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A Study of Development a Big Data-based CS Model for Maritime Traffic Assessment

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Abstract : *This research develops a big data-based CS model for maritime traffic assessment, motivated by global shipping growth, the impact of COVID-19, changes in consumer culture, and Industry 4.0 expansion in maritime sectors. Maritime traffic, crucial for global trade, demands effective management for safety and efficiency. This study aims to quantitatively and objectively evaluate maritime traffic smoothness by analyzing ship operation data. The CS model focuses on unique maritime characteristics, leveraging big data to enhance traffic management solutions and safety. The research methodology includes analyzing domestic and international trends and data to reflect maritime spatiality and continuity. The model's efficacy is tested through case studies on major port routes, comparing it with existing models to suggest improvements. This new approach provides a framework for optimizing maritime traffic routes and supports autonomous, unmanned, and smart ship operations, setting a new paradigm for maritime traffic management.*

Key words : *big data, maritime traffic flow, maritime traffic flow characteristics, spatiality, continuity, CS model*

1. Introduction

Based on reviews by shipping research institutions such as Clarksons, Alphaliner, Drewry, and UNCTAD (UNCTAD, 2023; Clarkson, 2023), the capacity and cargo volume of container ships, bulk carriers, and tankers are increasing annually, and this trend is expected to continue. Despite the COVID-19 pandemic causing an economic downturn and reduced maritime freight, increased consumer demand and economic recovery have led to rising shipping rates and continued container ship orders (BIMCO, 2023; Freightwaves, 2023). The maritime sector is also advancing autonomous ships (MASS) and smart navigation technologies, utilizing IoT, big data, sensors, and AI—key elements of the fourth Industrial Revolution (Mitsui & Co, 2019).

Consequently, the International Maritime Organization (IMO) and shipping companies are conducting studies and pilot projects to ensure the safety and reliability of autonomous ships. These advancements are expected to innovate the shipping industry, offering benefits in environmental protection and cost reduction, with commercialization expected soon. As the global economy grows, maritime traffic is also increasing, highlighting the need for effective management to tackle issues like congestion, port delays, and safety concerns. Ongoing studies focus on accident prediction, risk assessment, and management systems.

Maritime traffic has unique features compared to other transportation modes. Ships can autonomously set routes as long as seaworthiness is maintained, and traffic flow continues steadily without sudden speed changes due to the characteristics of ship movements (Lee, 2023). Operators tend to follow well-established routes tested over time for safety in various maritime conditions. This is observed both in coastal and open sea routes. The IMO's "Ship's Routeing" provides recommended routes, and services like WRI, AWT, and WNI offer routes based on weather forecasts, leading to consistent navigation flow.

Meanwhile, current models for assessing maritime traffic risks and traffic flow are diverse. They mainly evaluate navigation risks, operator burden, collision, and grounding probabilities, focusing on individual ship navigation and route conditions. South Korea's maritime safety diagnostic system also requires traffic flow assessments for setting water areas,

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constructing facilities, or developing ports (MLTMA, 2009).

These approaches enable detailed analysis but have limitations in comprehensively understanding the macroscopic characteristics and flow of overall maritime traffic. Additionally, by relying on human factors as key variables, there are inherent challenges in validating the results and potential debates over their interpretation and application. To address these limitations, this study aims to develop a big data-based CS model that quantitatively evaluates maritime traffic flow. By focusing on objective data such as course and speed, this model reduces reliance on subjective operator decisions. In this study, AIS data accumulated during ship navigation was used. Given that the data volume increases exponentially depending on the scope and period of the investigation, prioritizing necessary data for quantitative analysis is essential.

The key contribution of this study is its focus on the spatiality and continuity of maritime traffic flow. Spatiality refers to the autonomy of ships in adapting to environmental conditions, while continuity reflects the steady nature of traffic flow with stable speeds and minimal sudden changes. This study distinguishes itself from existing research by offering a model that provides a holistic, objective analysis of traffic flow, moving away from human judgment-based qualitative assessments.

