Infrastructure

The density and structure of traffic, navigational hazards, local climate, topography, environmental requirements, commercial aspects and the scope of area covered by VTS system determine the requirements for the use of VTS devices and subsystems [3]. The equipment needed to perform the tasks of a VTS system may include the following devices [3]:

- VTS radar system;
- Automatic Identification System (AIS);
- Very High Frequency (VHF) operational communication;
- Closed-Circuit Television (CCTV) systems;
- Radio Direction Finders (RDF);
- hydrometeorological equipment;
- VTS data management and information systems.

A comparison of the VTS systems operating in Poland, taking into account each system's technical infrastructure is presented in Table 4.

Table 4. Comparison of the VTS systems in Poland according to the criterion technical infrastructure (our own elaboration based on [53–56]).

Technical Infrastructure	VTS Zatoka Gdańska	VTS Ławica Słupska	VTS Świnoujście-Szczecin
Radar system	Yes	Yes	Yes
Coverage of radar system	full coverage	full coverage	full coverage
AIS system	Yes	Yes	Yes
Coverage of AIS system	full coverage	full coverage	full coverage
VHF communication system	Yes	Yes	Yes
Coverage of VHF system	full coverage	full coverage	full coverage
CCTV System	Yes	Yes	Yes
Coverage of CCTV system	full coverage	full coverage	full coverage
Radio Direction Finder	Yes	Yes	No
Hydro-meteo system (own weather stations)	Yes	Yes	Yes
Hydro-meteo system (integrated with the VTS application)	Yes	Yes	Yes
VTS data management and information system connected to the European SafeSeaNet server	Yes	Yes	Yes
Integrated VTS operators' consoles	Yes	Yes	Yes
Total number of VTS system units (devices)	37	19	57

To sum up, it should be highlighted that the technical infrastructure and equipment of each VTS system differs in terms of total number of units (devices) and depends on the need to ensure specific services.

4.4. Traffic Management

The differences in traffic management provided by analyzed VTS system are also observed. Vessels' traffic lanes managed by the VTS Zatoka Gdańska and VTS Ławica Słupska systems are presented in Figure 4. In turn, the location of ports (brown circles)

and selected fragments the of Świnoujście–Szczecin fairway (green circles) are shown in Figure 5.

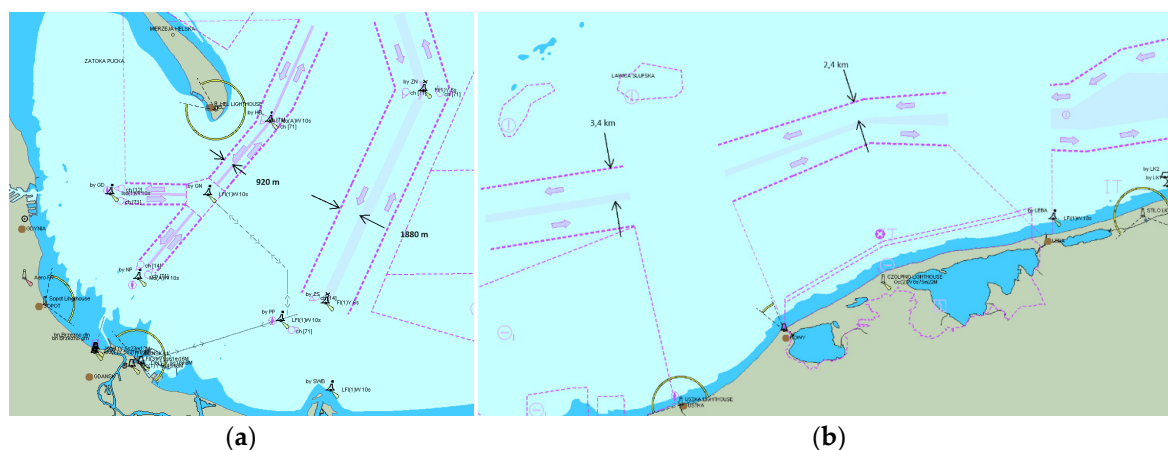


Figure 4. Configuration of vessels' traffic lanes. (a) VTS Zatoka Gdańska. (b) VTS Ławica Słupska [11].

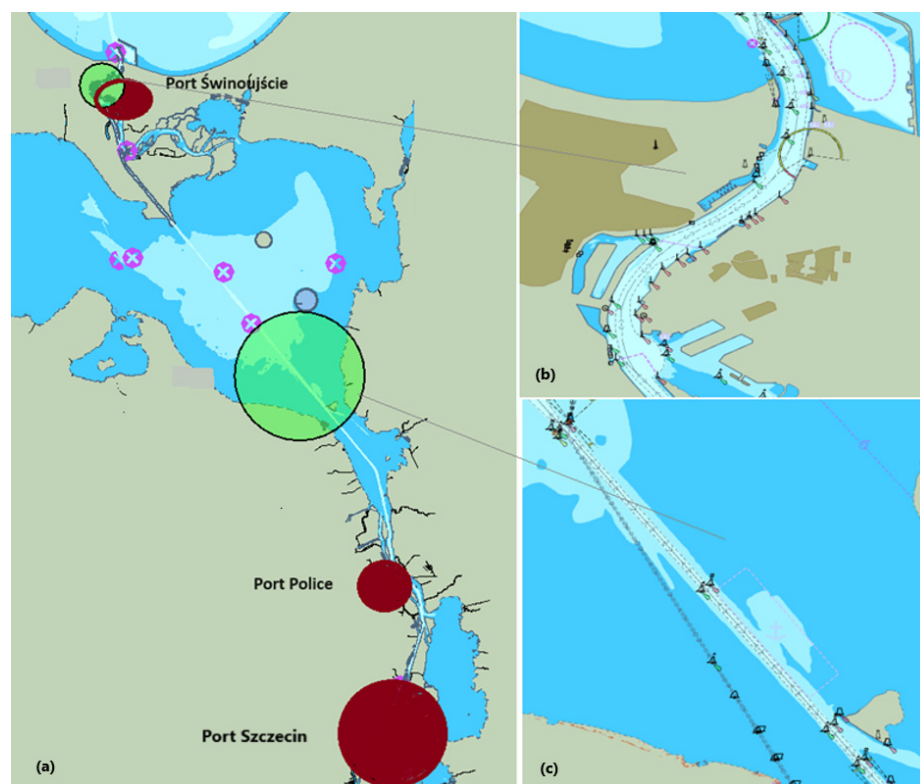


Figure 5. Schematic location of ports along the Świnoujście–Szczecin fairway. (a) General overview of the fairway, (b,c) enlarged characteristics of the two fairway sections (marked with green circles on (a)) (our own elaboration based on [11]).

A comparative analysis of the VTS systems taking into account traffic management is presented in Table 5. The features possessed and lacking by the analyzed systems were considered.

Table 5. Comparison of the VTS systems in Poland according to the criterion traffic management (our own elaboration based on [53–56]).

