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STRATEGIC AND MARITIME IMPLICATIONS OF THE PLANNED FSRU TERMINAL IN GDAŃSK: A COASTAL INFRASTRUCTURE PERSPECTIVE

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Purpose: The purpose of this study is to assess the impact of the planned location of the FSRU (Floating Storage Regasification Unit) terminal in the waters of the Gulf of Gdańsk with respect to the safety of navigation. The analysis is focused on determining the intensity of traffic of different classes of sea vessels in the approach area to the port of Gdańsk, indicating an increased risk of potential collision scenarios. The study covers the frequency of vessel passage through the two control gates, allowing the application of probabilistic risk assessment models for future LNG transhipment operations.

Design/methodology/approach: The study used in the article consisted of examining how the intensity and structure of traffic of various types of vessels in the approach channels to the Port of Gdańsk affect the collision risk level in the context of maritime safety of the planned FSRU terminal construction.

Findings: Probabilistic modelling of the number of collisions between vessels based on AIS gate data showed that cargo and container vessels pose the greatest collision risk due to their frequent movements and variable traffic intensity. The possibility of manoeuvring collisions involving passenger, service and fishing vessels was also identified. The study points to the need to implement flexible traffic management and tools for safety prediction and management.

Research limitations/implications: The probabilistic models used are effective in the overall assessment of dynamics, but do not fully reflect the complexity of interactions between ships and the impact of hydrometeorological conditions. The assumptions made about the randomness and independence of events do not take into account actual operational procedures, such as entry schedules or pilotage. In the future, it would be worthwhile to broaden the approach to the issue by including models that take into account seasonal variations in vessel traffic and environmental data in order to increase the accuracy of hazard forecasting and support safety decisions in the FSRU terminal area.

Practical implications: The results of the study can be used in the planning and organisation of maritime traffic in the Port of Gdańsk area, particularly in the context of integration with the operation of the FSRU terminal. The proposed approach makes it possible to predict potential collision situations. The implementation of such a model can improve navigational safety, increase fairway capacity and reduce the risk of congestion or incidents. For port operators and

traffic management institutions, such as VTS, this means more efficient resource management and better preparation for handling special vessels, such as LNG.
Originality/value: The paper presents the application of probabilistic models based on AIS data to assess navigational safety in the area of the planned FSRU investment. The value of the study lies in its practical approach to navigational safety analysis with a view to the future operation of the terminal. The results may be useful for maritime traffic management authorities, port planners and teams responsible for assessing the impact on the marine environment. The method developed can also be used in other ports with a similar traffic structure.
Keywords: FSRU, LNG terminal, maritime safety, navigational risk, coastal infrastructure, LNG import security, floating energy infrastructure.
Category of the paper: Viewpoint.

1. Introduction

With the dynamic changes in the energy sector, LNG infrastructure, including floating FSRU terminals, is becoming increasingly important. However, this requires not only an assessment of their importance to the gas supply system, but also an in-depth analysis of the potential impact on shipping safety. The planned FSRU investment in Gdansk, to be located at one of the most strategic points in the Baltic Sea, raises the need for an interdisciplinary look at the issues of risk, technology, location and maritime traffic management.

Studies show that the LNG sector has an elevated risk profile, particularly in the areas of port and coastal operations. A review of the literature on risk analysis in the marine LNG sector indicates a wide range of risks: from collisions, explosions and spills to operational errors due to human and environmental factors (Abdelmalek, Guedes, 2023). Attention was drawn to the need for a systematic approach to safety, which becomes particularly relevant in light of the planned location of the FSRU in the Gulf of Gdansk.

The drive to enhance energy security through diversification of gas sources is reflected in the use of multi-criteria decision-making methods that support the planning of efficient and safe LNG infrastructure (Devaraj et al., 2021). The use of FSRU terminals in this context increases the flexibility of energy systems, but requires a careful assessment of the hydrographic and operational conditions of the basin in which the unit is to be sited.

In this context, criteria for the selection of the terminal location - developed taking into account navigational and hydrotechnical considerations, especially in areas with heavy traffic and extensive port infrastructure, such as the Bay of Gdansk (Mrozowski, 2024) - are of particular importance. An appropriate location method, taking into account both navigational safety and cost optimisation, is the key to minimising operational risk. At the same time, to ensure an adequate level of operational safety, the use of autonomous monitoring systems is increasingly being proposed to support risk assessment and enable rapid response in emergency situations. Solutions of this type are proving particularly useful in areas of limited visibility and intensive maritime traffic - i.e. conditions typical of the area of the planned FSRU terminal in Gdansk (Miętkiewicz, 2021).

