

INTENSITY OF MARITIME TRAFFIC ON THE KOŁOBRZEG-BORNHOLM ROUTE AND SAFETY OF NAVIGATION: RISK ANALYSIS AND RECOMMENDATIONS

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Purpose: The objective of the study was to analyse the intensity and structure of maritime traffic on the Kołobrzeg–Bornholm route and to identify areas of increased navigational risk.

Design/methodology/approach: AIS data and HELCOM accident records from 2004 to 2023 were used. The analysis was carried out using the IALA IWRAP Mk2 tool, based on the Formal Safety Assessment (FSA) methodology, taking into account risk matrices and elements of the logic tree method.

Findings: Clear differences in traffic intensity were identified on three sections (LEG 9-11). The highest traffic load occurs in LEG 11 (over 5500 vessels, mainly cargo ships and tankers). LEG 10 serves as a transit route, while LEG 9 serves as a local route. The areas with the highest traffic coincide with the locations of historical maritime accidents. The results are presented in the form of intensity matrices and heat maps.

Research limitations/implications: The study does not include an analysis of the costs of the proposed solutions or the legal issues related to their implementation, which limits the possibility of a full assessment of the feasibility of the recommendations. Technical risks, such as navigation system disruptions, and the perspective of local stakeholders, which is important for the practical implementation of the changes, have also been omitted.

Practical implications: The results obtained may support the decisions of maritime authorities and safety system operators. It is recommended to implement a VTS system, TSS plans and improve traffic organisation in the Kołobrzeg port area.

Social implications: The proposed measures may increase navigation safety, environmental protection and reduce the number of accidents, especially in the recreational and passenger sectors. The study also supports the concept of sustainable maritime transport.

Originality/value: The study integrates AIS and HELCOM data and the FSA approach for a specific region of the Baltic Sea. It is one of the few studies on the Kołobrzeg–Bornholm route and may be useful for decision-makers and the scientific community involved in maritime safety.

Keywords: AIS, navigational safety, maritime risk assessment, Formal Safety Assessment, risk matrix, logical tree method.

Category of the paper: Research paper.

1. Introduction

The South Baltic region, which includes the Pomeranian Bay, the island of Bornholm and the Polish coast with the port of Kołobrzeg, is an important shipping hub for both cargo and passenger shipping. The busy pattern of shipping routes in the region indicates a high level of traffic intensity - especially in the area between Bornholm and the coast of Central Pomerania. A significant proportion of this traffic is generated by the international ferry connection between Kołobrzeg and the port of Nexø on Bornholm, which has not only a transport function, but also a tourist and economic function.

Data from the Kolobrzeg Seaport Master Plan shows that already in 2018, approximately 30,000 passengers used the Kolobrzeg-Bornholm ferry connection (Master Plan ZPM v.3.0). This figure shows that the route is in high demand, with the port of Kolobrzeg playing an important role in the connections to Denmark and Scandinavia. In addition to simply transporting passengers, this route is also important for the development of tourism, trade and interregional cooperation.

The aim of this study is to identify the structure and intensity of maritime traffic on the Kołobrzeg–Bornholm route and to indicate areas of increased navigational risk. The study is based on an analysis of AIS data and HELCOM marine accident records from 2004 to 2023, using the IALA IWRAP Mk2 tool. The methodology is embedded in the Formal Safety Assessment (FSA) framework, and the results obtained were evaluated using a risk matrix and decision tree elements.

The main research hypothesis assumes that the greatest threats to navigation safety in the study area occur in areas with the highest traffic density and where local routes intersect with international shipping lanes. The specific objective is to indicate whether the current traffic organisation requires systemic intervention (e.g. in the form of VTS or TSS).

The planned expansion of Kolobrzeg's port infrastructure, including the construction of a modern ferry terminal with logistics facilities and parking spaces, is intended to further increase the capacity of this route and improve the quality of passenger service (Master Plan ZPM v.3.0). In addition to its transport function, the terminal is also intended to integrate cultural and tourist functions, acting as a natural barrier separating the transshipment part from the spa and resort part.

Taking into account analyses of vessel traffic at sea and planned investments, it can be concluded with high probability that the intensity of shipping in the area will continue to increase. Ensuring navigational safety, protecting the marine environment and further developing the infrastructure to handle the growing number of vessels and passengers therefore remains a key challenge. The remainder of this article will examine in more detail the traffic structure, the impact of the Kolobrzeg-Bornholm connection on the region and the prospects for its development.