VTS System	Selected Features of Traffic Management
VTS Zatoka Gdańska	• Indicating and selecting appropriate sea routes for the serviced vessels; • Managing vessels entering to the ports of Gdynia, Gdańsk, and Port Północny, which are located radially around the Gulf of Gdańsk; • Utilizing the arrangement of navigation routes and the TSS, which practically eliminates the issue of two-way traffic; • Assigning directional entry and exit lanes for vessels, allowing them to pass each other safely; • Monitoring of vessel traffic regardless of weather conditions such as wind speed, visibility and water levels; • Not involved in planning vessel queuing; such decisions are made by another decision-making center (the Harbor Master Duty Service); • Not responsible for the most sensitive stage of a vessel's entry into the port (the section from the Pilot Station to the quay), where additional services such as pilotage and tug assistance are planned.
VTS Ławica Słupska	• A lack of direct management of vessel traffic using the TSS system; • The width of the directional traffic lanes ensures the free flow of vessels through the zone; • The directional traffic lanes are wide enough, allowing for safe and unobstructed movement of vessels without operator assistance.
VTS Świnoujście-Szczecin	• Traffic management covers the entire process from the moment the vessel is taken over at the boundary of the VTS system's responsibility until docking, and for departing vessels, from docking to leaving the port; • Vessel traffic planning includes all aspects related to the ship's visit to the port, requiring coordination of various activities and services; • The decision-making process involves multiple stakeholders, including Port Captain services and Port Authority coordination; • The VTS operator actively participates in the decision-making process at every stage of the vessel's entry and exit from the port, unlike VTS Gulf of Gdańsk, where the operator receives a pre-made decision; • VTS Świnoujście-Szczecin operators are involved in managing associated services such as pilotage and towing; • The decision-making process is the result of collaboration between two VTS centers, as well as other stakeholders and associated services.

To sum up, it should be mentioned that the VTS Zatoka Gdańska system primarily focuses on managing sea routes and traffic monitoring, while more detailed port operations are handled by the Harbor Master's Office. In turn, VTS Ławica Słupska operates more as a monitoring system, providing the infrastructure necessary for safe vessels navigation without actively managing their movement. The complexity of traffic management within the VTS Świnoujście-Szczecin system, where operators play an essential role in planning and coordinating activities at every stage of the vessel's traffic in ports, should be highlighted.

4.5. Risks Related to Vessel Traffic in the Area Covered by the VTS Systems

To address the issue of risks associated with vessel traffic in areas covered by the VTS systems, the IWRAP MK II software [57] was used to calculate the probability of collision. The aim of IWRAP MK II is to provide the user with a standardized quantitative method for calculating the probability of a collision in analyzed waterway [58]. The need to use this type of software follows directly from recommendations in the literature [3].

The IWRAP MK II software uses historical data extracted from each AIS, which are statistically processed to achieve the intended results. An AIS is mandatory for seagoing

vessels and the data are transmitted by transmitters operating on VHF channels. According to international regulations [59], the transmitted data are divided into three groups: static data, dynamic data and voyage-related data. Among the relevant data used for statistical processing are a vessel's position, course and speed; identification data such as ship's name; draught; longitude; latitude; etc.

The calculation was based on the model and a set of causation factors [57], which can be understood as the probability that a ship will not take evasive action to avoid running aground or a collision (Table 6).

Table 6. IALA Default Causation Factors [57].

Condition	Causation Factor
Head on collisions	0.5×10^{-4}
Overtaking collisions	1.1×10^{-4}
Crossing collisions	1.3×10^{-4}
Collisions in a bend situation	1.3×10^{-4}
Collisions in a merging situation	1.3×10^{-4}
Grounding, forgot to turn	1.6×10^{-4}

Once the assumed waterway model has been defined, the IWRAP MK II software can calculate the resulting annual average collisions, groundings and shoal entries. The results can be displayed in tabular or graphical form using color coding [57].

While creating the model for the described VTS systems, some simplifications have been applied: historical data on collisions, groundings and incidents have not been considered; specific local conditions related to harbor traffic have not been taken into account; and the traffic of small units such as yachts and fishing vessels has not been considered. The authors' intention was to build a model generated for the same conditions for each VTS system. Collisions in head on and overtaking situations were considered.

Historically available AIS data were collected for the period 1 January 2021 to 30 September 2021. Figures 6–8 show the results achieved from the IWRAP MK II software [57].

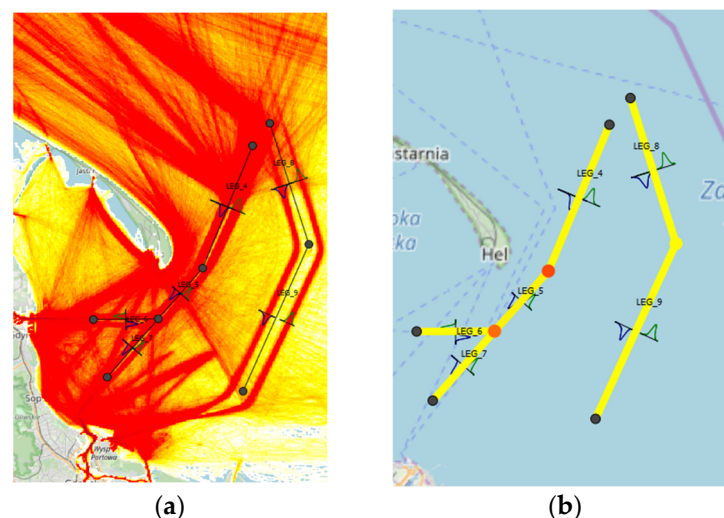


Figure 6. Area covered by the VTS Zatoka Gdańska system. (a) Density map of ships' movements on each individual LEG. (b) Probability of collision on each individual LEG (our own elaboration based on [57]).

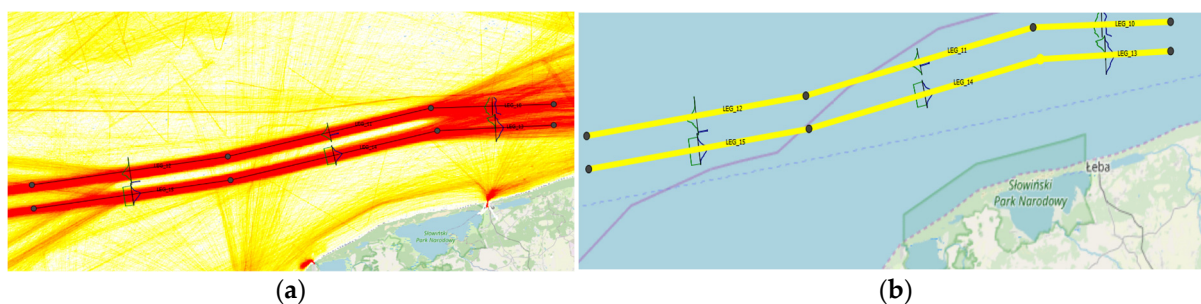


Figure 7. Area covered by the VTS Ławica Słupska system. (a) Density map of ships' movements on each individual LEG. (b) Probability of collision on each individual LEG (our own elaboration based on [57]).

