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# Improving the Maritime Traffic Evaluation with the Course and Speed Model

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**Abstract:** Recent projections from marine transportation experts highlight an uptick in maritime traffic, attributed to the fourth industrial revolution's technological strides and global economic rebound. This trend underscores the need for enhanced systems for maritime accident prediction and traffic management. In this study, to analyze the flow of maritime traffic macroscopically, spatiality and continuity reflecting the output of ships are considered. The course–speed (CS) model used in this study involved analyzing COG, ROT, speed, and acceleration, which can be obtained from the ship's AIS data, and calculating the deviation from the standard plan. In addition, spatiality and continuity were quantitatively analyzed to evaluate the smoothness of maritime traffic flow. A notable finding is that, in the target sea area, the outbound and inbound CS indices are measured at 0.7613 and 0.7501, suggesting that the outbound ship flows are more affected than inbound ship flows to the liquidity of maritime traffic flow. Using the CS model, a detailed quantitative evaluation of the spatiality and continuity of maritime traffic is presented. This approach facilitates robust comparisons over diverse scales and periods. Moreover, the research advances our understanding of factors dictating maritime traffic flow based on ship attributes. The study insights can catalyze the development of a novel index for maritime traffic management, enhancing safety and efficiency.

**Keywords:** spatiality; continuity; CS model; maritime traffic flow

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## 1. Introduction

According to the statistical data from analytical agencies specializing in the maritime transportation market (Clarkson, Alpha Liner, Drury, etc.) and UNCTAD's Review, the volume of cargo on container ships, bulk carriers, and tankers has been increasing annually [1]. This upward trend is expected to persist in the future. Furthermore, there is a strong emphasis on developing technologies for smart and autonomous ships that utilize the Internet of Things, big data, artificial intelligence, and other cutting-edge innovations. The imminent commercialization of autonomous ships is anticipated to further bolster maritime traffic.

Maritime transport continues to dominate the global cargo movement. As the prevalence of autonomous ships rises, ensuring safe and efficient maritime traffic management will become increasingly crucial. These studies encompass methods to assess maritime traffic risks and predict maritime accidents based on the increasing volume of maritime activity. The vessel traffic service (VTS) systems currently in place rely on human resources for maritime traffic management.

Unlike road traffic, which operates on designated roads, maritime traffic enjoys autonomy in navigation, as long as seaworthiness is ensured. To facilitate safe navigation, ship operators use historically used navigation patterns or established routes. The use of historically used navigation patterns or conventional routes is because they have been tested and verified for a long time, and the accumulated data of actual ship passage prove it and have reliability. Also, they refer to routes recommended by publications, such as the International Maritime Organization's (IMO) "Routes for Ships", or recommended routes provided by services, such as Weather Routing (WRI), Applied Weather Technology (AWT), and Weather News (WNI) based on climate forecasts and ship navigation databases. As a result, a certain level of consistent navigation flow is observed on open waters as well as on designated navigation passages.

Within this context, this study introduces a method that quantitatively assesses the smoothness of maritime traffic flow based on the existing traffic flows generated by a large number of sailing vessels. This method is crucial for determining the smoothness of maritime traffic flow and thus predicting the traffic flow and secondary behavior of unmanned and smart ships. Additionally, they can provide valuable insights to identify and enhance the current traffic flow configurations.

The paper is organized as follows. Section 2 describes the literature review and research methodology, and Section 3 presents the improving marine traffic flow assessment. Section 4 presents the theory and results of the evaluation model. Finally, Section 5 concludes the paper by discussing the evaluation results, limitations and suggesting future work directions.

## 2. Literature Review

Collecting data through traffic surveys is a crucial step in estimating traffic volume. In the case of road traffic, the scope of the report and the entity responsible for its implementation are distinguished according to the relevant laws. Typically, traffic volume and movement are assessed by studying the origin and destination (O/D) traffic volume. This method involves surveying observation points, either manually or with machines, to extract data samples. The collected data are then compared with screen line survey results and household interviews to validate the survey's accuracy [2,3].

However, the scope of movement for maritime transport is considerably broader than that of road traffic, rendering the same survey method inadequate owing to the significant restrictions on observation points at sea. Therefore, the IMO mandates that all passenger ships, including domestic cargo ships of 500 tons or more, irrespective of their size, and international service ships of 300 tons or more, must be equipped with an installed AIS [4]. Additionally, domestic vessels are required to install and operate a vessel pass (V-Pass) in compliance with the Fishing Vessels Act. This system automates port entry declarations for fishing boats, enabling rapid responses to marine accidents and facilitating data collection from ships traversing various oceanic areas, including domestic coasts.

AIS holds high value in analyzing the data related to diverse maritime traffic as it is standardized by the International Telecommunication Union (ITU) and the International Electrochemical Commission (IEC). Moreover, it can be directly set up and operated on ships. Nevertheless, errors might arise due to incorrect global positioning system (GPS) settings during the initial setup [5].

These AIS data are used as the basis for a variety of assessments, such as automated maritime routing [6], or risk analyses related to maritime traffic, collision probability, and congestion levels. This study primarily focuses on researching the marine traffic assessment, specifically utilizing the AIS for maritime traffic [7,8]. In a local context, a risk assessment model is developed to evaluate maritime traffic hazards in coastal waters. The model is formulated through a survey of domestic ship operators, a research endeavor commissioned by the Ministry of Land, Transport, and Maritime Affairs. Recognized as the potential assessment risk (PARK) model, it is employed for risk assessment in a domestic coastal setting.

Several studies have adopted the PARK model for risk assessments. For instance, the collision avoidance algorithm was examined by implementing the Convention on the

International Regulations for Preventing Collisions at Sea (COLREGS) using the PARK model [9]. Additionally, compared this model with a collision warning algorithm for small fishing boats [10]. In other countries, an Environmental Stress (ES) model [11] has been developed. This model provides a quantitative index of the shipbuilding difficulties faced by ship operators. The comprehensive aggregation of the ES value (ESA) comprises environmental stress due to surroundings (ESLs) and traffic environment stress induced by other ships (ESSs). This research utilizes ship maneuvering simulations and surveys to ascertain the risks associated with a ship's surroundings, distinguishing the risks based on surrounding ships and the topography. However, this assessment is limited to sea areas with a unidirectional traffic flow or wide sea areas without obstructions.

To evaluate domestic application effectiveness, the research was conducted by comparing the risks perceived by pilots during on-site operations with the results from the ES model, and the results were aligned [12]. Furthermore, an analysis was performed using the ES model and the IALA Waterway Risk Assessment Program (IWRAP) of the International Association of Maritime Aid Organizations (IALA) to determine the risk factors of certain ships for offshore wind power plants. [13]. Others used both ES models and fuzzy logic methods to study the risk factors and their weights [14].