Despite the growing importance of maritime transport in the southern Baltic Sea region, previous studies have focused mainly on major transit routes and ports in large agglomerations. There is a lack of detailed analyses of smaller but heavily used local routes, such as Kołobrzeg–Bornholm, particularly taking into account AIS operational data, local conditions and risk analysis.

According to the available literature, no studies have been found that directly address the assessment of navigation safety on this specific route using the FSA methodology and IWRAP tools. This study therefore fills an important research gap and provides both practical and scientific value, serving as a basis for further operational analysis and maritime traffic management decisions.

2. Literature review and safety standards

2.1. Maritime incidents and case studies

A study by Goerlandt and co-workers analysed 45 marine incidents during the winter season in the North Baltic area. The findings indicate that collisions are particularly common in convoy navigation situations involving icebreakers, where deteriorating manoeuvring conditions and reduced visibility increase the likelihood of bow collisions (Goerlandt et al., 2017).

In turn, the MIMIC project analysis shows that in addition to typical maritime accidents, the region is also exposed to threats of an asymmetric nature, including acts of infrastructure sabotage, cyber attacks or illegal discharges of dangerous cargo. Although the risk of classic piracy is assessed as low, the Baltic should be treated as an area of high vulnerability to critical infrastructure disruption incidents (Fransas et al., 2013; Tuominen, 2013).

Statistical studies (Usewicz, 2018) and expert assessments confirm that human error, technological limitations (e.g. faulty AIS data or outdated electronic charts) and the complexity of the navigational situation are the main determinants of incidents, even in seemingly routine coastal routes.

2.2. Risk assessment models and methods

In analytical practice in the Baltic, the FSA (Formal Safety Assessment), recommended by the IMO, is most commonly used. It consists of five steps: hazard identification, risk analysis, assessment of mitigation actions, cost-benefit analysis and formulation of recommendations (IMO, 2015; Shin, 2019).

For the quantitative assessment of the risk of collision and shoaling, the IWRAP Mk2 model developed by IALA is a particularly useful tool. This programme estimates the probability of incidents based on AIS data and the trajectories of vessels in designated shipping corridors.

Its application in the Baltic region allows for an accurate mapping of the risk profile and the identification of critical points (Szubrycht, 2020; IALA, 2012).

Non-standard risk analyses (e.g. sabotage, criminal activity), on the other hand, used the three-stage 'threat-vulnerability-consequence' model developed in the MIMIC project. This model combines the assessment of threat credibility, target vulnerability and possible consequences, offering a flexible approach to hybrid risk (Tuominen, 2013).

2.3. Research methodology

The aim of this study was to investigate the intensity and structure of maritime traffic in the South Baltic, with a focus on the Kolobrzeg-Nexo (Bornholm) ferry route and its shipping environment. The study was carried out according to the following steps shown in Figure 1.