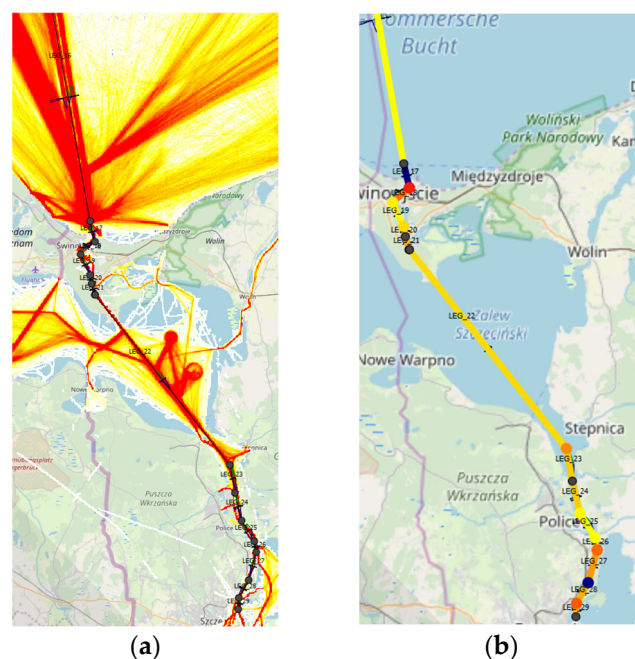


Figure 8. Area covered by the VTS Świnoujście–Szczecin system. (a) Density map of ships' movements on each individual LEG. (b) Probability of collision on each individual LEG (our own elaboration based on [57]).

The layout of the defined recommended shipping lane is divided into sections (LEGs) and the probabilities of collision at each section (LEG) for the described VTS systems were calculated. The color of the lines have the following meanings: blue—very high intensity/probability, red—high intensity/probability, orange—medium intensity/probability, yellow—low intensity/probability.

The summary of the calculated probabilities of collision in head on and overtaking situations at each LEG of the described VTS systems is shown in Figure 9.

A comparison of the VTS systems taking into account the criterion probability of collision related to default causation factors is presented in Table 7. Table 7 shows the LEGs of the VTS systems, where the probability of collision was assessed to be higher than the set probability value p .

Based on data presented in Figure 9 and Table 7, it can be concluded that the highest probability of analyzed collisions is observed in the case of vessels' movements within the Świnoujście–Szczecin fairway.

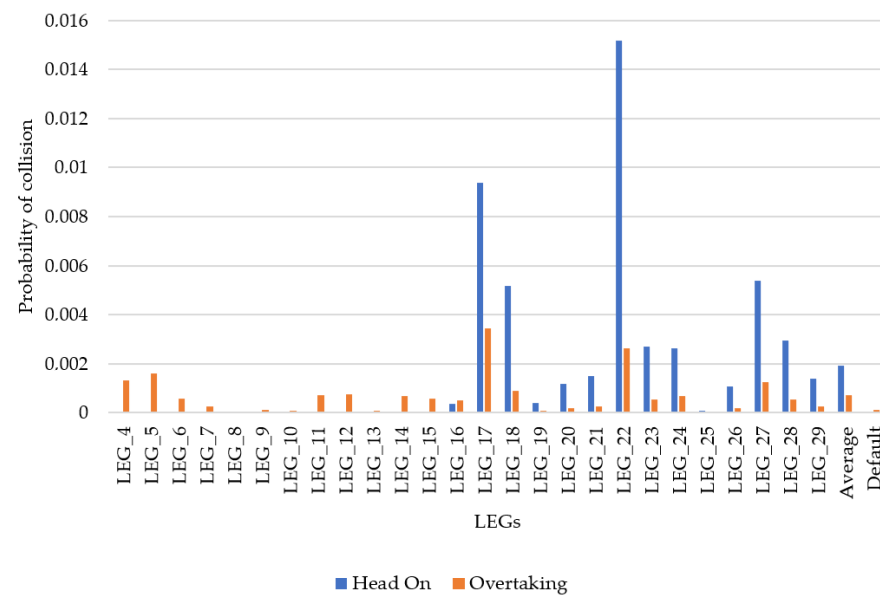


Figure 9. Probability of collision on individual sections (LEGs) in relation to limits identified by IWRAP MK II. LEGs 4–9 are assigned to VTS Zatoka Gdańska, LEGs 10–15 are assigned to VTS Ławica Słupska and LEGs 16–29 are assigned to VTS Świnoujście–Szczecin (our own elaboration based on [57]).

Table 7. Comparison of the VTS systems in Poland according to the criterion probability of collision related to default causation factors (own elaboration based on [57]).

VTS System	Probabilities of Collision Related to Default Causation Factor on Each LEG			
	Head on Collisions		Overtaking Collisions	
	LEGs for Which $p > 0.5 \times 10^{-4}$	Calculated p Values	LEGs for Which $p > 1.1 \times 10^{-4}$	Calculated p Values
VTS Zatoka Gdańska	Not applicable	Not applicable	Leg 4 Leg 5	1.3×10^{-3} 1.6×10^{-3}
VTS Ławica Słupska	Not applicable	Not applicable	Leg 11 Leg 12 Leg 14 Leg 15 Leg 16	0.7×10^{-3} 0.7×10^{-3} 0.7×10^{-3} 0.6×10^{-3} 0.5×10^{-3}
VTS Świnoujście-Szczecin	Leg 17 Leg 18 Leg 19 Leg 20 Leg 21 Leg 22 Leg 23 Leg 24 Leg 26 Leg 27 Leg 28 Leg 29	9.4×10^{-3} 5.2×10^{-3} 0.4×10^{-3} 1.2×10^{-3} 1.2×10^{-3} 15.3×10^{-3} 2.7×10^{-3} 2.6×10^{-3} 1.1×10^{-3} 5.4×10^{-3} 2.9×10^{-3} 1.4×10^{-3}	Leg 17 Leg 18 Leg 20 Leg 21 Leg 22 Leg 23 Leg 24 Leg 26 Leg 27 Leg 28 Leg 29	3.4×10^{-3} 0.9×10^{-3} 0.2×10^{-3} 1.2×10^{-3} 2.6×10^{-3} 0.5×10^{-3} 0.7×10^{-3} 0.2×10^{-3} 1.2×10^{-3} 0.6×10^{-3} 0.3×10^{-3}

4.6. Traffic Management Functions in Relation to the Implementation of Regulation (EU) No. 1315/2013

In order to assess the effectiveness of vessel traffic management and, in particular, the feasibility of meeting the requirements of [13,14], the ways of traffic management within

the specific systems should be analyzed in more detail. In relation to the objectives set in the document Regulation (EU) No 1315/2013 [14], the configuration and parameters of dedicated shipping routes and the resulting ability to ensure smooth, efficient two-way traffic; the occurrence of so-called “bottlenecks”; the queuing of vessels; the network of decision-making links and information circulation; and the ability to support the decision-making of VTS operators with advanced information and communication technologies will be of primary importance and influence the operation of Polish VTS systems.

With regard to the objectives set in document [13] related to traffic management, the main challenge seems to be related to the change in the definition of the declared services performed by a VTS system. As in the case of meeting the objectives contained in [14], decision support for VTS operators seems essential.

The TEN-T development aims are, among others, to build a coherent, efficient, multimodal and high-quality transport infrastructure across the EU; to reduce the environmental and climate impact of transport; and to increase the safety and the resilience of the network [60,61]. An effective operation of transport system within the EU is crucial to contribute to the improvement of the single internal market functioning, stimulate the economic growth of the region, and also increase the competitiveness of individual Member States and the entire EU on a global scale [60].