Ultimately, the results derived from this model are intended to offer valuable insights for improving maritime traffic management. The model is expected to serve as a critical indicator in proposing optimal traffic flow routes for autonomous ships and smart navigation technologies, as well as predicting secondary behaviors.

2. Maritime traffic flow model

2.1 Characteristics of maritime traffic flow

In general, the main variables influencing road traffic flow are speed, density, and volume (Gazis et al, 2006). In contrast, maritime traffic flow requires consideration of multiple factors from the planning stage, such as marine geography, weather, and ocean currents, alongside dynamic characteristics of the vessel and crew. These elements significantly impact safety.

Maritime traffic involves diverse vessel types, including container ships, tankers, bulk carriers, and LNG vessels, adding complexity not only in handling but also in maintenance and regulatory compliance. Factors such as traffic volume, navigation rules, port regulations, and optimal speed must also be considered. Therefore, understanding maritime traffic flow requires a comprehensive grasp of environmental factors, vessel diversity, operator expertise, and international regulations.

Maritime traffic flow can be categorized into spatiality and continuity. Spatiality refers to the autonomy of vessels in adjusting routes to avoid obstacles, adverse weather, or other traffic, allowing for the selection of the safest and most efficient path. Unlike land or air transport, ships are not confined to fixed routes. Continuity relates to the uninterrupted nature of maritime traffic, similar to highways without traffic lights. Vessel speeds are optimized for fuel efficiency and adherence to schedules, emphasizing the importance of efficiency in large-scale transport.

Fig.1 illustrates a simplified process of the factors related to the spatiality and continuity, which are representative characteristics of maritime traffic flow.

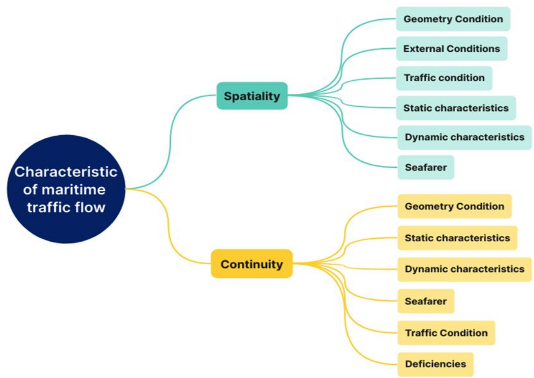


Fig. 1 Simple process based on the characteristics of maritime traffic

Fig. 2 illustrates how vessels form traffic flow through changes in course and speed, shaped by operator decisions. These decisions, based on various factors, form navigation patterns, reflecting spatiality and continuity in maritime traffic flow.

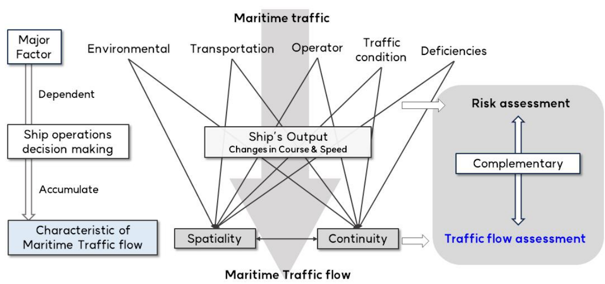


Fig. 2 Formation of maritime traffic flow

2.2 Review of current models for maritime traffic flow

The purpose of evaluating maritime traffic flow currently conducted can be found in domestic literature, where it is specified as reproducing the flow of vessel traffic and quantitatively analyzing the operational burden on ship operators (MOF, 2024). Accordingly, evaluating maritime traffic flow using existing models implies assessing the level of risk during the maritime traffic survey period based on the operator's experience.

Table 1 summarizes the models commonly used in maritime traffic flow evaluation according to the guidelines for implementing maritime traffic safety diagnostics in South Korea, along with their respective characteristics.