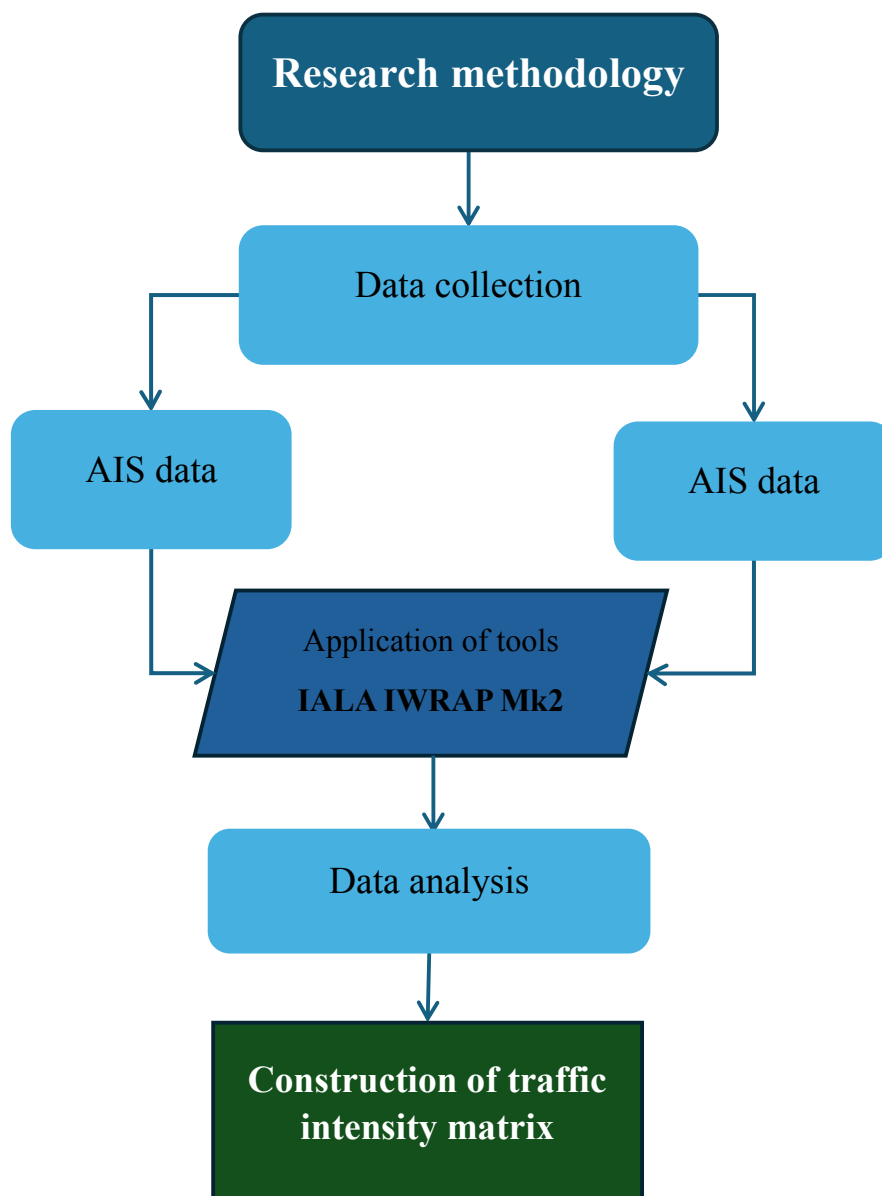


Figure1. Stages of traffic intensity analysis.

Source: own elaboration.

The primary source of data was the AIS (Automatic Identification System), an automatic vessel identification system that allows the position, course, speed, vessel type and its technical parameters (length, draught, (IMO) type) to be tracked in real time. AIS data was obtained from publicly available databases, as well as in cooperation with maritime institutions and maritime surveillance system operators.

Complementary data from Maritime Authorities were used on port classification, vessel assignment to specific routes and seasonal characteristics of traffic in the analysed basin.

All registered vessels were assigned to one of six categories:

- freighters (cargo) - vessels transporting bulk and general cargo,
- ferries - mainly passenger-car ferries, including the Kołobrzeg-Nexo ferry,
- fishing boats - vessels active in the coastal strip,
- recreational craft - smaller motor boats and sailing boats,
- yachts - sailboats registered in Baltic ports and visiting Kolobrzeg,
- passenger vessels - larger units serving tourist traffic.

For data analysis, the tool used was **IALA IWRAP Mk2** (Interactive Web-based Review and Analysis Platform), which allows:

- loading and filtering large AIS data sets,
- visualisation of traffic intensity over a given time and spatial interval,
- classification of units by type and technical parameters,
- export of heat maps and charts for further analysis and presentation of results.

Thanks to these functionalities, it was possible to present both an overall picture of maritime traffic and detailed trends in ferry and fishing traffic in the analysed area.

Based on the collected data, a traffic intensity matrix was developed, showing the number of units crossing specific sectors of the geographical grid (grids) in units of time (hours, days, weeks). Each cell of the matrix corresponds to a specific section of the water body and contains information on:

- the number of units assigned to a given type,
- the frequency of their presence in a given sector,
- the duration of stay within a sector.

The matrix was generated using the in IALA **IWRAP Mk2** tool and provided the basis for creating heatmaps showing the traffic intensity in different parts of the analysed area. This made it possible to precisely delineate the most heavily used routes and traffic congestion areas, including sensitive sections around Bornholm and the approaches to Kołobrzeg.