Lastly, a study utilized machine learning to analyze traffic flow and applied the ES model to design appropriate route widths [15]. A maritime traffic flow simulation in Korea incorporated the use of the ES model. Additionally, the blocking coefficient (BC) model illustrates the potential risk of a specific ship colliding with nearby vessels or obstacles. And the subjective judgment (SJ) model [16] offers an objective representation of the collision risk, as perceived by the ship's operator. The determination of the SJ value considers factors such as whether the ship in question is a burdened vessel in crowded areas, is maintaining its course, or is an overtaking vessel.

However, these models emphasize risk assessment based on subjective indexes with the direct involvement of the originator or ship operator, and do not focus on analyzing the liquidity of maritime traffic flow from a macro-perspective. Maritime traffic flow is affected by external environmental conditions, traffic condition, traffic rules, and more; therefore, it is important to adopt a macroscopic perspective [17]. Additionally, to accurately evaluate traffic flow, it is crucial to collect and analyze traffic flow data over a specific period and identify the correlations within these data. Consequently, the traffic datum accumulated by the vessel is an important reflection of the conditions at the time, and a quantitative assessment that measures the fluidity of the traffic flow itself that may be advantageous. Accordingly, this study aims to establish a standard plan based on traffic flow data, identify the deviation of each ship, and derive the quantitative indicators.

## 3. Maritime Traffic Flow Model

Traffic flow, or traffic stream, pertains to the movement of people and vehicles proceeding in the same direction. It can be envisioned as traffic traversing across one, two, or even more lanes [18]. Traffic flow models illustrate the relationship among the three variables of velocity, density, and traffic volume. These models can elucidate traffic flow characteristics, such as delay, congestion, and bottlenecks. While typically employed in road traffic facilities, various single-mode models have been studied, with Greenshields (linear model) [19], Greenberg (algebraic model), and Underwood (exponential model) [20] being representative examples. A recent study assumed that excessive speed was the cause of accidents in road traffic and compared the deviation of driving speed by vehicle type to the speed limit [21].

To investigate the applicability of these traditional traffic flow models to maritime traffic, the data were collected and compared. The results exhibit significant similarities to road traffic flow. However, the effectiveness was found to be low in the velocity–density model [22], which could be attributed to the inherent properties of maritime traffic.

Maritime traffic flow refers to one or more courses or flows that manifest when sea vessels move at specific speeds over a designated period. The key terms in the maritime traffic flow assessment encompass comprehensive environmental stress, navigation risk, and ship operating difficulty. These terms assess the operational burden of a ship as a risk. Prominent models include ES, PARK, BC, and SJ, each displaying unique characteristics (Table 1).

**Table 1.** Representative model of the marine traffic flow assessment.

| Model | Object | Target | Input Data | Output |
|---|---|---|---|---|
| ES | Mariner's Stress | Fairway, Waterway | • Mariner's survey<br>• Topographical condition<br>• Traffic condition | $ES_A$ (0–1000) |
| PARK | Mariner's Stress | Fairway, Waterway | • External condition<br>• Mariner's survey<br>• Topographical condition<br>• Traffic condition | PARK Value (0–7) |
| BC | Collision Risk (Potential) | Fairway, Waterway | • Ship collision avoidance support model<br>• TCPA, DCPA<br>• Topographical condition<br>• Traffic condition | BC (0–1) |
| SJ | Collision Risk (Subjective) | Fairway, Waterway | • Distance for ship<br>• Traffic condition | SJ (−3–+3) |

Maritime traffic necessitates a distinct approach compared to road traffic. In road traffic, once the mode of transport and route to the destination are established, the primary variables influencing the arrival time are velocity, density, and traffic volume [23]. However, in maritime traffic, after setting the mode of transport and route, several other considerations come into play. These include variables such as weather conditions, sea state, water depth, course-keeping quality based on ship movement characteristics, turning capacity, ship age, surrounding traffic volume and navigation, port regulations, ship operator characteristics, optimal speed, and more [24,25]. Hierarchical and coupling models have been used to propose mechanisms of factors affecting marine traffic flow [26]. Therefore, the characteristics of maritime traffic can be broadly categorized as spatiality, continuity, specificity, and safety. Among these, spatiality is the most significant property distinguishing maritime traffic from road traffic. It refers to spatial autonomy. Maritime traffic enjoys navigational autonomy in navigable sea areas. This means that a suitable course can be chosen during navigation planning within a sea area or route, as long as seaworthiness is not compromised. Furthermore, the COLREGS applies to ships, allowing maneuvers, such as overtaking and crossing, to be considered relative to other vessels. Thus, while maritime traffic is autonomous, recognizing and utilizing historically used navigation patterns or conventional routes can enhance efficiency and minimize risks. This is because these are routes that have been tested and proven over time.

Continuity pertains to the consistent velocity of maritime traffic. There are no traffic lights or stop signs at sea, resulting in an uninterrupted flow similar to that of highways. Moreover, except for some smaller vessels, speed adjustments are not immediate. Ships typically sail at an optimal speed suitable to their specific characteristics, such as type, size, and cargo type. As a result, changes in a ship's speed are gradual and not overly pronounced. Specificity refers to the environmental and human factors influencing maritime traffic. Unlike road traffic, maritime traffic is significantly impacted by external factors, such as climate and sea conditions. Variables, such as tides, wave height, and water depth, can significantly influence a ship's motion. Other contributing factors include weather conditions, such as wind and fog, sea route structure, support systems, obstructions, qualifications, and the training of ship operators, their health, and the number of crew members.

Safety encompasses the subjective risks perceived by ship operators due to interactions related to maritime traffic or traffic volume. Despite the uninterrupted flow, maritime traffic can still experience collision scenarios, such as crossings, encounters, and overtaking, which are not common in road traffic. Additionally, faults or failures in vessels can lead to substantial delays and even paralyze ports. Other factors include the cargo volume of nearby ports and peak times.

Spatiality and continuity focus on the ship's output, allowing for the assessment of the smoothness of maritime traffic flow from a macroscopic perspective. However, specificity and safety offer a microscopic perspective, assessing the risks of maritime traffic based on factors influencing ship behavior. These indices should complement each other to provide a comprehensive understanding of maritime traffic. (Figure 1).