To assess the impact of VTS systems on the operation of TEN-T, the individual indicators were identified (Table 8). These indicators have been determined based on Article 4 of Regulation (EU) No. 1315/2013 [14], demonstrating the categories of the trans-European transport network objectives. Table 8 contains four main categories of TEN-T network activities: cohesion, efficiency, sustainability and increasing the benefits for its users, as well as component tasks in accordance with [14]. The authors assessed tasks within the particular categories and pointed out measures to reflect the scale of the VTS systems’ impacts on the implementation of the individual tasks. The following point scale was adopted:

- 0 points—no impact;
- 1 point—has an impact;
- 2 points—has a significant impact.

The assessment was carried out based on the author’s experience and materials provided by particular VTS systems managers. Each task was valued with awarded points. The obtained results made it possible to indicate the impact of particular VTS systems on the TEN-T.

On the basis of the assessment presented in Table 8, it can be assumed that the VTS Świnoujście–Szczecin system (with a slight advantage over the VTS Zatoka Gdańska system) has the greatest impact on the activities undertaken under Regulation (EU) No. 1315/2013 [14].

After summing up the impact of the VTS systems within individual categories, it is possible to distinguish eight tasks [14] on which the VTS systems have the greatest impact:

- The promotion of economically efficient, high-quality transport contributing to further economic growth and competitiveness;
- Efficient use of new and existing infrastructure;
- Cost-efficient application of innovative technological and operational concepts;
- Contribution to the objectives of low greenhouse gas emissions, low-carbon and clean transport, fuel security, reduction of external costs and environmental protection;
- Promotion of low-carbon transport with the aim of achieving by 2050 a significant reduction in CO₂ emissions, which is in line with the relevant EU CO₂ reduction targets;
- Ensuring safe, secure and high-quality standards for both passenger and freight transport;
- Supporting mobility, even in the event of natural or man-made disasters, and ensuring accessibility to emergency and rescue services;

- The establishment of infrastructure requirements, in particular, in the field of interoperability, safety and security, which will ensure quality, efficiency and sustainability of transport services.

Despite the fact that the area managed by VTS Ławica Słupska is not located within TEN-T transport corridors network, it was taken into account because it serves ships calling at ports that are the elements of mentioned network. Moreover, the area managed by VTS Ławica Słupska covers routes essential for short sea shipping. In the authors' opinion, this system also impacts the selected TEN-T tasks.

Table 8. Assessment of the VTS systems' impact on the implementation of individual TEN-T tasks (our own elaboration based on [14]).

Categories	Category Indicator (TEN-T Task)	VTS Zatoka Gdańska	VTS ** Ławica Słupska	VTS Świnoujście– Szczecin	Total
Cohesion	Accessibility and connectivity of all regions of the union	2	1	2	5
	Reduction of infrastructure quality gaps between member states	2	1	2	5
	Interconnection between transport infrastructure	1 *	0	2	3
	Possessing a transport infrastructure that reflects the specific situations in different parts of the EU	2	0	2	4
Efficiency	The removal of bottlenecks	2	0	2	4
	The interconnection and interoperability of national transport networks	2	1	2	5
	Optimal integration and interconnection of all transport modes	2	0	2	4
	The promotion of economically efficient, high-quality transport, contributing to further economic growth and competitiveness	2	2	2	6
	Efficient use of new and existing infrastructure	2	2	2	6
	Cost-efficient application of innovative technological and operational concepts	2	2	2	6
Sustainability	Development of all transport modes in a manner consistent with ensuring transport that is sustainable and economically efficient in the long term	2	0	2	4
	Contribution to the objectives of low greenhouse gas emissions, low-carbon and clean transport, fuel security, reduction of external costs and environmental protection	2	2	2	6
	Promotion of low-carbon transport with the aim of achieving by 2050 a significant reduction in CO ₂ emissions, which is in line with the relevant EU CO ₂ reduction targets	2	2	2	6

Table 8. Cont.

Categories	Category Indicator (TEN-T Task)	VTS Zatoka Gdańska	VTS ** Ławica Ślupska	VTS Świnoujście– Szczecin	Total
Increasing the benefits for its users	Meeting the mobility and transport needs of its users within the EU and in relations with third countries	2	0	2	4
	Ensuring safe, secure and high-quality standards for both passenger and freight transport	2	2	2	6
	Supporting mobility, even in the event of natural or man-made disasters, and ensuring accessibility to emergency and rescue services	2	2	2	6
	The establishment of infrastructure requirements, in particular in the fields of interoperability, safety and security, which will ensure quality, efficiency and sustainability of transport services	2	2	2	6
	Total points per VTS system	33	19	34	86

* The assessment took into account the integration of road/rail and maritime transport modes with European inland navigation. ** Indirect impact of VTS Ławica Ślupska on the TEN-T has been assessed, considering that the area managed by this system is not located within TEN-T transport corridors network.

4.7. Possibilities of Implementing the IMO Resolution Guidelines A.1158(32)

When considering the possibilities of implementing the IMO resolution [13], the basic differences between the two documents [1] and [13] should be indicated. Resolution [1] was implemented in 1997; all three described VTS systems have been adopted and applied the requirements contained in this document from the beginning of their existence and a work organization based on three defined services was implemented (see Section 1). The new resolution [13] entered into force on 15 December 2021; none of the Polish VTS systems have implemented it so far. The new resolution [13] in its provisions moves away from defining services in favor of actions and the need to develop scenarios of the occurrence of various situations that may pose a threat to ships, navigation and the natural environment. The new resolution does not define services but specifies a set of activities that should be taken to mitigate the development of dangerous situations [13].

The above-mentioned set of intended activities has been divided into three groups, each with its own purpose, as follows [13]:

1. Providing timely and relevant information on factors that may influence ship movements and assist onboard decision-making;
2. Monitoring and managing ship traffic to ensure the safety and efficiency of ship movements;
3. Responding to developing unsafe situations.

An assessment of the IMO Resolution Guidelines A.1158(32)'s current implementation by the analyzed VTS systems is presented in Table 9. The purposes (activities) assigned to the specific groups identified in Resolution [13] were evaluated. The authors assessed the particular activities performed by the VTS systems operating in Poland using the following measurements:

- YES—the activity is performed,
- NO—the activity is not performed,
- IN PART—the activity is performed in part.

Based on the results of assessment presented in Table 9, it can be concluded that the implementation of Resolution [13] for the three VTS systems should be as follows:

- In the case of the VTS Zatoka Gdańska system, it should not be difficult. The implementation of new rules will require formal changes and provisions in internal documents and operational procedures.
- In the case of the VTS Ławica Słupska system, even though most of the tasks are not currently being carried out, the adaptation of this VTS system to the new rules should not be a problem. The movement of ships in TSS VTS Ławica Słupska is based on the “free passage” principle for transit through the territorial sea, which is regulated by the international UNCLOS Convention [62]. The implementation of activities resulting from Resolution [13] will involve updating internal documents and procedures of particular VTS systems.
- In the case of the VTS Świnoujście–Szczecin system, there is the current lack of possibilities to support vessels in dangerous situations with navigational assistance. Nowadays, due to the configuration and parameters of the fairway, as well as the capabilities of the navigation systems, the Maritime Office in Szczecin does not introduce such a service. Lack of vessel traffic support by this type of service is compensated by introduction of mandatory pilotage service on the approach to Świnoujście port and within the Świnoujście–Szczecin fairway.

Table 9. Assessment of the IMO Resolution Guidelines A.1158(32)’s current implementation of particular purposes by the analyzed VTS systems [own elaboration based on [13]].