An understanding of the technological specificities of such facilities is essential for the correct identification of risks. Knowledge of regasification processes, mooring systems and connections to onshore transmission infrastructure provides the foundation for building realistic risk scenarios and designing effective safety measures for offshore operations (Beadnall, MacHardy, 2025). The implementation of state-of-the-art offshore technologies, such as innovative safety and processing systems for installation components, is playing an increasingly important role in enhancing navigational safety in the FSRU infrastructure environment (Shipley et al., 2021). These improvements allow for better operational control, faster response to emergency situations and reduced risk of maritime traffic disruptions, which is particularly important in areas of heavy shipping.

In the context of the increasing intensity of maritime traffic in the area of the planned FSRU terminal, technological solutions to ensure the stability of the vessel in changing hydrodynamic conditions are important. Innovations in maintaining the position of offshore units, including FSRUs, have a direct impact on reducing the risk of disruption to navigation and improving the predictability of their behaviour in the navigation space (Xuanze et al., 2024).

Under conditions of increased maritime traffic, it becomes crucial to take into account potential disruptions resulting from emergencies associated with FSRU operations. Scenarios such as uncontrolled unit drift, regasification failures or gas releases can significantly affect the safety of shipping in the immediate terminal environment. Risk analysis models are used not only to identify possible critical events, but also to design safety systems and response procedures in line with the ALARP (As Low As Reasonably Practicable)-approach of reducing risk to a reasonably acceptable level (Xiao et al., 2024).

The analysis of threats within Polish ports points to significant problems related to the concentration of vessel traffic, the limited effectiveness of surveillance systems and the lack of consistency in institutional responsibility for safety (Christowa, 2023). Data acquired from AIS reveals clear patterns of accumulation of vessels at critical approach points, which can lead to overloading of the navigation infrastructure. The introduction of FSRUs in such a busy environment requires not only the upgrading of the physical port infrastructure, but more importantly the integration of traffic management systems and the strengthening of operational cooperation between port services, the Maritime Search and Rescue Service and terminal operators.

The introduction of this type of terminal in the Gdansk area should be considered not only as a local infrastructure investment, but as part of a sensitive LNG value chain that includes extraction, sea transport, regasification and distribution. Each of these stages represents a potential source of risk. Its disruption can have serious economic and environmental consequences (Shingan, 2024). Locating the FSRU in a strategic port further highlights the importance of coordinated risk management - both locally and systemically. In an environment of intensifying maritime traffic, dynamic factors such as course changes, current and wave action and hydrodynamic interactions between vessels become particularly important. These parameters are crucial in modelling collision scenarios and analysing spatial hazards in the immediate vicinity of the FSRU (Goksu, Arslan, 2024). Their inclusion in risk analyses becomes indispensable, especially in spatially restricted areas such as the Gulf of Gdansk, where even small manoeuvring deviations can lead to serious disruptions in navigational traffic.

One of the key tools supporting the assessment of navigational safety around LNG terminals are formal risk assessment methods, based on quantitative analysis and the opinions of maritime and gas safety professionals (Wang et al., 2024). These methods make it possible not only to identify the direct hazards associated with terminal operations, but also to consider their potential secondary effects - both on the marine environment and on the operation of port infrastructure. Of particular importance here is the comprehensive analysis of the consequences of accidents, such as explosions, fires or uncontrolled gas releases. Consequence models indicate the need for planning buffer zones, isolation measures and effective evacuation procedures, especially in the context of an urbanised and intensively exploited area such as the Gdańsk port region (James, Renjith, 2025). The wider context of the planned investment also points to the geopolitical and regulatory implications of the presence of the FSRU in the Baltic Sea space. According to infrastructural analyses of the region, the development of LNG terminals may foster the process of the so-called securitisation of the maritime space - in which technical elements are closely associated with political and military aspects (Berling et al., 2023). The location of the FSRU in Gdansk fits into this trend, raising the importance of precise planning, institutional coordination and risk management not only on a local, but also on a regional scale.