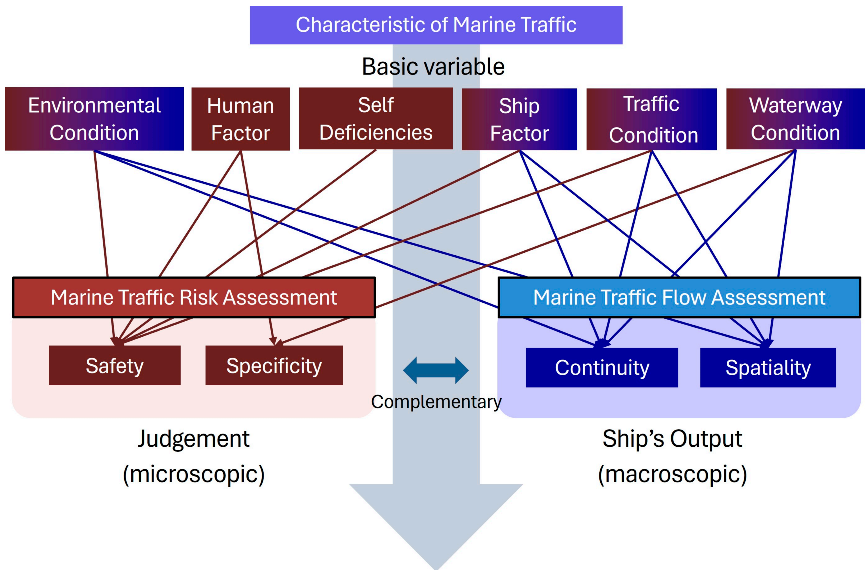



**Figure 1.** Evaluation method according to maritime traffic characteristics.

## 4. Evaluation of Maritime Traffic Flow with the CS Model

### *4.1. Overview*

Changes in course and speed are the outputs of a ship's navigation, which are based on the combined judgment of the ship's operator and the ship's navigation instruments as the ship sails. Based on this concept, we designed a course–speed (CS) model. This model serves as a method for evaluating maritime traffic flow by tracking changes in the course and speed. This model emphasizes spatiality and continuity, which are essential characteristics of maritime traffic. When a ship sails, numerous variables influence its movement. However, the CS model primarily focuses on course changes and speed variations, using these factors to assess the fluidity of maritime traffic flow.

When a ship navigates a specific sea route or area, the distribution of its sailing trajectory generally follows a normal distribution across the cross-section of traditional maritime traffic flow [27]. Any behavior deviating from this norm implies a disruption in the smoothness of the maritime traffic flow. For instance, changes in the typical course or navigational patterns in certain situations, deviating from conventional navigation routes, indicate a failure to maintain spatiality. Likewise, any changes in speed that do not adhere to the ship's optimal speed, considering its specific characteristics, suggest a failure to uphold continuity.

The CS index (Ics) is calculated based on the spatiality index (Ispa) and continuity index (Icon) as follows:

$$\mathrm{I_{cs}} = \mathrm{mean}(\mathrm{I_{spa}} + \mathrm{I_{con}}), \tag{1}$$

The spatiality index (Ispa), as defined in Equation (2), quantifies the disparity in speed and acceleration between the ship under assessment and the standard plan. In contrast, the continuity index (Icon), as defined in Equation (3), measures the variance in the course over ground (COG) and rate of turn (ROT) between the ship under assessment and the standard plan:

$$I_{spa} = \frac{1}{2n}\left(\sum_{k=1}^{n} D_k(v)+\sum_{k=1}^{n} D_k(a)\right), \quad (2)$$

$$I_{con} = \frac{1}{2n}\left(\sum_{k=1}^{n} D_k(\theta)+\sum_{k=1}^{n} D_k(r)\right), \quad (3)$$

where n represents the number of target ships for assessment and Dk(x) represents the difference between the standard plan and the target ship.

The standard plan entails collecting AIS data over a specific period as ships traverse the assessment sea area. These data are then categorized based on ship size and traffic volume, yielding an average and dispersion for each ship at distinct points. The differences in velocity (v), acceleration (a), course over ground (θ), and rate of turn (r) between the standard plan and the ship under assessment are calculated as shown.

$$D_k(x) = \int \left( \frac{\sqrt{\left(\overline{x}(t) - x_k(t)\right)^2}}{\mu(t)} \right) dt, x \in v, a, \theta, r, \quad (4)$$

where $\overline{x}$ refers to the average of the standard plan, $u$ represents the standard deviation of the standard plan, and $x_k(t)$ denotes the value of ship k at location t.

### 4.2. Evaluation with CS Models

The selected assessment area was the entry route of Ulsan Port. Ulsan Port is an international port with a wide variety of vessels; basically, it has a high traffic volume, so various vessel patterns can be observed, and it has the characteristics of showing a balanced traffic volume at any time of the day, so it is an appropriate data sample to apply to the CS model. The AIS data from 1 to 30 September 2019 were used. Figure 2 illustrates the data for the target sea area.

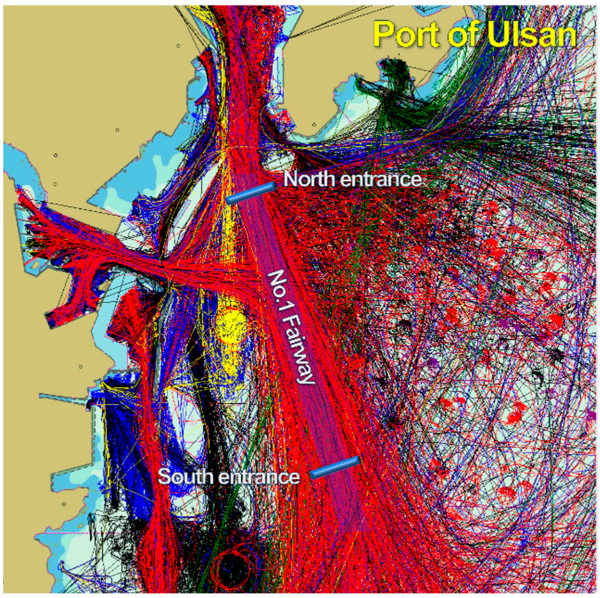



**Figure 2.** Target sea area.

The data were preprocessed to remove outliers and interpolate the missing values. Standard plans for speed, acceleration, COG, and ROT were calculated from the preprocessed data. The data categorized by size can be accessed using each standard plan. Find Dk(x), Dk(a), Dk(θ), and Dk(r). Based on this, Ispa and Icon were obtained. Ics represents the average of Ispa and Icon. Figure 3 schematically illustrates the data processing and CS model calculation procedures.