2.4. Research gap and development of AIS-based approaches.

In recent years, researchers have been increasingly interested in the use of AIS data in the context of preventive maritime risk assessment. Du et al. (2021) proposed an innovative approach to detecting near misses in the northern Baltic Sea, pointing to the possibility of

combining vessel trajectory data with the interpretation of navigational manoeuvres. This study is an important reference point for the development of tools to support real-time risk assessment.

In turn, the work of Kiersztyn et al. (2025) focuses on the quality of AIS data, analysing the impact of errors and omissions in the data on the accuracy of statistical inference and risk modelling. It was pointed out that irregularities in the input data can significantly distort the picture of navigational hazards, which should be taken into account when planning preventive measures.

Hybrid threats are also an important issue in the latest literature. Zaharia (2024) discusses cases of GPS and AIS interference in the Baltic Sea region, pointing to the growing risk of spoofing and jamming in the context of maritime safety and critical infrastructure. These phenomena, although often difficult to detect, can significantly affect the effectiveness of traffic monitoring systems.

Despite developing research in these areas, there is a lack of studies combining operational analysis of local traffic, risk assessment and the specific characteristics of smaller but intensive routes, such as Kołobrzeg–Bornholm. This paper attempts to fill this gap by integrating AIS data, spatial analysis and elements of the FSA methodology using a specific shipping route as an example.

3. Characteristics of the study area and measurement points used

3.1. Gate Traffic Analysis

As part of the detailed analysis of marine traffic intensity in the Kołobrzeg area, three measurement gates (gate lines) were defined, located at strategic locations in the southern Baltic in the immediate vicinity of the port. Their purpose was to:

- to capture the traffic intensity on the Kołobrzeg-Nexo (Bornholm) ferry route,
- recording vessels travelling on the latitudinal (west-east) transit axis,
- measuring local entry/exit traffic to the port of Kołobrzeg, including fishing and tourist traffic.

Each of the gates was oriented perpendicularly to the main direction of unit flow. In addition, histogram grids were used to enable:

- counting units by type (freight, passenger, fishing, recreational),
- analysis of directions (e.g. northbound or southbound),
- evaluation of seasonal traffic patterns.

Figure 2 shows three gates: LEG-9, LEG-10 and LEG-11, located in the Kołobrzeg area. Each has a distinct analytical function - from recording ferry traffic, to international transit, to local port activity.

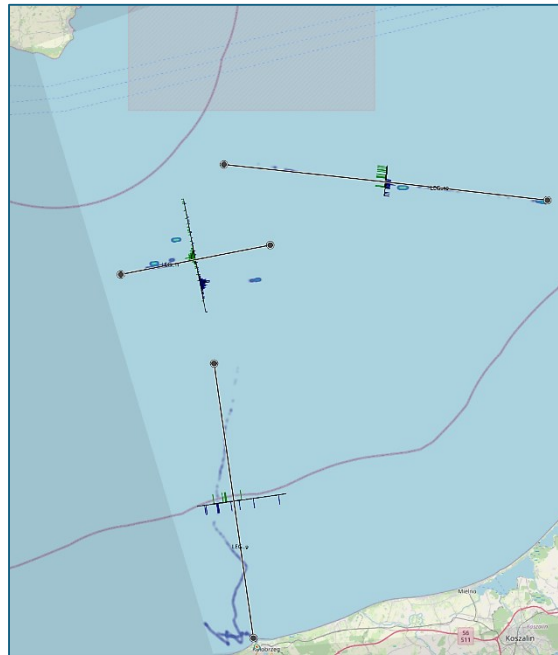


Figure 2. Survey gates.

Source: own elaboration in IWRAP Mk2 software.

- LEG-9 (Kołobrzeg – Bornholm).
The gate, aligned north-south, crosses the main passenger ferry route between Kołobrzeg and the port of Nexø on Bornholm. It also analyses local fishing and recreational traffic. The histogram clearly shows more northbound traffic, especially in summer.
- LEG-10 (latitudinal transit).
A gateway aligned parallel to latitude, crossing one of the main Baltic transit routes (from Germany and Denmark towards the Gulf of Gdansk). It records mainly large commercial units. Histograms show intense and balanced traffic in both directions (east ↔ west).
- LEG-11 (entrance to Kołobrzeg harbour).
Closest to shore, gate positioned perpendicular to the approach track to Kołobrzeg harbour. It allows accurate registration of all vessels entering and leaving the port: cutters, passenger ships, yachts and commercial vessels. Visible intensity of local traffic.