Based on the available literature on collision and risk assessment in shipping, the use of advanced predictive and probabilistic models is growing Based on the available literature on collision and risk assessment in shipping, the use of advanced predictive and probabilistic models is growing in importance. Work (Vukša et al., 2022; Xin et al., 2021) shows the effectiveness of combining AIS data with a Monte Carlo simulation approach to realistically represent collision scenarios in port conditions. A systems approach to risk assessment in multi-element vessel traffic has been developed in studies (Perkovič et al., 2024; Bakdi et al., 2020) which highlight the importance of integrating analytical methods with adaptive safety frameworks. The importance of implementing effective technical measures and behavioural analyses has been documented in (Ma et al., 2022; Wang et al., 2025) among others, where an attempt has been made to assess the influence of operational factors on collision risk levels. Stochastic models, as highlighted in (Faghih-Rooh et al., 2014; Nguyen, 2018), play a fundamental role in estimating the probability of incidents while taking into account spatial and temporal uncertainties. Further studies (Huang, Ung, 2023; Wang et al., 2023) show that the variability of trajectories and the manoeuvring constraints of vessels have a significant impact on the risk dynamics in approach sectors. In an intensive port environment, AIS data analysis integrated with GIS spatial models (Li et al., 2019) and artificial neural network (RNN)-based approaches (Liu et al., 2020) enables the location of critical areas and the dynamic tracking of risk changes in real time. Furthermore, the development of classification methods based on semantic and statistical analysis - as outlined in (Ma et al., 2023) - opens new perspectives in the context of predictive vessel traffic management, including FSRUs, in areas of high vessel density.

2. Materials and Methods

2.1. Scope of the study and geographical context

The study focuses on the analysis of navigational hazards in the area of the approach to the Port of Gdansk, where the construction of the FSRU terminal - a floating unit for the reception and regasification of liquefied natural gas - is planned in the coming years. At the same time, the area remains a key shipping hub due to the intensive operation of the Baltic Hub container terminal. Of particular importance here is the harbour entrance area, which - as one of the busiest shipping locations in the southern Baltic - requires precise identification of potential risks associated with the co-existence of different ship classes.

The planned FSRU terminal investment will be located in the north-eastern part of the Port of Gdańsk, in the waters of the Gulf of Gdańsk. The terminal will be adapted to handle two FSRUs, each with a capacity of up to 174,000 cubic metres of LNG. The construction will also include a specialised quay with a length of approximately 520 metres, which will enable two units to be moored simultaneously. The entire infrastructure will be located approximately 3.3 kilometres from the shore, and gas will be transported to land via a subsea pipeline connected to the national transmission system (Kiejzik-Głowińsk, 2023). Figure 1 shows the area of the planned project.

The area of the Gulf of Gdansk is covered by the TSS (Traffic Separation Scheme), under the supervision of the VTS Gulf of Gdansk. The TSS includes dedicated lanes to order traffic and prevent collisions in busy shipping conditions (UMG, 2023). The fairway leading to the Northern Port, including access to strategic terminals such as the Baltic Hub (formerly DCT) and the planned FSRU terminal, is one of the most advanced hydrotechnical basins in the Polish coastal zone. Thanks to a series of modernisation works, this track has been adapted to handle the largest commercial vessels sailing the Baltic.

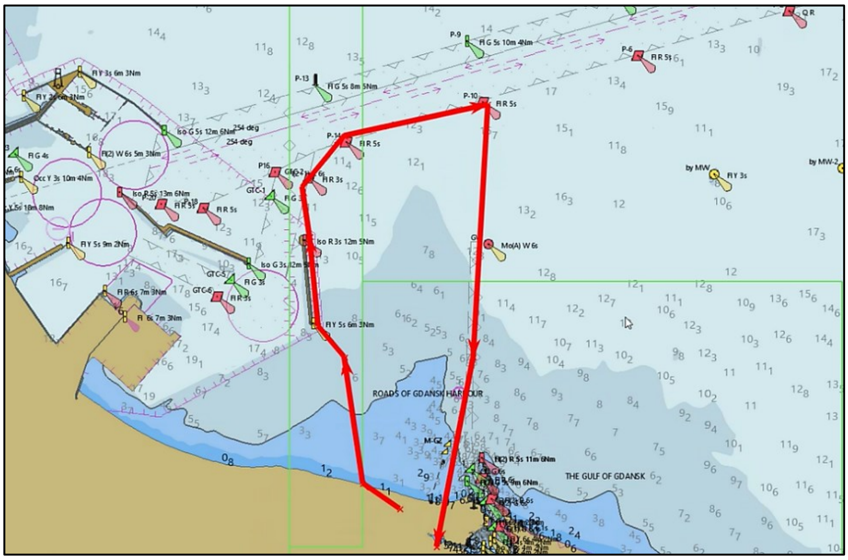

Figure 1. Designated operational area of the FSRU area in the Gulf of Gdansk.