Group of VTS Systems Purposes	Purpose Assigned to the Specific Group	VTS Zatoka Gdańska	VTS Ławica Słupska	VTS Świnoujście – Szczecin	Comments
1. Providing timely and relevant information on factors that may influence ship movements and assist onboard decision-making, including the following:	1.1. Position, identity, intention and movements of ships	YES	YES	YES	• In the analyzed VTS systems, this activity is carried out under the currently provided services
	1.2. Maritime safety information	YES	YES	YES	• In the analyzed VTS systems this activity is carried out under the currently provided services
	1.3. Limitations of ships in the VTS area that may impose restrictions on the navigation of other ships	YES	NO	YES	• In VTS Zatoka Gdańska and VTS Świnoujście–Szczecin, this activity is carried out under the currently provided services • In VTS Ławica Słupska, no action is required due to the system configuration
	1.4. Other information such as reporting formalities and ISPS code details	YES	YES	YES	• In the analyzed VTS systems, this activity is carried out under the currently provided services
	1.5. Support for, and cooperation with, allied services	YES	YES	YES	• In the analyzed VTS systems, this activity is carried out under the currently provided services

Table 9. Cont.

Group of VTS Systems Purposes	Purpose Assigned to the Specific Group	VTS Zatoka Gdańska	VTS Ławica Słupska	VTS Świnoujście – Szczecin	Comments
2. Monitoring and managing ship traffic to ensure the safety and efficiency of ship movements, including the following:	2.1. Planning ship movements in advance	YES	NO	YES	- In VTS Zatoka Gdańska and VTS Świnoujście–Szczecin this activity is carried out under the currently provided services - In VTS Ławica Słupska, no action required due to the system configuration
	2.2. Organizing ships under way	YES	NO	YES	- In VTS Zatoka Gdańska and VTS Świnoujście–Szczecin, this activity is carried out under the currently provided services, - In VTS Ławica Słupska, no action is required due to the system configuration
	2.3. Organizing space allocation	YES	NO	YES	- In VTS Zatoka Gdańska and VTS Świnoujście–Szczecin, this activity is carried out under the currently provided services - In VTS Ławica Słupska, no action is required due to the system configuration
	2.4. Establishing a system of traffic clearances	YES	NO	YES	- In VTS Zatoka Gdańska and VTS Świnoujście–Szczecin, this activity is carried out under the currently provided services, - In VTS Ławica Słupska, no action is required due to the system configuration
	2.5. Establishing a system of voyage or passage plans	YES	NO	YES	- In VTS Zatoka Gdańska and VTS Świnoujście–Szczecin, this activity is carried out under the currently provided services - In VTS Ławica Słupska, no action is required due to the system configuration

Table 9. Cont.

Group of VTS Systems Purposes	Purpose Assigned to the Specific Group	VTS Zatoka Gdańska	VTS Ławica Słupska	VTS Świnoujście – Szczecin	Comments
2. Monitoring and managing ship traffic to ensure the safety and efficiency of ship movements, including the following:	2.6. Providing route advice	YES	NO	YES	- In VTS Zatoka Gdańska and VTS Świnoujście–Szczecin, this activity is carried out under the currently provided services - In VTS Ławica Słupska, no action is required due to the system configuration
	2.7. Ensuring compliance with and enforcement of regulatory provisions for which they are empowered	YES	NO	YES	- In VTS Zatoka Gdańska and VTS Świnoujście–Szczecin, this activity is carried out under the currently provided services - In VTS Ławica Słupska, no action is required due to the system configuration
3. Responding to developing unsafe situations, including the following:	3.1. A ship unsure of its route or position	YES	NO	IN PART	- In VTS Zatoka Gdańska, this activity is carried out under the currently provided services - In VTS Ławica Słupska, no action is required due to system configuration - In VTS Świnoujście–Szczecin, this activity is performed partly due to the lack of navigational assistance
	3.2. A ship deviating from the route	YES	NO	IN PART	- In VTS Zatoka Gdańska, this activity is carried out under currently provided services - In VTS Ławica Słupska, no action is required due to the system configuration - In VTS Świnoujście–Szczecin, this activity is performed partly due to the lack of navigational assistance
	3.3. A ship requiring guidance to an anchoring position	YES	NO	IN PART	- In VTS Zatoka Gdańska, this activity is carried out under currently provided services - In VTS Ławica Słupska, no action is required due to the system configuration - In VTS Świnoujście–Szczecin, this activity is performed partly due to the lack of navigational assistance

Table 9. Cont.

Group of VTS Systems Purposes	Purpose Assigned to the Specific Group	VTS Zatoka Gdańska	VTS Ławica Słupska	VTS Świnoujście – Szczecin	Comments
3. Responding to developing unsafe situations, including the following:	3.4. A ship that has defects or deficiencies, such as navigation or maneuvering equipment failure	YES	NO	IN PART	• In VTS Zatoka Gdańska, this activity is carried out under currently provided services • In VTS Ławica Słupska no action is required due to the system configuration • In VTS Świnoujście-Szczecin, this activity is performed partly due to the lack of navigational assistance
	3.5. Severe meteorological conditions	YES	NO	IN PART	• In VTS Zatoka Gdańska, this activity is carried out under currently provided services • In VTS Ławica Słupska no action is required due to the system configuration • In VTS Świnoujście-Szczecin, this activity is performed partly due to the lack of navigational assistance
	3.6. A ship at risk of grounding or collision	YES	NO	IN PART	• In VTS Zatoka Gdańska, this activity is carried out under currently provided services • In VTS Ławica Słupska, no action is required due to the system configuration • In VTS Świnoujście-Szczecin, this activity is performed partly due to the lack of navigational assistance
	3.7. Emergency response or support for emergency services	YES	NO	IN PART	• In VTS Zatoka Gdańska this activity is carried out under currently provided services • In VTS Ławica Słupska, no action is required due to the system configuration • In VTS Świnoujście-Szczecin, this activity is performed partly due to the lack of navigational assistance

5. Discussion

To summarize the abovementioned considerations, Table 10 was developed, showing the level of difficulty in implementing the provisions of the analyzed regulations introduced by the IMO [13] and European Parliament [14]. The following values were used for the assessment:

- 3—indicated considerable difficulty in performing functions or implementing changes;
- 2—indicated medium difficulty in performing functions or implementing changes;
- 1—indicated low difficulty in performing set functions or implementing changes.

Table 10. Assessment of the level of difficulty in implementing the provisions under review.

Analyzed Regulations	VTS Zatoka Gdańska	VTS Ławica Słupska	VTS Świnoujście–Szczecin
Regulation (EU) No. 1315/2013	1	Not considered	2
Resolution A.1158(32)	1	3	3
Total points per VTS	2	3	5

The assessment was carried out based on the authors' knowledge and experience. Among the analyzed VTS systems, the VTS Świnoujście–Szczecin system is by far the least susceptible to the implementation and realization of changes. This is due to the complexity of decision-making processes, location, parameters of the fairway, whose sensitivity to hydrometeorological factors and the occurrence of “bottlenecks” have an impact on the disruption of ship traffic and, consequently, on navigation safety. On the other hand, the VTS Świnoujście–Szczecin has the great impact on shaping vessel traffic safety and efficiency.