Each of the three gates was the entry point for developing a traffic intensity matrix, which was used to create heat maps, daily profiles and seasonal analyses. Their distribution allowed the precise capture of both international traffic and local port activity in Kołobrzeg.

3.2. Shape of the Seabed and Depths

The analysed area is characterised by varied bathymetry. In the immediate vicinity of the coast (near Kołobrzeg), shallows of up to 15-20 metres dominate, with clearly marked coastal strips and naturally occurring seabed elevations. North of the Kołobrzeg-Bornholm line, in the vicinity of the fairways and transit lanes, depths reach 40-60 metres, allowing for free passage of seagoing vessels.

The main shipping lanes coincide with areas with depths of more than 30-40 metres, making them optimal for large vessels. The area does not contain significant underwater obstacles, but its structure - combined with the high volume of traffic - requires careful navigational coordination.

3.3. Characteristics of maritime traffic Kołobrzeg-Bornholm

Below is Table 1 showing comparative data from the three offshore sections of the routes (LEG 9, 10 and 11) on the intensity and structure of vessel traffic.

Table 1.
Traffic intensity and structure at gates LEG 9 – LEG 11

LEG	North/West traffic	South/East traffic	Details North/West	South/East detail
LEG 9	90	151	Cargo: 30, Recreational: 60	Fishing: 45, Recreational: 91, Other: 15
LEG 10	210	302	Tankers: 60, Cargo: 120, Passenger: 15, Support: 15	Cargo: 287, Passenger: 15
LEG 11	2664	2864	Tankers: 452, Cargo: 2122, Passenger: 45, Support: 30, Others: 15	Tankers: 605, Cargo: 2003, Passenger: 45, Support: 91, Recreational: 30, Other: 90

Source: own elaboration.

Interpretation of the data from the three consecutive sections of the sea route between Kołobrzeg and Bornholm (LEG 9-11) allows one to see a clear functional division of the route and differentiation in the intensity and type of sea traffic. LEG 9, located closest to Kołobrzeg, is characterised by the lowest traffic intensity and a predominance of recreational vessels (151 in total in the southern traffic and 60 in the northern traffic) and fishing vessels (45). There are also single cargo vessels. This demonstrates the local character of this section - it mainly serves tourism, fishing and the port of Kołobrzeg. LEG 10 has an intermediate function between coastal zone and the main route. Traffic here is more diversified - cargo ships dominate (more than 400 units in both directions), and there are also tankers and passenger ships. This is a typical transit section, connecting the port to the open sea. Although its width is smaller than the others (only 5000 m), its draught and length allow it to handle large commercial vessels. LEG 11 is the main maritime traffic corridor in the study area. It records very intensive traffic - more than 5500 vessels in both directions combined. The predominant vessels are cargo ships (more than 4100), tankers (1057) and support and passenger vessels. Interestingly, pleasure craft and various other vessels also appear, indicating the great diversity of functions

of this route. LEG 11 has the largest draught (up to 15 m), allowing it to handle the largest vessels. It is undoubtedly the most important section in the route analysed.

From a spatial point of view, a clear shift in the functions of the route can be seen: from local port service at LEG 9, through the transitional section at LEG 10, to the wide, deep and most heavily trafficked international maritime corridor at LEG 11. This distribution is indicative of a functional layering of traffic, with each section playing a different, complementary role in the Baltic Sea transport system.

4. Traffic intensity matrix and shipping safety analysis

Based on the collected maritime traffic data in sections LEG 9, LEG 10 and LEG 11, as well as maritime accident data collected by HELCOM between 2004 and 2023 (43 incidents in the South Baltic), a maritime traffic intensity matrix was developed. The matrix was generated using processed data from the IALA IWRAP Mk2 programme and included:

- the number of vessels assigned to a given type (cargo, tankers, recreational, passenger, etc.),
- the frequency of their presence in a given geographical sector,
- the dwell time of the vessels in the grids analysed.

This made it possible to create a heatmap showing the highest traffic density.