Table 1 Representative model of the marine traffic flow and risk assessment

Model	Object	Target	Output
ES	Mariner's stress	Fairway, Waterway	ES_A (0 - 1000)
PARK	Mariner's stress	Fairway, Waterway	PARK Value (0 - 7)
BC	Collision risk (Potential)	Fairway, Waterway	BC (0 - 1)
SJ	Collision risk (Subjective)	Fairway, Waterway	SJ (−3 - +3)

According to the maritime traffic flow evaluation models, if an operator's stress level or collision risk is high, the risk level of the area increases, suggesting the traffic flow may not be smooth. However, from a macroscopic perspective, the traffic may still flow smoothly. This highlights the subjectivity in linking operator stress and collision risk with traffic flow, as these factors depend heavily on the operator's judgment.

Differences in experience, competence, and perception of risk among operators lead to varying interpretations of maritime traffic complexity, affecting their risk management and decision-making processes (Grech et al, 2008). Maritime risk is influenced not only by environmental factors but also by the static and dynamic characteristics of vessels, the operator's proficiency, experience, health, and crew size. Thus, using risk as a direct measure of traffic flow has limitations.

Given these complexities, an ideal evaluation should take a macroscopic view and prioritize quantitative analysis of traffic flow characteristics over qualitative assessments based on operator judgment.

3. Develop CS model for maritime traffic flow assessment

3.1 Overview

When a vessel navigates a route or specific sea area, the distribution of vessel trajectories across a cross-section of customary maritime traffic flow is known to follow a normal distribution (Kim et al, 2016). Vessels that deviate from this distribution tend to be interpreted as outliers. However, in the CS model, as long as there is no interference with other vessels in navigable waters (such as fairway limit), even if a vessel deviates from the distribution, it is interpreted as having no significant impact on the macroscopic maritime traffic flow. The focus is on the distribution of course and speed exhibited by vessels in different situations rather than on the trajectory distribution itself, and these distributions are used as evaluation criteria for maritime traffic flow.

Fig. 3 shows the conceptual diagram of applying the CS model to the Standard Plan. The CS index, used to evaluate the smoothness of maritime traffic flow, is calculated based on the spatiality index and the Continuity Index. Here, the standard plan is a key component of the CS model, serving as a benchmark to determine whether the spatiality and continuity characteristics of maritime traffic flow are maintained, and it is related to the central limit theorem.

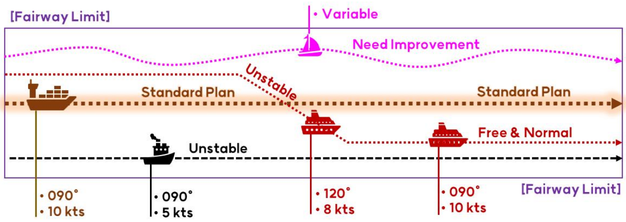


Fig. 3 CS model evaluation concept map

The CS index, used to evaluate the smoothness of maritime traffic flow, is calculated based on the spatiality Index and the continuity Index.

$$CSi = Ci \times Si \quad (1)$$

$$Ci = \frac{1}{n}\left(\sum_{k=1}^{n} D_k(\theta)\right) \quad (2)$$

$$Si = \frac{1}{n}\left(\sum_{k=1}^{n} D_k(v)\right) \quad (3)$$

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

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

Where refers to the average of the standard plan, u represents the standard deviation of the standard plan, and xk(t)denotes the value of ship k at location t.

CS model can apply different evaluation criteria depending on the usage environment, such as environmental and navigational characteristics. If factors influencing spatiality and continuity can be quantified, they can be considered in each index.

$$CSi = \alpha(Ci \times Si) \quad (5)$$

3.2 Evaluation of CS index

The CS index is an indicator representing the smoothness of actual maritime traffic flow and is classified into six conditions, ranging from Optimal Condition to Severe Unstable Condition. The CS index is set with reference to the LOS (Level of Service) of road traffic flow (Do, 2017) and is categorized into four statuses: Free, Normal, Unstable, and Improvement, considering the characteristics of transport facilities, transport modes, traffic volume, and service area differences (Lee, 2024).