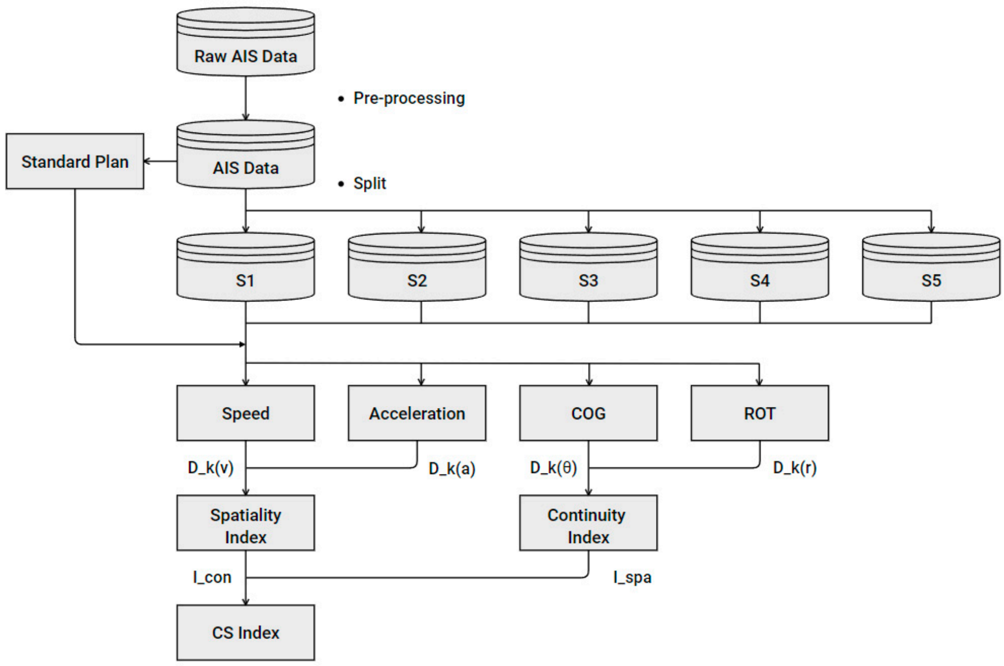



**Figure 3.** Data processing and CS model calculation procedures.

The continuity index was computed by analyzing the speed and acceleration distribution of ships traversing the assessment area, categorized by size. Using the AIS data of the target sea area, the speed was plotted against distance, and for the acceleration, the value was obtained by differentiating the speed in the same way. The results are shown in Figures 4–7. The categories were as follows: S1 (length overall, LOA, under 50 m), S2 (LOA: 50–100 m), S3 (LOA: 100–150 m), S4 (LOA: 150–200 m), and S5 (LOA: 200–250 m).

The standard plan of the speed and acceleration distribution for S1 exhibited more significant fluctuations compared to the distributions for S2 to S5. This was attributed to the tendency of smaller ships (under a 50 m LOA), which could be attributed to the characteristic of small ships below an LOA of 50 m rapidly reacting to the reduction in and acceleration of speed, as well as various types of ships passing by.

Figure 8 illustrates the analyses of Dk(v) and Dk(a), respectively, for continuity. Dk(v) mainly ranges from about −5 to +5 knots during port entry, compared to the standard plan. D(a)k typically falls between −2 to +2 knots. However, a greater deviation from the standard plan was observed during port entry rather than departure. The values of D(v)k and D(a)k depended on the ship's navigation speed and acceleration; thus, they could vary based on the designated location and time of the target assessment area. Such values may diverge in areas with nonlinear segments, intersections of navigation flows with varying directions, and within harbors. Temporal variations may arise during peak navigation periods, as well as discrepancies between the day and night.

The spatiality index was computed by analyzing the COG and ROT distribution according to ship size for vessels passing through the target assessment area. The outcomes are presented in Figures 9–12, with categories S1 (under a 50 m LOA), S2 (50–100 m LOA), S3 (100–150 m LOA), S4 (150–200 m LOA), and S5 (200–250 m LOA). Similar to the speed and acceleration distributions for continuity, the standard plan of COG and ROT distributions for S1 exhibited more significant fluctuations compared to the distributions for S2 to S5.