Source: Own development using the OpenCPN electronic map programme.

In terms of length, the track extends for more than 11 kilometres, providing sufficient manoeuvring space for the entry and exit of ocean-going vessels. It has a bottom width of up to 600 metres, which - combined with a suitable cross-section profile - allows two-way navigation. This is very important in terms of maintaining traffic flow and maximising the use of port slots. The most important navigational parameter, however, is depth. The technical depth of the track reaches 18 metres, which allows vessels with a draught of up to 15 metres to navigate safely. It is worth noting here that the minimum actual depths - depending on the section - vary between 11.00 and 11.70 metres, due to bathymetric differences and local geological conditions of the seabed. On the track it is possible to navigate vessels of up to 355 metres in length and up to 60 metres in width, which in practice means a full service for ULCS-class container ships. Thanks to these parameters, Gdańsk has become one of the few Baltic ports able to directly accommodate the most powerful ships without the need for transhipment in the roadstead. The entire navigation infrastructure is under the day-to-day supervision of the Maritime Office in Gdynia and the VTS system Gulf of Gdansk (UMG, 2023, Port of Gdansk, 2024). Vessel traffic within the Gulf of Gdansk, especially on the approach to the Northern Port in Gdansk, follows strict navigational rules. Due to the intensive traffic of commercial vessels, including container ships and tankers, specific speed limits are in place to ensure the safety of navigation, to protect the hydrotechnical infrastructure and to minimise hydrodynamic impacts on the environment and the shore. Below is a summary of the allowable ship speeds on key sections of the fairways in the Port of Gdansk area, according to the current Maritime Authority Order (Table 1).

Table 1.
Summary of permitted vessel speeds on key fairway sections in the Port of Gdansk area

Track section / Zone	Description	Maximum permitted speed
Reda of the Gulf of Gdansk	Anchorage and manoeuvring area before entering the harbour	9 knots[1]
Manoeuvre with remote control (manoeuvring/ passing)	Replacement of the ship's sea pilot	6 knots
Approach track to the harbour heads	Entrance area - last section before the harbour	7 knots
Waterway from headwaters to sluice gates	Internal section of track along quays	4 knots
Lock steering wheel and lock itself	The most precise manoeuvring section, requiring caution	safe speed, max. 3 knots

Source: (Regulation No. 11 of the Director of the Maritime Office in Gdynia of 8 September 2022).

The analysis used maritime traffic data from 2019-2022, collected based on two gates - virtual control cross sections mapped in the area of the approach to the ports of the Gulf of Gdansk. Their purpose was to capture the directions of vessel movements, traffic volume and shipping structure, including the main waterways and their intersections (Figure 2).

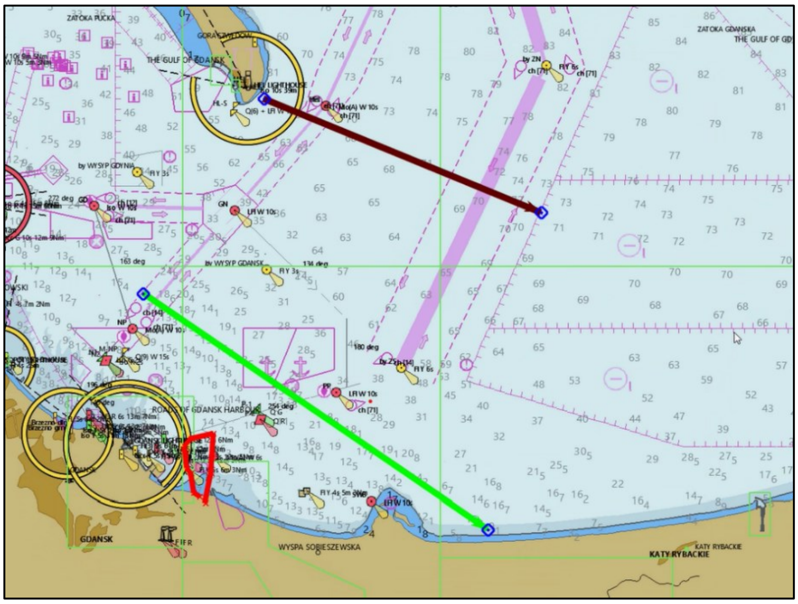

Figure 2. Designated control gate lines for vessel traffic monitoring in the context of FSRU impacts.