The highest density was recorded in the LEG 11 section, where more than 5500 vessels passed through the analysed sector, including as many as 4000 cargo ships and 1000 tankers. This is a strategic international route - both in terms of traffic volume and in terms of the characteristics of the ships with large draught and tonnage.

In the LEG 10 section, traffic was moderate but varied - cargo vessels and tankers dominated, while in LEG 9, located closest to Kołobrzeg, recreational and local traffic (boats, fishing boats) prevailed. The draught of vessels in this section was the lowest, which limited the possibility for larger vessels to enter.

HELCOM data indicate 43 maritime incidents in the analysed region over the last 20 years. The apparent concentration of incident points around Kołobrzeg and on routes leading to Bornholm may be related to traffic congestion in key sectors and the presence of a variety of vessel types on common routes. Particularly sensitive are the intersections between local and international routes - typical, for example, of the LEG 10 transition section.

The matrix in Figure 3 below shows the spatial intensity of maritime traffic in the Kolobrzeg-Bornholm route area, divided into a 3x3 grid corresponding to the geographical sectors. Values in cells are the total number of vessels registered in a given area.

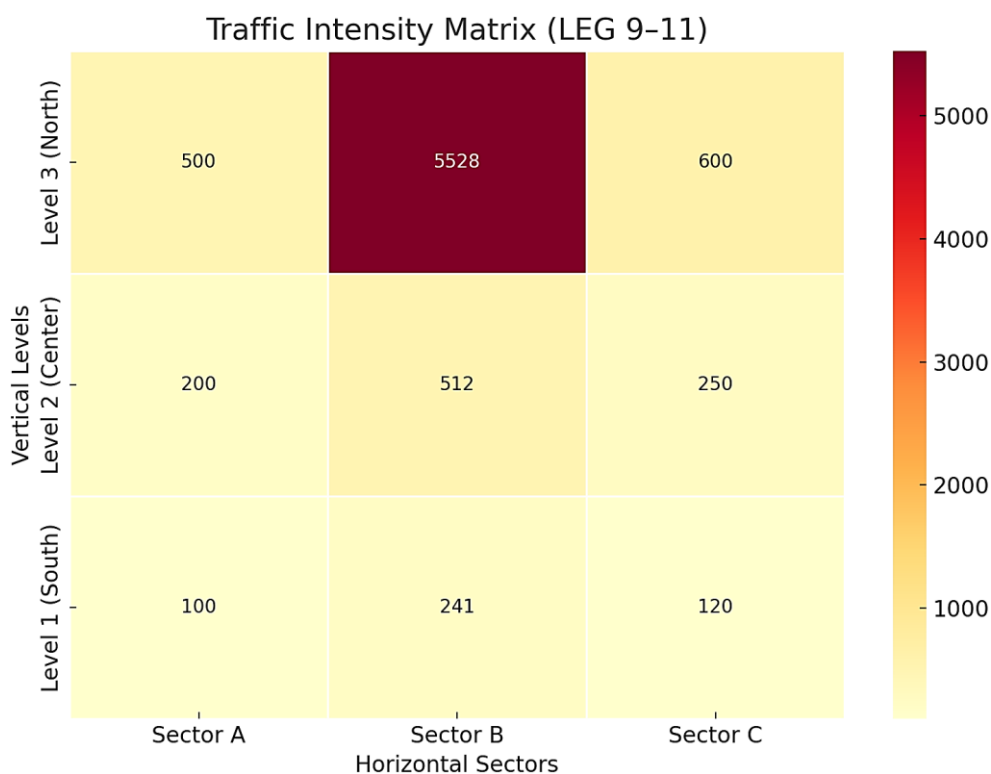


Figure 3. Traffic intensity matrix.

Source: own elaboration.

The highest intensity is found in the middle sector of the northern level (Sector B, Level 3) - this corresponds to section LEG 11. As many as 5528 vessels passed through this section, confirming its role as a major international maritime corridor. LEG 10, represented by the middle sector of the middle level (Sector B, Level 2), shows moderate traffic - 512 units, mainly cargo ships and tankers. LEG 9, i.e. the sector closest to the Kołobrzeg coast (Sector B, Level 1), is the area with the lowest traffic (241 units) - dominated by recreational and fishing vessels.