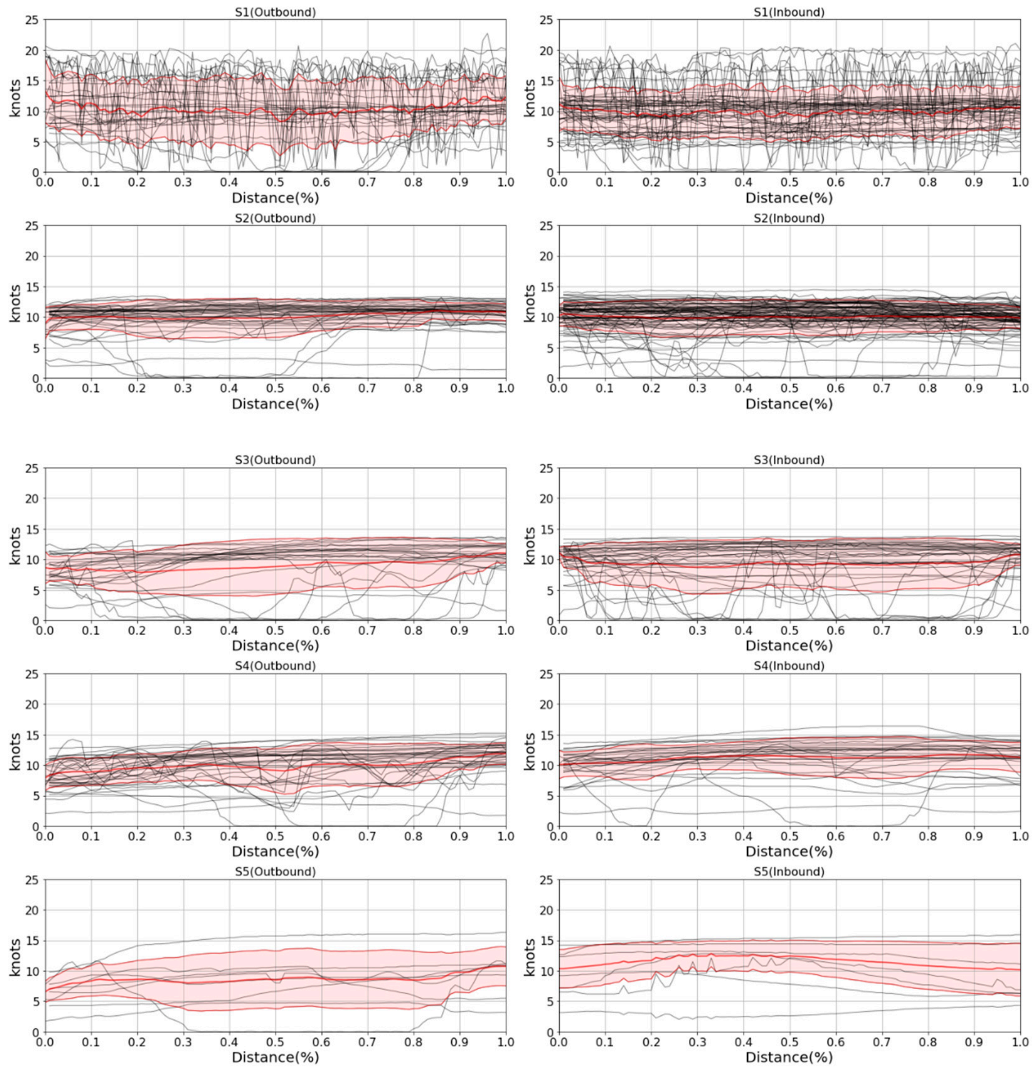



**Figure 4.** Speed distribution by ship size.

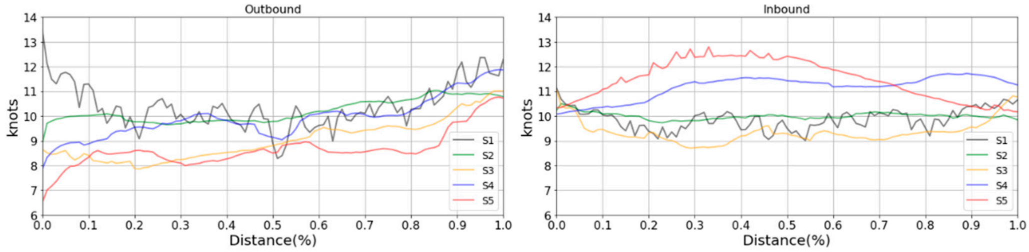



**Figure 5.** Speed standard plan comparison by ship size.

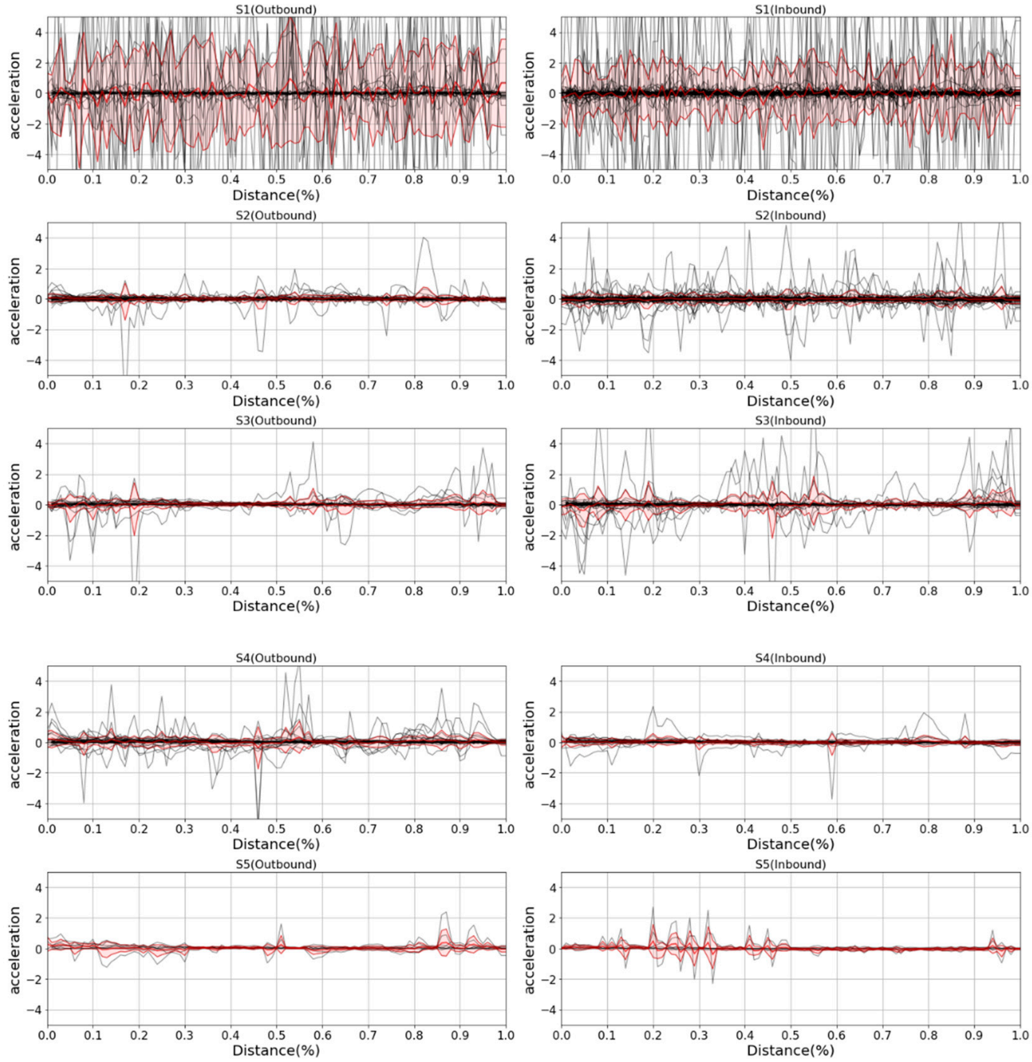



**Figure 6.** Acceleration distribution by ship size.

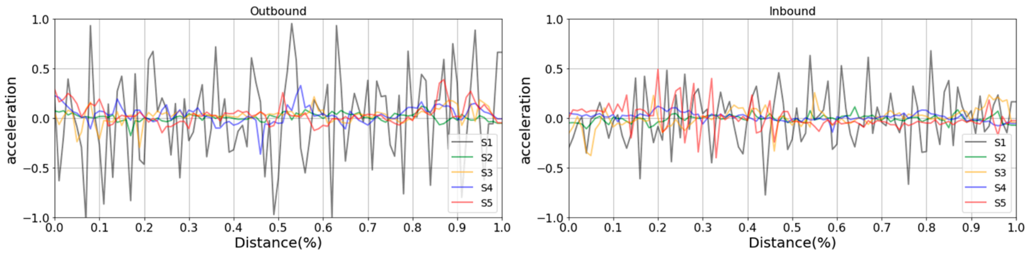
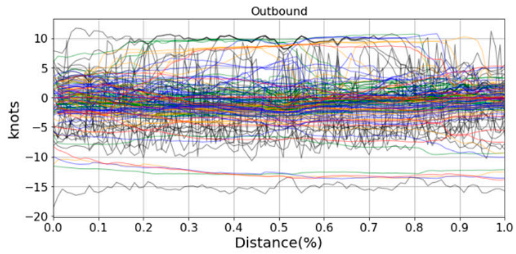
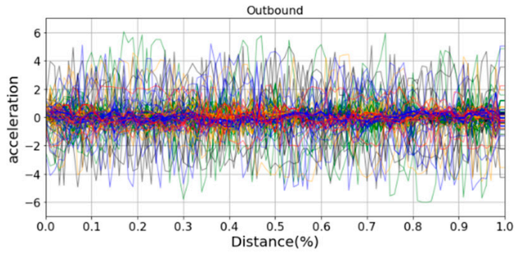