Source: Own development using the OpenCPN electronic map programme.

Gate 1 (green) comprises the track leading to the main approach track to the Baltic Hub and the future FSRU, passing through the TSS (Traffic Separation Scheme) "Gulf of Gdansk". The geographical position of this gate is defined by the following coordinates of two interconnected points:

Point 1: 54°29′04.8″N, 018°42′42.7″E

Point 2: 54°21′06.3″N, 019°02′43.9″E

[1] 1 knot [kn] = 0,51(4) m/s.

Gate 2 (brown) refers to the less frequented alternative track, located within the Traffic Separation Scheme (TSS) "Gulf of Gdansk". The geographical coordinates of the gateway have been defined by points respectively:

Point 1: 54°35′38.9″N, 018°49′43.4″E

Point 2: 54°31′48.6″N, 019°05′50.2″E

This gate runs across the axis of the approach track from the south-east, crossing the expected route of LNG-carriers and other commercial vessels heading to the container terminals and the planned FSRU.

The two gates act as analytical tools to carry out an assessment of traffic flow, the structure of vessel types, the directions of entrances and exits from the port area, as well as potential route collisions and navigation conflicts.

2.2. Applied navigation survey methodology in the area of the two gates

The navigational analysis in the area of the approaches to the Port of Gdansk was based on collected data acquired for the Baltic Sea area between 2019 and 2022. The data included information on the position, time and type of vessels crossing two spatially defined survey gates, located in the water traffic sectors within the approach fairway.

The QGIS environment was used to process the spatial data, while the quantitative analysis was carried out using Python programming tools. To map the variability and uncertainty of collision risk, a Monte Carlo simulation was used, generating 10,000 samples for each unit type and year from a Poisson distribution whose mean corresponds to the expected value. The results made it possible to define ranges of minimum values, maximum values and standard deviations, which allowed the identification of potentially extreme cases (outliers) and risk accumulation sites.

In addition, a mathematical model based on a Poisson distribution was used to estimate the average vessel traffic volume in the area under study. This is a classical approach used to describe the number of independent events (e.g. vessels passing through control gates) occurring per unit time, provided that these events do not influence each other's occurrence and are randomly distributed in time. The adoption of a Poisson distribution was justified by the nature of the observed AIS data, in which the successive arrivals of vessels into the survey sector are dispersed in time and occur independently of each other. This made it possible to determine not only the average traffic intensity (expressed as the number of vessels per hour), but also to model the probability of occurrence of a certain number of vessels in a given time interval. The average vessel traffic intensity was modelled as a Poisson process, for which the probability of occurrence of exactly n vessel passes through the survey gate (1 or 2) at time t is described by the relation (Ross, 2014):

$$P(n;\lambda t)=\frac{(\lambda t)^{n}e^{-\lambda t}}{n!} \tag{1}$$

where:

P(n; λt) - probability of exactly nnn events occurring at time ttt,

λ - average number of events per unit time (here: vessels per hour),

t - length of the observed period (e.g. 1 hour),

e- Euler's constant (≈ 2.71828),

n! - the strong of the number nnn (Ross, 2014).

The data obtained enabled quantitative characterisation of maritime traffic intensity and identification of patterns of vessel transits through sensitive sectors of the approach track. This provided a starting point for further collision risk modelling and analysis of the co-occurrence of vessels of different classes in the study area.

The navigation research methodology used in the area of two defined AIS measurement gates is characterised by accuracy and reliability thanks to the use of data from the AIS system. The data used in the study comes from HELCOM sources based on numerous signal reception stations located along the Baltic Sea coast. The accuracy of the data depends on several factors, such as signal quality, reporting frequency and data processing procedures. HELCOM uses data processing procedures that include:

- Removal of duplicates and erroneous records (e.g. incorrect IMO or MMSI numbers).
- Filtering data according to parameters such as speed over ground (SOG) and course over ground (COG).
- Standardisation of data formats in accordance with IEC 61162-1.

These processes ensure high data quality and consistency, which are essential for the creation of traffic density maps and statistical analysis (HELCOM 2024).