It should be noted that presented research has a number of limitations:

1. The provided assessments show the authors' opinion on investigated issues, based on their knowledge and experience. In future research studies, the involvement of greater number of experts will be essential.
2. Seven criteria were identified for the comparative analysis of the operation of the VTS systems. However, this limited number of criteria may impact the reliability of achieved results. Increasing the number of assessment criteria may be considered by authors when conducting future studies.
3. While assessing the adjustment of the VTS systems operating in Poland to current regulations introduced by the IMO and European Parliament, two documents were analyzed. Selection of other EU regulations for the detailed analysis will be taken into account by authors in their future work.
4. The assessment of risks related to vessel traffic in the area covered by the VTS systems was based only on the calculation of the probability of collisions related to default causation factors. More detailed analysis of vessel traffic risks is planned.
5. The AIS data collected for the period 01.01.2021. to 30.09.2021. was used to analyze the probability of collision at each section of the described VTS systems. Repeating the study using year-round data can give a better overview of current changes in shipping safety in the areas managed by the VTS systems.
6. The research study focuses on the assessment of VTS systems operating in Poland. Therefore, the comparative analysis of VTS systems operating in Poland and other countries will be considered.

6. Conclusions

The article presents the comparative analysis and evaluation of three VTS systems operated in Poland. The review and assessment of the adjustment of the VTS systems operating in Poland to current regulations introduced by the IMO and European Parliament was carried out.

Based on the conducted research results, it can be stated that the examined VTS systems' current adjustment to the analyzed regulations is different depending on each system's configuration and possessed infrastructure, parameters of fairways, traffic regulations and other criteria.

Recommendations to improve the VTS systems operated in Poland in relation to the chosen areas are presented in Table 11. These recommendations reflect current trends in maritime operations, including the need of autonomous units service, digitization of maritime traffic management and sustainability. The most susceptible and possible improvements of the operation of the VTS systems seem to be within the following:

- Decision-making processes related to traffic management,
- The framework of cooperation with allied services providers.

Table 11. Recommendations to improve the VTS systems.

Area	Recommendations
Traffic management improvement	• Implementation of self-learning real-time risk assessment systems that operate in 'long-term planning', 'near real-time' and 'real-time' modes. • Implementation of systems for the analysis of hydrometeorological data, considering hydrometeorological parameters and historical vessel traffic data, which supports the 'long-term planning mode' by analyzing future traffic and conditions. • Providing VTS operators with tools to better manage routes and traffic through long-term analysis and real-time monitoring.
Reduction of risks related to vessel traffic in the areas covered by the VTS systems	• Implement systems that identify potential hazards in near real-time to assist VTS operators in detecting non-compliance and making decisions. • Enabling more effective incident management in a 'real-time' mode that focuses on immediate response to emergencies. • Integration of analytical systems with other process participants, including automatic report generation that supports a 'long-term planning' mode.
Better collaboration with allied services providers	• Improved diagnosis of information circulation and decision-making processes between participants and decision-makers of a ship's visit to a port, which is particularly relevant in the 'long-term planning' and 'near real-time mode'. • Integration of analytical systems within 'long-term planning', 'near real-time' and 'real-time' modes. • Decision support for VTS operators with advanced, dedicated applications that can operate in all three modes.
Adjusting VTS systems to TEN-T requirements	• Continued research on the effectiveness and reliability of new technologies. • Regular evaluation of the implemented systems in terms of their effectiveness in improving the safety and efficiency of navigation. • Adapting systems to changing regulatory and technological requirements, with particular emphasis on the operational modes indicated by IALA G1111-1 [63].

Considering the results of the comparative analysis, it can be assumed that the proposed recommendations will mostly concern the VTS Świnoujście-Szczecin. In order to increase both efficiency and feasibility of the operation of VTS systems, it is necessary to consider changes and improvements in individual components and features of the VTS systems. However, some of these features are not amenable to change, e.g., fairway parameters, location and internal and external conditions (as described in this article).

As far as allied services are concerned, improvements will consist of a diagnosis of the information flows and decision-making processes between all participants and decision-

makers influencing a ship's visit to a port. This task will be analyzed by authors in their next publications.

Regarding traffic management issues, a study of information flows will also be undertaken. At this stage of the research, the necessity for decision support for VTS operators, with an advanced dedicated application, can be established.

Among the factors affecting traffic management, one of the most important are weather conditions. These conditions, and in fact the effective management of hydrometeorological information, can have a significant impact on improving port availability and decision-making processes. Better management of hydrometeorological information can follow the introduction of mathematical weather models for use by the VTS operators, replacing the numerical forecasts offered so far by the state provider. This issue will be subjected to a research process, especially regarding possible risks related to the reliability of the mathematical models used.

Future research activity by the authors will focus on the analysis of risk factors related to decision-making process and their impact on traffic planning for vessels within the Świnoujście–Szczecin Fairway.

Research results may be of interest to managers of maritime administration, port authorities and other decision-makers responsible for the safe navigation of vessels and traffic management.

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References

1. Resolution A.857(20) Adopted on 27 November 1997 Guidelines for Vessel Traffic Services. International Maritime Organization, London. Available online: [https://www.wcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/AssemblyDocuments/A.857\(20\).pdf](https://www.wcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/AssemblyDocuments/A.857(20).pdf) (accessed on 15 April 2024).
2. International Convention for the Safety of Life at Sea (SOLAS), International Maritime Organization, London. 1974. Available online: <https://www.imo.org/en/KnowledgeCentre/ConferencesMeetings/Pages/SOLAS.aspx> (accessed on 10 April 2024).
3. IALA VTS Manual Edition 8.4 (June 2024). Available online: <https://www.iala-aism.org/product/m0002/> (accessed on 4 June 2024).
4. Jacyna, M.; Wasiak, M.; Lewczuk, K.; Chamier-Gliszczyński, N.; Dąbrowski, T. Decision problems in developing proecological transport system. *Rocz. Ochr. Środowiska* **2018**, *20*, 1007–1025.
5. Gołębiowski, P.; Żak, J.; Jacyna-Gołda, I. Approach to the Proecological Distribution of the Traffic Flow on the Transport Network from the Point of View of Carbon Dioxide. *Sustainability* **2020**, *12*, 6936. [CrossRef]
6. Zabielska, A.; Jacyna, M.; Lasota, M.; Nehring, K. Evaluation of the efficiency of the delivery process in the technical object of transport infrastructure with the application of a simulation model. *Ekspluat. I Niezawodn. Maint. Reliab.* **2023**, *25*, 1. [CrossRef]