**Figure 7.** Acceleration standard plan comparison by ship size.




(**a**)




(**b**)

**Figure 8.** (**a**) Dk(v) analysis results; (**b**) Dk(a) analysis results.

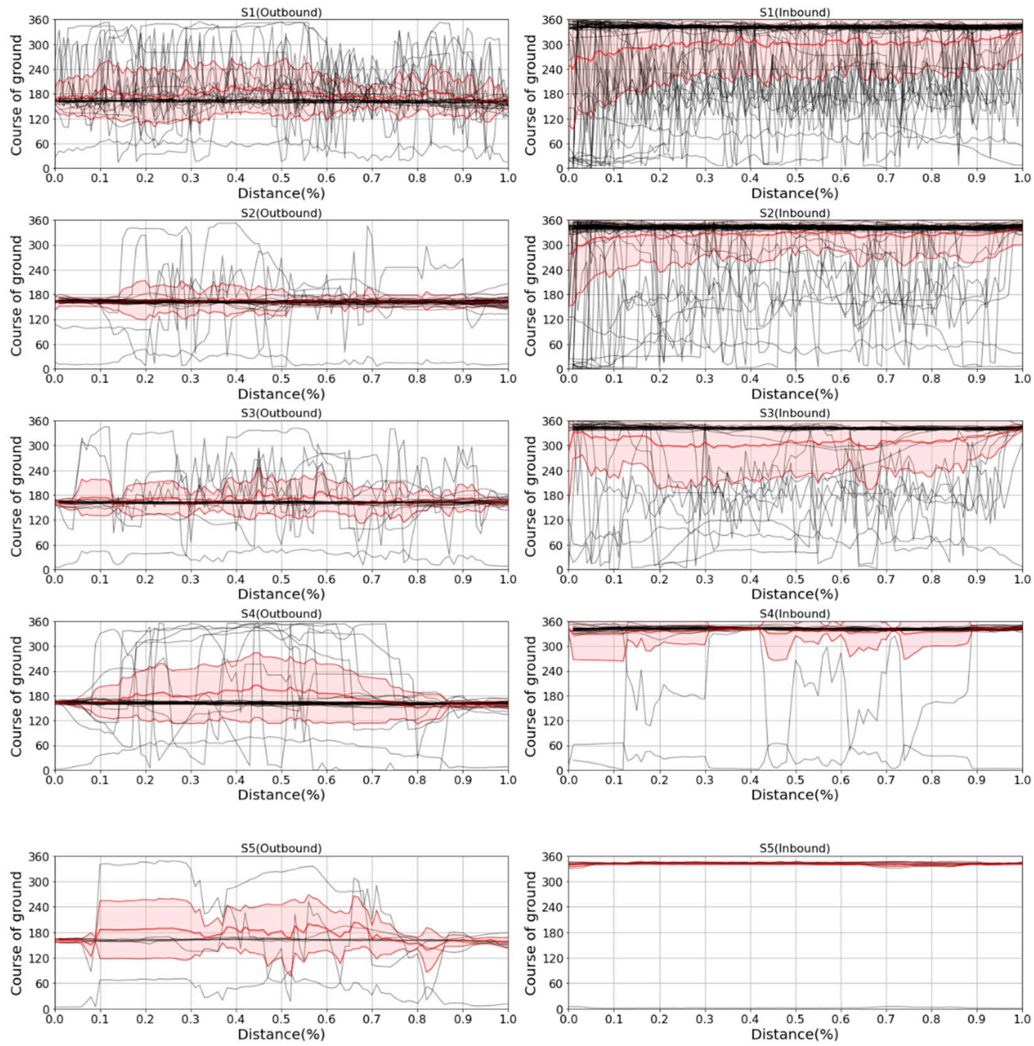



**Figure 9.** COG distribution by ship size.

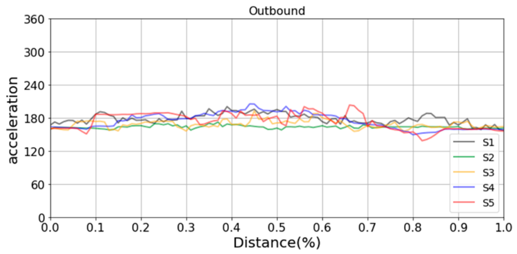



**Figure 10.** COG standard plan comparison by ship size.

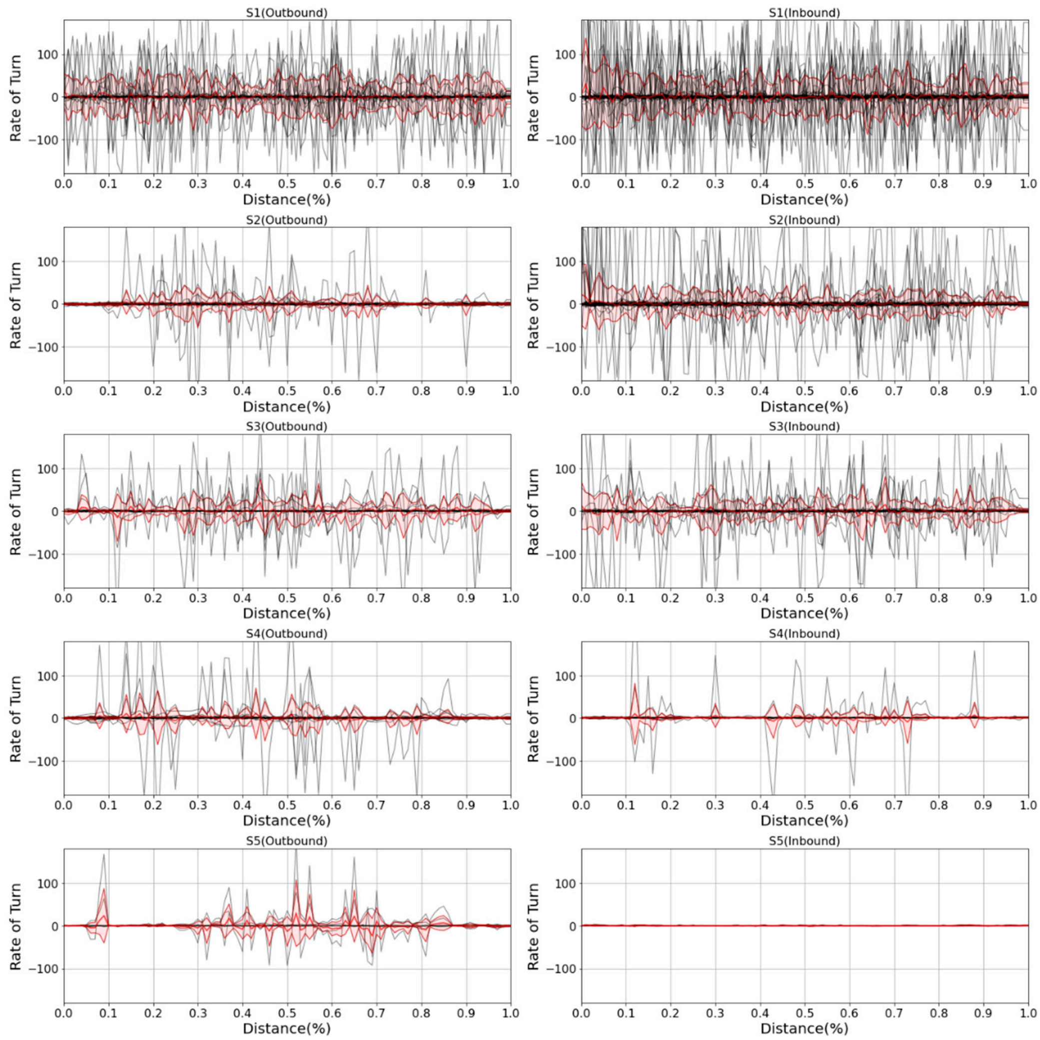



**Figure 11.** ROT distribution by ship size.

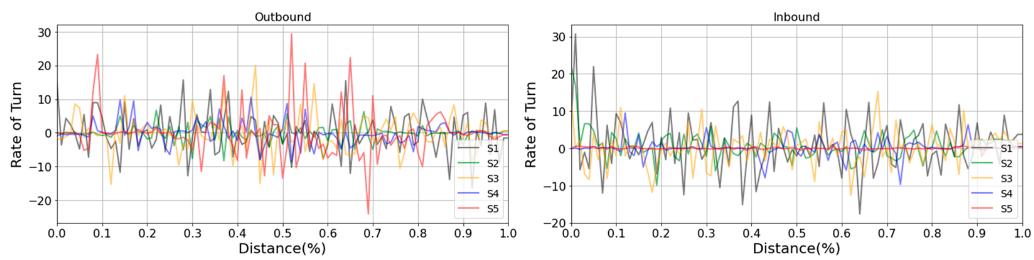
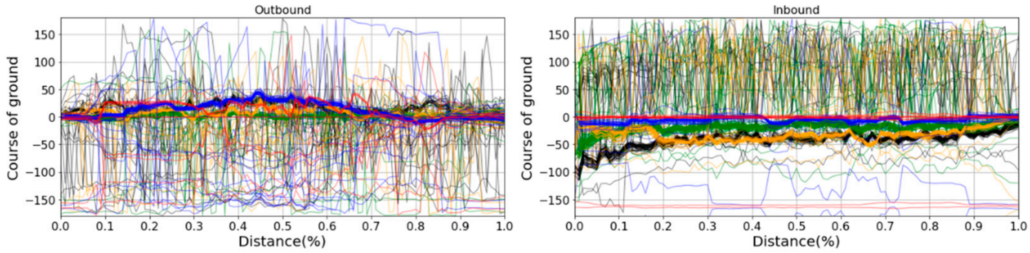



**Figure 12.** ROT standard plan comparison by ship size.

This was attributed to the tendency of smaller ships (under a 50 m LOA) to alter their course rapidly, resulting in a higher rate of convergence and a corresponding increase in the ROT value. This implied that smaller ships often deviated from the general navigation pattern, which was also considered a part of the traffic flow.

Figure 13 presents the results of the Dk(θ) and Dk(r) analyses for spatiality. Dk(θ) was primarily distributed from around −5 to +45 degrees during departure and −100 to +5 degrees during port entry in relation to the standard plan. Dk(r) was mainly distributed from −100 to +5 degrees.