3. Results

3.1. Probabilistic modelling of the number of vessel collisions based on gated data

As a result of the Monte Carlo simulations (10,000 trials) for selected ship classes, it was found that the highest values of expected collision risk occurred for cargo and container vessels. For these groups, the average risk exceeded the 1.5 event level, with values even several times higher than the average observed in some draws, indicating high variability. Passenger vessels were also characterised by a noticeable level of risk, although slightly lower and more stable. For smaller vessels, such as fishing or service vessels, the risk remained low, but their share of risky situations may increase as a result of co-occurrence with larger vessels with limited manoeuvrability. The scatter of results (analysed as range and standard deviation) was particularly evident in the cargo and container groups, suggesting potentially irregular waves of traffic or periods of increased activity in these sectors of the approach track.

To illustrate the variation in collision risk by unit type, a box plot was drawn up to show the distribution of the number of potential collisions, taking into account the median, interquartile range and outliers (Figure 3). The line inside the box indicates the median value, i.e. the most typical result among the samples. The height of the box corresponds to the interquartile range (IQR- Interquartile Range), indicating the variability of results within the middle 50% of values. "Whiskers" on the graph delineate the range of data with no outliers and cover the interval from the minimum value to the maximum value within 1.5 IQR. Points outside this range are outliers - rarer but possible scenarios with higher risk.

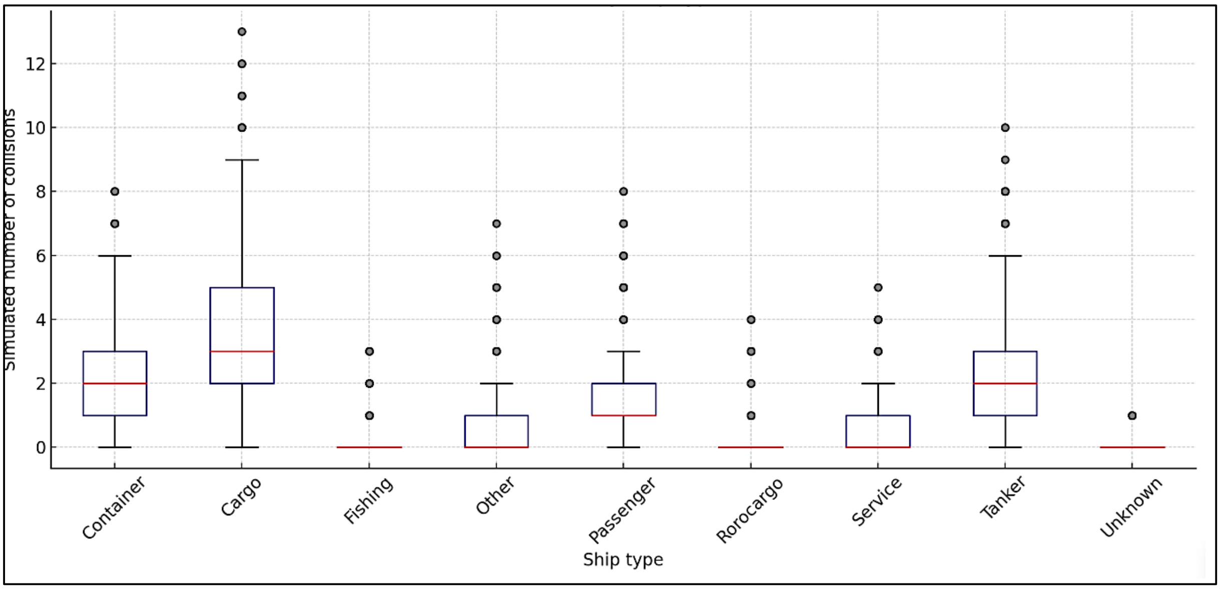

Figure 3. Distribution of the number of potential collisions, taking into account the median, interquartile range and outliers.

Source: Own development.

The box plot shows the variability and characteristics of simulated collision risk for each class of vessel. Cargo and Container vessels stand out for having the highest medians and the widest interquartile range (IQR), indicating their dominant share of traffic, the highest overall level of collision risk and the significant instability of this risk over time. The greatest spread and high level of unpredictability of risk was observed for Cargo vessels and, to a lesser extent, Tanker vessels. The presence of long 'whiskers' and numerous outliers indicates the possibility of periods of significant traffic congestion. Outliers in these groups signal potentially rare but particularly dangerous scenarios - such as the accumulation of several collisions in a short time frame. Passenger, Service and Fishing vessels, on the other hand, are characterised by relatively narrow boxes and short whiskers, indicating a low and stable level of risk. In their case, the risk increases mainly when co-occurring with large vessels with limited manoeuvrability. Although these vessels are of less systemic importance in terms of direct collisions, their presence remains important for human safety and environmental protection.