7. Ordinance No. 3 of the Director of the Maritime Office in Gdynia of April 28, 2008. (In Polish)
8. Ordinance No. 4 of the Director of the Maritime Office in Gdynia of May 24, 2021, on amendments to the area of activity and tasks of the Vessel Traffic Services VTS Slupsk Bank. (In Polish)
9. Port Regulations (2013) Ordinance No. 3 of the Director of the Maritime Office in Szczecin of July 26, 2013, Port Regulations. Available online: https://www.ums.gov.pl/po/2013/Zarz_3_2013.pdf (accessed on 10 April 2024).
10. Act of 21 March 1991 on Maritime Areas of the Republic of Poland and Maritime Administration (Dz.U. 1991 nr 32 poz. 131). Available online: <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU19910320131> (accessed on 11 April 2024). (In Polish)
11. VTS system software, managed by Maritime Office in Szczecin, Poland. 2024.
12. National Maritime Safety System Stage I. Available online: https://www.umgdy.gov.pl/fundusz_europejski/krajowy-system-bezpieczenstwa-morskiego-ksbm-etap-i/ (accessed on 20 May 2024).
13. Resolution A.1158(32) Adopted on 15 December 2021 (Agenda Item 12) Guidelines for Vessel Traffic Services, International Maritime Organization, London. Available online: [https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/AssemblyDocuments/A.1158\(32\).pdf](https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/AssemblyDocuments/A.1158(32).pdf) (accessed on 20 May 2024).
14. Regulation (EU) No 1315/2013 Of the European Parliament and of the Council of 11 December 2013 on Union Guidelines for the Development of the Trans-European Transport Network and Repealing Decision No 661/2010/EU Text with EEA Relevance. Available online: http://publications.europa.eu/resource/cellar/f277232a-699e-11e3-8e4e-01aa75ed71a1.0006.03/DOC_1 (accessed on 20 May 2024).
15. Cheng, X.; Sui, Z.; Wen, Y.; Han, D. An improved maritime traffic situation complexity model for intelligent maritime management in the inland ferry area. *Comput. Electr. Eng.* **2024**, *119*, 109612. [CrossRef]
16. Ekici, C.V.; Öztürk, Ü.; Şenol, Y.E. A data-driven Ship Risk Profile model for Turkish Straits (TS-SRP) using Machine Learning. *Ocean. Eng.* **2024**, *311*, 119002. [CrossRef]
17. Belcore, O.M.; Polimeni, A.; Di Gangi, M. Performance analysis for a maritime port with high-frequency services: An Italian case study. *Case Stud. Transp. Policy* **2024**, *17*, 101263. [CrossRef]
18. Jankowski, D.; Möller, J.; Wiards, H.; Hahn, A. Decentralized Documentation of Maritime Traffic Incidents to Support Conflict Resolution. *J. Mar. Sci. Eng.* **2022**, *10*, 2011. [CrossRef]
19. Formela, K.; Neumann, T.; Weintrit, A. Overview of definitions of maritime safety, safety at sea, navigational safety and safety in general. *TransNav* **2019**, *13*, 285–290. [CrossRef]
20. Neumann, T. Development of ICT networks in maritime transport applications. *Adv. Marit. Technol. Eng.* **2024**, *1*, 61–69. [CrossRef]
21. Szcześniak, J.; Weintrit, A. Europejskie systemy kontroli i śledzenia ruchu statków—geneza, zasady funkcjonowania oraz perspektywy rozwoju. *Zesz. Nauk. Akad. Morskiej W W Gdyni* **2012**, *77*, 78–92. Available online: <https://sj.umg.edu.pl/sites/default/files/ZN183.pdf> (accessed on 24 November 2024). (In Polish).
22. Czermański, E.; Zaucha, J.; Oniszcuk-Jastrząbek, A.; Pardus, J.; Kiersztyn, A.; Czerwiński, D. Valuation of marine areas for merchant shipping: An attempt at shipping spatial rent valuation based on Polish Marine Areas. *Front. Mar. Sci.* **2024**, *11*, 1352598. [CrossRef]
23. Paulauskas, V.; Filina-Dawidowicz, L.; Paulauskas, D. Navigation of Ships in Channel Bends under Special Conditions Using Sensors Systems. *Sensors* **2022**, *22*, 8783. [CrossRef] [PubMed]
24. Czaplewski, K.; Świerczyński, S. A Method of Increasing the Accuracy of Radar Distance Measurement in VTS Systems for Vessels with Very Large Dimensions. *Remote Sens.* **2021**, *13*, 3066. [CrossRef]
25. Janković, P.; Murtić, S.; Zorko, A. Water Traffic Management Systems in Ports for Logistics and Seaport Services. In *Sustainable Business Management and Digital Transformation: Challenges and Opportunities in the Post-COVID Era, Proceedings of the SymOrg 2022, Belgrade, Serbia, 11–14 June 2022*; Lecture Notes in Networks and Systems; Mihić, M., Jednak, S., Savić, G., Eds.; Springer: Cham, Switzerland, 2023; Volume 562. [CrossRef]
26. Heikkilä, M.; Himmanen, H.; Soininen, O.; Sonninen, S.; Heikkilä, J. Navigating the Future: Developing Smart Fairways for Enhanced Maritime Safety and Efficiency. *J. Mar. Sci. Eng.* **2024**, *12*, 324. [CrossRef]
27. Çağlayan, Ö.; Aymelek, M. An Integrated Multi-Criteria Decision Support Model for Sustainable Ship Queuing Policy Application via Vessel Traffic Service (VTS). *Sustainability* **2024**, *16*, 4615. [CrossRef]
28. Hsieh, M.-H.; Xia, Z.; Chen, C.-H. Human-centred design and evaluation to enhance safety of maritime systems: A systematic review. *Ocean. Eng.* **2024**, *307*, 118200. [CrossRef]
29. Crestelo Moreno, F.; Soto-López, V.; Menéndez-Teleña, D.; Roca-González, J.; Suardiáz Muro, J.; Rocas, C.; Paíno, M.; Fernández, I.; Díaz-Secades, L.A. Fatigue as a key human factor in complex sociotechnical systems: Vessel Traffic Services. *Front. Public Health* **2023**, *11*, 1160971. [CrossRef]
30. Carson-Jackson, J.; Fiorini, M.; Galloro, M. Educational Approaches for Personnel in Vessel Traffic Services. In *Proceedings of the 2023 IEEE 10th International Workshop on Metrology for AeroSpace (MetroAeroSpace)*, Milan, Italy, 19–21 June 2023; pp. 568–573. [CrossRef]