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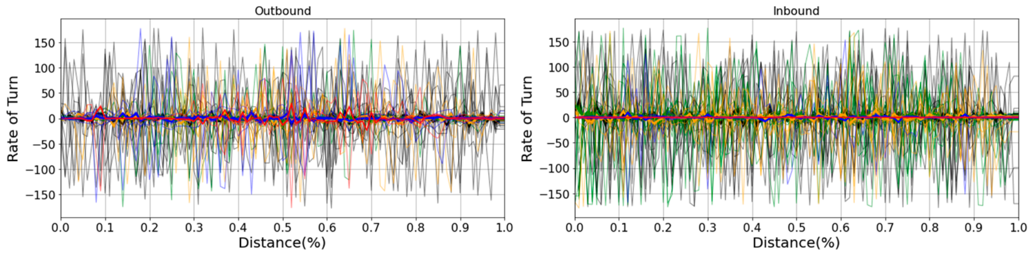


(**b**)

**Figure 13.** (**a**) Dk(θ) analysis results; (**b**) Dk(r) analysis results.

As Dk(θ) and Dk(r) depend on the COG and ROT of ships, their values, akin to Dk(v) and Dk(a), might vary based on the chosen location and time for the target assessment area. Any deviation from the standard plan in these metrics indicates the spatial characteristics of maritime traffic.

The outcomes of the continuity index, derived from the analyses of Dk(v) and Dk(a) for each ship size, are presented in Table 2. Similarly, the results of the spatiality index, obtained from the analyses of Dk(θ) and Dk(r) for each ship size, can be found in Table 3. Notably, a higher index value indicates a more substantial impact on the fluidity of maritime traffic flow, signifying a deviation from the standard navigation plan. The data in Table 2 reveal that the overall outbound continuity index outperforms the inbound index, and the data in Table 3 reveal that the inbound spatiality index outperforms the outbound index.