3.2. Modelling of the intensity of unit movements at the measuring gates (gate 1 and gate 2)

A Poisson process model was used to assess the volume and structure of maritime traffic on the approach fairway to the Port of Gdansk. The passage of vessels through the two defined measurement gates was treated as independent events occurring in time. The determined values of traffic intensity (λ) for individual ship classes were the basis for further modelling of the co-occurrence of vessels and collision risk analysis.

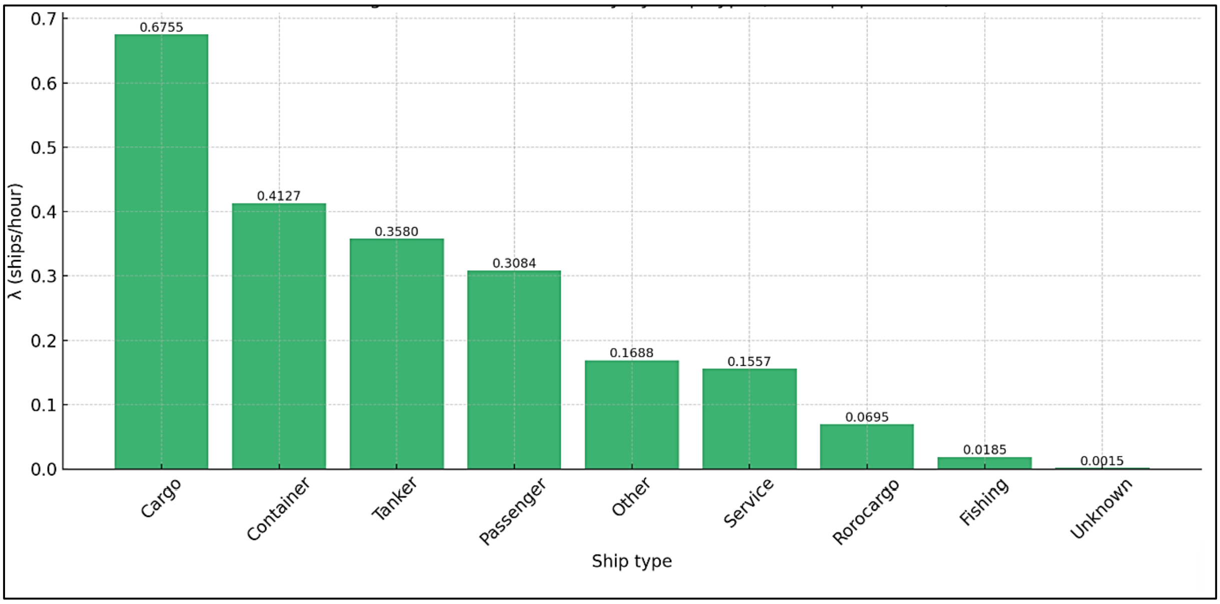

Figure 4. Average unit traffic (λ).

Source: Own development.

Figure 4 shows the average unit traffic volume (λ), expressed as number of crossings per hour. Values were estimated using AIS data from 2019-2022, covering the total number of crossings through both survey gates. Following a probabilistic approach, the model assumed stationarity and independence of events over time, typical of a Poisson process. The analysis showed that the highest traffic intensity is found in the groups of Cargo and Container units, which confirms their dominant share in the service of the approach track to the Port of Gdansk. Their average intensity exceeds 0.5 vessels per hour, which means that a vessel of this class passes through the surveyed sector on average every 1-2 hours. The λ values for Tanker, Passenger and Service vessels are moderate, while for Fishing, Rorocargo and Unknown vessels indicate activity of an irregular or episodic nature.

The estimated traffic intensities are crucial in the context of further analyses - both for modelling the real-time co-occurrence of units and for assessing local sector congestion. The λ parameters can also form the basis for planning slot schedules, designing approach infrastructure and optimising traffic management systems in areas with higher collision risk.

The analysis refers to a box plot, which provides relevant information to identify critical situations, the height of the boxes and the length of the 'whiskers' visualise the level of variability and the extent of typical risk. The dots indicate rare but potentially negative scenarios and can be the basis for considering critical cases.