5. Discussion

The analysis of maritime traffic on the Kołobrzeg–Bornholm route provided valuable operational data, but for a more complete picture, several important limitations must be taken into account. Firstly, the study omitted a cost-benefit analysis of the proposed measures, which is an important element of the FSA methodology. An estimated economic assessment of the implementation of VTS or TSS systems could increase the practical significance of the recommendations. Secondly, the effectiveness of implementation depends on legal conditions and the need for coordination with international institutions, which may slow down the

decision-making process. This is particularly true for the reorganisation of shipping routes in areas with complex jurisdictions.

Due to the growing threats related to the disruption of electronic and navigation systems, future research should also consider less typical forms of risk.

The introduction of new technical solutions should be carried out in cooperation with local maritime authorities, such as port authorities, ferry operators and waterway users, as their involvement may determine the success of the entire project.

6. Conclusions and Recommendations

On the basis of the conducted study, which included analysis of AIS data, assessment of maritime traffic intensity and HELCOM maritime incident records, it was possible to obtain a complete picture of the functioning of the shipping lane between Kołobrzeg and Bornholm. This approach made it possible not only to identify areas with the highest traffic density, but also to identify sectors particularly exposed to navigational risk.

The highest density of vessels was recorded on the section designated as LEG 11, which functions as the main transit channel in the area. A significant number of vessels - more than 5500 - move there, of which cargo vessels and tankers predominate, often with considerable draught and displacement. Their presence in large numbers generates considerable strain on maritime infrastructure and raises the potential risk of collisions. Significantly, it is in this area that the highest number of maritime accidents has been recorded in the last two decades, as confirmed by analysis of HELCOM data. LEG 10 acts as a buffer - a transition zone - where local and international traffic mixes. The presence of vessels of different types, including passenger, commercial and auxiliary vessels, creates conditions conducive to incidents, especially when crossing routes or changing courses in a confined space. On the other hand, LEG 9, located closest to the shoreline and the port of Kołobrzeg, serves mainly recreational craft, fishing boats and coastal traffic. Despite the relatively small number of vessels passing through there, it is on this section that special attention should be paid to the risk of collision with larger harbour craft. Traffic with different technical characteristics - e.g. motor boats and commercial vessels - moves in the same body of water, without a clear separation of lanes.

In the light of the above observations, it is reasonable to make some specific recommendations to improve the safety of navigation and to manage maritime traffic in the study area more efficiently. Firstly, it is advisable to implement a VTS (Vessel Traffic Service) system in the most heavily trafficked sections, especially within LEG 11 and LEG 10. This will allow for the real-time tracking of vessels and the prevention of potential collision situations. The next step should be to consider the formal introduction of segregated maritime traffic lanes (TSS), which will sort out navigation directions and reduce the risk of navigational errors.

With regard to LEG 9, it is recommended to intensify surveillance activities and to develop local rules on priority and safe speed, taking into account the specificities of recreational and fishing vessels. Cyclical analysis using tools such as IWRAP Mk2 should also be an important supporting activity, allowing early detection of changes in traffic intensity and allowing response to emerging risk 'hotspots'. It is also not insignificant to strengthen cooperation with international institutions such as HELCOM, which collect accident data and enable early predictive analysis.

In conclusion, managing maritime traffic on the Kołobrzeg-Bornholm route requires a holistic approach based on both historical data and predictive analysis. Although the region is not one of the most congested globally, its particular location - at the junction of local and transit routes - means that even relatively minor disruptions can lead to major incidents. The recommendations presented in this thesis can serve as a starting point for further institutional action and as a basis for formulating maritime security policies locally and regionally.

The vessel traffic occurring between the island and the Polish coast may be an important aspect in planning a permanent ferry connection between Kołobrzeg and Bornholm, in particular with regard to the selection of the vessel or vessels and planning the schedule of courses, the optimal route of the vessel or vessels providing transport services. The intensity of vessel traffic in the analysed area, is a key factor that will influence the plans and implementation of the ferry crossing in terms of safety and economic aspects.

Further actions should include conducting a cost-benefit analysis of the proposed technical solutions (e.g. VTS, TSS), which will enable rationalisation of investments in the context of limited resources. It is also worth planning a phased implementation model (e.g. pilot in LEG 11). It would also be a good idea to consult with representatives of the maritime sector to take their views into account when planning actions. This approach will ensure greater effectiveness and social and institutional acceptance of measures to improve navigation safety.

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