**Table 2.** Results of the continuity index.

| | **Dk(v)** | | **Dk(a)** | | **Continuity Index** | |
|---|---|---|---|---|---|---|
| | **Outbound** | **Inbound** | **Outbound** | **Inbound** | **Outbound** | **Inbound** |
| S1 | 0.8548 | 0.8012 | 0.7854 | 0.5781 | 0.8201 | 0.6897 |
| S2 | 0.7712 | 0.7929 | 0.8045 | 0.7583 | 0.7879 | 0.7756 |
| S3 | 0.8426 | 0.8394 | 0.7826 | 0.7107 | 0.8126 | 0.7751 |
| S4 | 0.8849 | 0.8147 | 0.7496 | 0.7417 | 0.8172 | 0.7782 |
| S5 | 0.7629 | 0.8597 | 0.7366 | 0.7426 | 0.7497 | 0.8012 |

**Table 3.** Results of the spatiality index.

| | Dk(θ) | | Dk(r) | | Spatiality Index | |
|---|---|---|---|---|---|---|
| | Outbound | Inbound | Outbound | Inbound | Outbound | Inbound |
| S1 | 0.8359 | 0.8583 | 0.7105 | 0.7277 | 0.7732 | 0.7930 |
| S2 | 0.6148 | 0.6873 | 0.6884 | 0.6832 | 0.6516 | 0.6852 |
| S3 | 0.7054 | 0.7688 | 0.6383 | 0.6049 | 0.6718 | 0.6868 |
| S4 | 0.7772 | 0.6367 | 0.7181 | 0.7175 | 0.7476 | 0.6771 |
| S5 | 0.8115 | 0.8850 | 0.7519 | 0.7922 | 0.7817 | 0.8386 |

The CS index results, derived from the analyses of the continuity and spatiality indices, are listed in Table 4. The outbound and inbound CS indices registered values of 0.7614 and 0.7501, respectively. This means that, in the target sea area, the outbound ship flow demonstrated a slightly weaker adherence to the standard plan than the inbound flow, impacting the fluidity of maritime traffic.

**Table 4.** Results of the CS index.

| | Continuity Index | | Spatiality Index | | CS Index | |
|---|---|---|---|---|---|---|
| | Outbound | Inbound | Outbound | Inbound | Outbound | Inbound |
| S1 | 0.8201 | 0.6897 | 0.7732 | 0.7930 | 0.7967 | 0.7414 |
| S2 | 0.7879 | 0.7756 | 0.6516 | 0.6852 | 0.7198 | 0.7304 |
| S3 | 0.8126 | 0.7751 | 0.6718 | 0.6868 | 0.7422 | 0.7310 |
| S4 | 0.8172 | 0.7782 | 0.7476 | 0.6771 | 0.7824 | 0.7277 |
| S5 | 0.7497 | 0.8012 | 0.7817 | 0.8386 | 0.7657 | 0.8199 |
| Avg. | 0.7975 | 0.7640 | 0.7252 | 0.7361 | 0.7613 | 0.7501 |

Various elements contribute to the CS index. These encompass ship-associated factors indicating the vessel's dynamic performance, traffic conditions evaluating the ambient traffic environment, distinctions between the open sea and harbor approaches, overall traffic volume, the efficiency of pilot services, and temporal factors. Based on the findings of this study, the characteristics of the sea route leading to the port are aptly captured by the CS model.

## 5. Conclusions and Future Work

Recent statistical data from marine transportation market research organizations indicate that maritime traffic volume might increase owing to global economic recovery and the impact of the fourth industrial revolution. Consequently, the prediction of marine accidents and the management of maritime traffic using risk assessment methods hold significant importance. However, unlike road traffic with real-time monitoring, maritime traffic requires optimizations based on historical data. The use of historically used navigation patterns or conventional routes occurs because they have been tested and verified for a long time, and the accumulated data of actual ship passage prove it and are reliable. Therefore, evaluating the suitability of maritime traffic flow necessitates a macroscopic perspective. To achieve this, this study classified maritime traffic characteristics into spatiality, continuity, specificity, and safety. Among these, spatiality and continuity, reflecting the output of ships, were considered to macroscopically assess the smoothness of maritime traffic flow based on ship AIS data. The employed CS model assessed maritime traffic flow using the changes in course and speed. This involved analyzing the COG, ROT, speed, and acceleration of each ship at specific points and calculating the deviation from the standard plan.

The analysis results of maritime traffic flow for the first sea route of Ulsan Port using the CS model are as follows: the outbound continuity index is higher than the inbound, and the inbound spatiality index is higher than the outbound. However, the same trend was not observed for different ship sizes. The outbound and inbound CS indices were measured at 0.7613 and 0.7501, respectively. This means that, in the target sea area, the outbound ship flow demonstrates a slightly weaker adherence to the standard plan than the inbound flow, impacting the fluidity of maritime traffic. Several factors influenced the CS index, including ship-related factors that determined the dynamic performance of the vessel, traffic conditions that assessed the surrounding traffic environment, open sea and harbor approaches, traffic volume, pilot services, and time. The assessment results of this research show that the characteristics of the sea route approaching the port are reflected in the CS model. This model quantitatively analyzes spatiality and continuity, two crucial characteristics of maritime traffic, to assess the smoothness of maritime traffic flow. Moreover, the model allows for intercomparisons based on the assessment range and time, offering valuable insights. To further enhance maritime traffic management, analyzing the factors that impact maritime traffic flow for each ship type and size can lead to the development of novel indices.

However, this research had several limitations, detailed as follows: first, our analysis was based on the data collected during a specific timeframe. Nonetheless, maritime traffic flow can fluctuate due to changes in aquatic facilities, port development, and the environmental context. Moreover, traffic flow can change over time, suggesting that future analyses should consider various periods (annually, seasonally, hourly, etc.) and specific circumstances.

Second, our study area was confined to the primary sea route of Ulsan Port. While this route showcases considerable baseline traffic flow and diversity in ship size and type, most maritime traffic tends to form linearly along straight courses. Consequently, the continuity and spatiality indices constituting the CS model index might not be high. For a more comprehensive assessment, it appears necessary to compare areas with different maritime traffic flow characteristics, such as turning points, intersections of ship flow, and port entrances, rather than focusing solely on straight courses.

Additionally, exploring visualization methods is essential to effectively utilize maritime traffic flow assessment results in maritime traffic management systems. Further research should focus on developing new maritime traffic flow assessment methods, including real-time assessments based on the visualization data previously mentioned.

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## Abbreviations

| | |
|---|---|
| VTS | Vessel Traffic Service |
| IMO | International Maritime Organization |
| AIS | Automatic Identification System |
| V-Pass | Vessel Pass |
| COLREGS | International Regulations for Preventing Collisions at Sea |

| | |
|---|---|
| ES | Environmental Stress |
| ESA | Aggregation of ES Value |
| ESL | Environmental Stress due to Surroundings |
| ESS | Environment Stress Induced by Other Ships |
| IALA | International Association of Maritime Aid Organizations |
| IWRAP | IALA Waterway Risk Assessment Program |
| BC | Blocking Coefficient |
| SJ | Subjective Judgment |
| CS | Course Speed |
| COG | Course Over Ground |
| ROT | Rate Of Turn |

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