The λ values obtained provide a starting point for the overall assessment of traffic volume, but also for the identification of 'congestion points' in the navigational structure of the Port of Gdansk. An indication of the types of vessels dominating in a given spatio-temporal sector allows the design of risk scenarios targeting actual traffic configurations. The data can also be used to simulate the efficiency of time slot planning for LNG carrier vessels in the context of current traffic volumes in the approach fairways.

4. Discussion

In the context of the planned start-up of the FSRU terminal in the Northern Port area, special attention should be paid to future changes in the structure and intensity of vessel traffic. The impact of large LNG carriers - characterised by significant draught, limited manoeuvrability and the need to operate in specific hydrometeorological conditions - may significantly increase the load on the approach track, especially in the area of intersections with container and cargo traffic. The situation will require adjustments to both infrastructure and traffic management - taking into account forecasts of co-occurrence of vessels and dynamic allocation of shunting slots. The probabilistic approach used in this analysis, based on the Poisson process and Monte Carlo simulations, has allowed a quantitative assessment of traffic intensity and collision risk in typological terms. In contrast to static indicators of the number of calls, these methods allow the modelling of dynamic navigational phenomena - such as an increase in the risk of co-occurrence of vessels, stoppages, or local congestion in the fairways. Of particular cognitive value is the possibility to consider time as a random variable and move to a description of the system as a sequence of events with variable intensity, which opens the way for further predictive analyses. In port practice, the results obtained can form the basis for:

- estimating the capacity of the approach infrastructure,
- planning the time allocation of the impacts of LNG vessels and container ships,
- the development of models to support the operational decisions of VTS services,
- and building early warning systems based on AIS data and risk scenarios.

In the perspective of FSRU development, it seems reasonable to extend the current model with dynamic components (e.g. heterogeneous Poisson process, Cox model) and to use machine learning methods to classify high-risk situations. This would allow for more efficient real-time traffic management and the creation of separation and prioritisation strategies for operationally critical units.

The results of the analysis indicate a high intensity of ship traffic, with the co-occurrence of large-capacity vessels, such as tankers and container ships, having a direct bearing not only on local navigational safety, but also on the achievement of the state's strategic energy goals. The planned FSRU terminal in the Gulf of Gdansk is an element of critical infrastructure that supports the diversification of natural gas supplies and contributes to independence from eastern energy supplies. Therefore, the assessment of navigational risk in the area, although based on quantitative data, is part of a broader geopolitical context related to energy security and the functioning of the trans-European transmission networks.

5. Conclusions

The analysis carried out with the use of probabilistic models and automatic ship identification system data enabled a holistic view of the operation of the approach fairway to the Port of Gdansk - from the perspective of both traffic intensity and the associated collision risk. The particular value of this methodology is the ability to model navigational phenomena as a dynamic process, based on time and the co-occurrence of different types of vessels, which significantly extends the scope of classical static analyses. The results clearly show that the greatest operational risk is generated by Cargo and Container vessels. It is their abundance, variability in intensity of occurrence and dominance in traffic patterns that cause the greatest strain on the fairways, especially in the context of sharing space with other classes of vessels. Importantly, this risk is not due to one-off anomalies, but to the typical dynamics of port operations and the characteristics of commercial traffic. In addition, service, passenger and fishing vessels - despite lower volumes - may enter into a manoeuvring collision in situations of intersection with traffic of vessels with limited manoeuvrability. From the point of view of port practice, these results indicate the need for:

- develop a flexible traffic management system based on real data and co-occurrence scenarios,
- implementation of dynamic slot allocation, especially for maximum and LNG vessels,
- and to strengthen the role of predictive models in assessing current and projected loading on the fairways.

In the context of the commissioning of the FSRU terminal in the Northern Port, it is recommended that the current model be supplemented with elements of temporal variability (e.g. non-homogeneous Poisson processes), the inclusion of hydrometeorological conditions and the development of data analysis algorithms using machine learning. Future LNG units will operate in a strict weather and time frame, which requires a strict separation of their trajectories from container traffic and increased separation at hotspots such as track crossings and towing zones.

From a scientific point of view, the work confirms the effectiveness of the applied probabilistic and simulation methods in the analysis of real maritime traffic, while opening up perspectives for further research towards integrated predictive models. Well-calibrated stochastic approaches, combined with up-to-date AIS data and decision support systems, can provide a solid foundation for future solutions for navigational safety and efficient use of port infrastructure.

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