Table 2 Evaluation of CS index

Status	Description	CSi
Free	Optimal Condition	0 ~ 0.2
Normal	Smooth Condition	0.2 ~ 0.4
	Moderate Condition	0.4 ~ 0.6
	Moderately Unstable Condition	0.6 ~ 0.8
Unstable	Unstable Condition	0.8 ~ 1.0
Improvement	Severe Unstable Condition	Over 1.0

4. Evaluation of with CS model

4.1 Evaluation spatial and time setting

The evaluation area was set as the approach route to Busan Port, an international port with diverse vessel types. Due to high traffic volume, unsmooth flow often occurs, providing an opportunity to analyze and identify factors affecting traffic flow.

For the evaluation period, data from one year (2021 to 2022) was used. To include various environmental and temporal factors, 10 consecutive days of data were extracted without considering periods of special traffic or weather alerts. A total of 40 days of data, 10 per season, was sampled.

The data totaled 28,514,494 datasets, with a daily average of 712,862 data points and 27,702 AIS data points per hour, varying by season.

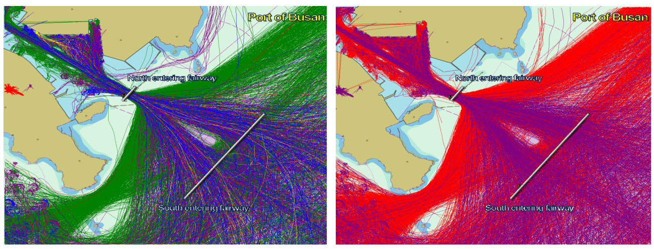


Fig. 4 (Left) LOA - over 50m ships (Right) Ships type - cargo ships, tankers

4.2 Setting the standard plan

To analyze the Standard plan in the evaluation area, outbound and inbound traffic were distinguished based on changes in course and speed. During the data analysis process, some outliers were removed. AIS data from ships in navigation can experience errors due to various factors such as ship status, speed, type, navigation area, and communication bandwidth. These errors were handled using outlier removal filters during the preprocessing stage.

For vessel size classification, six classes (S1 to S6) were defined based on ship length: S1 for vessels under 50m, S2 for 50m to 100m, S3 for 100m to 150m, S4 for 150m to 200m, S5 for 200m to 250m, and S6 for vessels between 250m and 300m.

Fig. 5 to 8 illustrate the Standard Plan according to the distribution of course and speed, categorized by traffic and ship size.