31. Zhang, F.; Liu, Y.; Du, L.; Goerlandt, F.; Sui, Z.; Wen, Y. A rule-based maritime traffic situation complex network approach for enhancing situation awareness of vessel traffic service operators. *Ocean. Eng.* **2023**, *284*, 115203. [CrossRef]
32. Praetorius, G. Vessel Traffic Service (VTS): A maritime information service or traffic control system? Understanding everyday performance and resilience in a socio-technical system under change. Ph.D. Thesis, Department of Shipping and Marine Technology, Chalmers University Of Technology, Gothenburg, Sweden, 2014. Available online: https://www.researchgate.net/publication/265611557_Vessel_Traffic_Service_VTS_a_maritime_information_service_or_traffic_control_system_Understanding_everyday_performance_and_resilience_in_a_socio-technical_system_under_change (accessed on 20 October 2024).
33. Nikghadam, S.; Vanga, R.; Rezaei, J.; Tavasszy, L. Cooperation between vessel service providers in ports: An impact analysis using simulation for the Port of Rotterdam. *Marit. Transp. Res.* **2023**, *4*, 100083. [CrossRef]
34. Arslan, E.; Nas, S. Conflicts Encountered with Bridge Team from the Perspective of Vessel Traffic Service Operators: A Research Within E-Navigation Concept. *Trans. Marit. Sci.* **2022**, *11*, 247–259. [CrossRef]
35. Malagoli, A.; Corradini, M.; Corradini, P.; Shuett, T.; Fonda, S. Towards a method for the objective assessment of cognitive workload: A pilot study in vessel traffic service (VTS) of maritime domain. In Proceedings of the 2017 IEEE 3rd International Forum on Research and Technologies for Society and Industry (RTSI), Modena, Italy, 11–13 September 2017; pp. 1–6. [CrossRef]
36. Hasanspahić, N.; Frančić, V.; Vujičić, S.; Mandušić, M. Safety leadership as a means for safe and sustainable shipping. *Sustainability* **2021**, *13*, 7841. [CrossRef]
37. Krystosik-Gromadzińska, A. Ergonomic assessment of selected workstations on a merchant ship. *Int. J. Occup. Saf. Ergon.* **2018**, *24*, 91–99. [CrossRef] [PubMed]
38. Crestelo Moreno, F.; Roca Gonzalez, J.; Suardiáz Muro, J.; García Maza, J.A. Relationship between human factors and a safe performance of vessel traffic service operators: A systematic qualitative-based review in maritime safety. *Saf. Sci.* **2022**, *155*, 105892. [CrossRef]
39. Fan, S.; Zhang, J.; Blanco-Davis, E.; Yang, Z.; Yan, X. Maritime accident prevention strategy formulation from a human factor perspective using Bayesian Networks and TOPSIS. *Ocean. Eng.* **2020**, *210*, 107544. [CrossRef]
40. Luling, Z.; Zhengxiong, J.; Lvzhen, R.; Xingfeng, D. Economic Evaluation of Vessel Traffic Service (VTS) Based on Survey Data and I.O. Analysis. *Am. J. Traffic Transp. Eng.* **2021**, *6*, 139–146. [CrossRef]
41. Filina-Dawidowicz, L.; Durczak, W. Decision-making issues in vessels traffic planning after the deepening of the Świnoujście—Szczecin fairway to 12.5 m. In Proceedings of the 40th International Business Information Management Association (IBIMA), Seville, Spain, 23–24 November 2022; pp. 539–549.
42. Lee, S.; Lee, C.; Kim, G.; Na, H.; Kim, H.; Lee, J.; Park, M. A study of S-100 based product specifications from a software implementation point of view: Focusing on data model representation, similar features and symbols, and ECDIS and VTS software. *J. Navig.* **2022**, *75*, 1226–1242. [CrossRef]
43. Torok, A.; Semenov, I.; Filina-Dawidowicz, L.; Durczak, W. The Impact of Information Distortions on Decision-Making: A Case Study in Land–Sea Transport Chain Planning. *Sustainability* **2024**, *16*, 5568. [CrossRef]
44. Gucma, S.; Gralak, R.; Jesion, P.; Łempicki, M.; Przywarty, M. Analiza bezpieczeństwa eksploatacji statków na przebudowanym torze wodnym Świnoujście—Szczecin. *Inżynieria Morska I Geotech.* **2021**, *6*, 230–236. (In Polish)
45. Mandal, S.; Nagarajan, V.; Sha, O.P. Navigational safety and traffic pattern analysis using AIS data on the western coast of India. *Curr. Sci.* **2018**, *114*, 2473–2481. Available online: <https://www.jstor.org/stable/26495760> (accessed on 20 October 2024). [CrossRef]
46. Liu, C.; Liu, J.; Zhou, X.; Zhao, Z.; Wan, C.; Liu, Z. AIS data-driven approach to estimate navigable capacity of busy waterways focusing on ships entering and leaving port. *Ocean. Eng.* **2020**, *218*, 108215. [CrossRef]
47. Zhang, Z.G.; Yin, J.C.; Wang, N.N.; Hui, Z.G. Vessel traffic flow analysis and prediction by an improved PSO-BP mechanism based on AIS data. *Evol. Syst.* **2019**, *10*, 397–407. [CrossRef]
48. Filina-Dawidowicz, L.; Durczak, W. Organization of Vessel Traffic on Dredged Świnoujście-Szczecin Fairway: VTS Operators' Viewpoint on the Use of Infrastructure for Ships Passing. *Eur. Res. Stud. J.* **2023**, *XXVI*, 152–169. [CrossRef]
49. Filina-Dawidowicz, L.; Durczak, W. Factors Influencing Vessel Traffic Organization during the Dredging Works on Świnoujście-Szczecin Fairway. In *Transport Means, Proceedings of the 27th International Scientific Conference, Palanga, Lithuania, 4–6 October 2023*; Kaunas University of Technology: Kaunas, Lithuania, 2023; pp. 662–667. [CrossRef]
50. Xiao, Z.; Fu, X.; Zhao, L.; Zhang, L.; Teo, T.K.; Li, N.; Zhang, W.; Qin, Z. Next-Generation Vessel Traffic Services Systems—From “Passive” to “Proactive”. *IEEE Intell. Transp. Syst. Mag.* **2023**, *15*, 363–377. [CrossRef]
51. Zhang, X.; Li, J.; Zhu, S.; Wang, C. Vessel intelligent transportation maritime service portfolios in port areas under e-navigation framework. *J. Mar. Sci. Technol.* **2020**, *25*, 1296–1307. [CrossRef]
52. International Maritime Organization, London. Resolution Msc.249(83), Adoption of a New Mandatory Ship Reporting System on the Approaches to the Polish Ports in the Gulf of Gdańsk (Adopted on 8 October 2007). International Maritime Organization, London. Available online: <https://www.umgdy.gov.pl/wp-content/uploads/2022/01/IRM-IMO-MSC.24983-VTS-Zatoka-Gdanska.pdf> (accessed on 10 April 2024).

53. Maritime Office in Gdynia. Available online: <https://www.umgdy.gov.pl/bezpieczenstwo-morskie> (accessed on 20 October 2024).
54. Maritime Office in Szczecin. Available online: <https://www.ums.gov.pl/bezpieczenstwo-morskie/vessel-traffic-en> (accessed on 20 October 2024).
55. Maritime Office in Gdynia, internal data. 2022. (In Polish)
56. Maritime Office in Szczecin, internal data. 2022. (In Polish)
57. IWRAP MK II application, license Maritime Office in Szczecin. 2024.
58. G1123 The Use of IALA Waterway Risk Assessment Program (IWRAP) Edition 2.1. June 2022; urn:mrn:iala:pub:g1123:ed2.1. Available online: https://www.iala.int/content/uploads/2021/08/Course-outline-IWRAP-MK-II_July-2021.pdf (accessed on 20 October 2024).
59. Resolution A.1106(29) Adopted on 2 December 2015 (Agenda item 10). International Maritime Organization, London. Available online: [https://www.wcdn.imo.org/localresources/en/OurWork/Safety/Documents/AIS/Resolution%20A.1106\(29\).pdf](https://www.wcdn.imo.org/localresources/en/OurWork/Safety/Documents/AIS/Resolution%20A.1106(29).pdf) (accessed on 20 October 2024).
60. Ministry of Infrastructure of the Republic of Poland. Available online: <https://www.gov.pl/web/infrastruktura/transeuropejska-siec-transportowa-ten-t> (accessed on 15 August 2024).
61. European Commission. Trans-European Transport Network (TEN-T). Available online: https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en (accessed on 25 November 2024).
62. United Nations. Available online: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf (accessed on 25 November 2024).
63. G1111-1 Producing requirements for the core VTS system. Edition 1.0, December 2022, urn:mrn:iala:pub:g1111-1:ed1.0. Available online: <https://www.iala.int/product/g1111-1/pdf> (accessed on 25 November 2024).

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