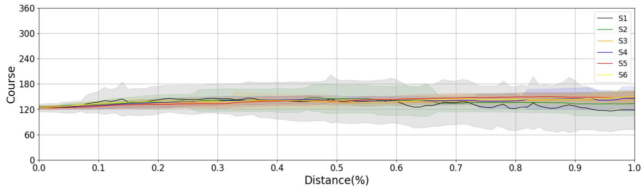


Fig. 5 Course standard plan comparison by ship size - outbound

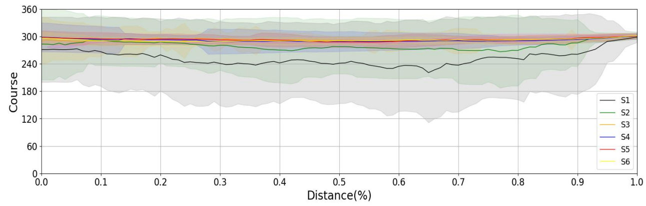


Fig. 6 Course standard plan comparison by ship size - inbound

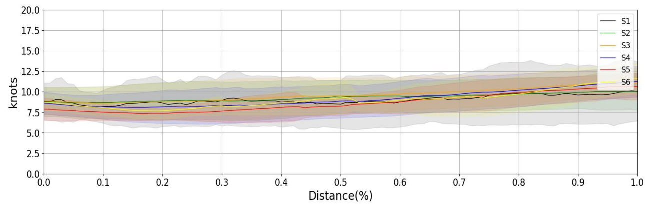


Fig. 7 Speed standard plan comparison by ship size - outbound

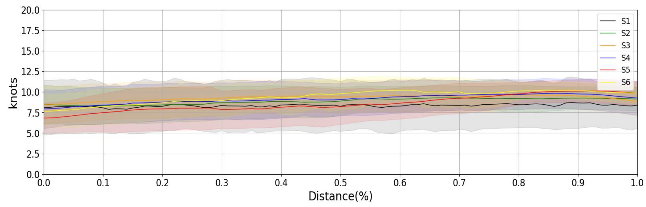
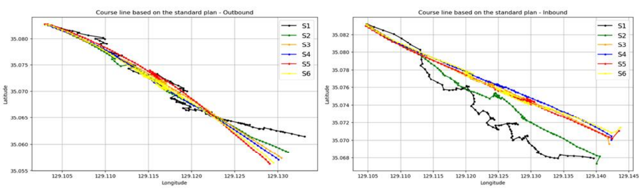


Fig. 8 Speed standard plan comparison by ship size - inbound

Additionally, the results of the two-dimensional spatial analysis according to the Standard Plan are shown in Fig. 9. It should be noted that the smoothness of maritime traffic flow is not necessarily represented by vessels precisely following the given trajectory on the two-dimensional plane, as the nature of maritime traffic flow characteristics may vary.



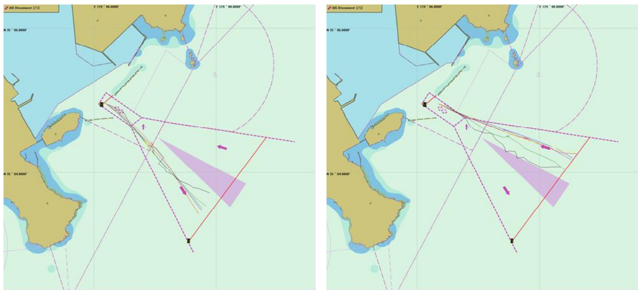


Fig. 9 Course line based on the standard plan

4.3 Spatiality and continuity analysis

The spatiality analysis results indicate that, compared to the Standard Plan, outbound traffic primarily ranged between -3deg. and +3deg., while inbound traffic ranged between -2deg. and +2deg.. The continuity analysis results show that outbound traffic mostly ranged from approximately -2.0 knots to +2.0 knots, and inbound traffic ranged from approximately -1.8 knots to +1.8 knots. Fig. 10 to 13 and Tables 3 to 4 present these results.

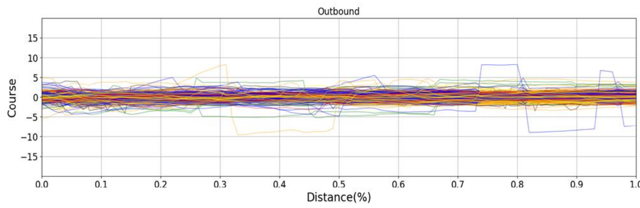


Fig. 10 Dk(Θ) Analysis Results - Outbound

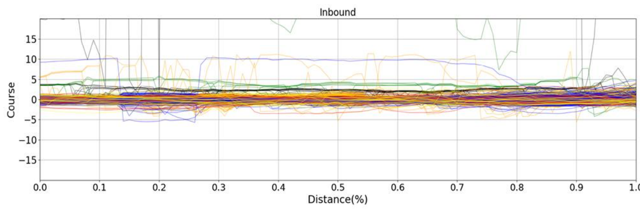


Fig. 11 Dk(Θ) Analysis Results - Inbound

Table 3 Results of the spatiality index

Size	Outbound	Inbound
S1	0.8265	0.8619
S2	0.8669	0.8985
S3	0.9208	0.9150
S4	0.8797	0.9228
S5	0.9071	0.8883
S6	0.9313	0.9213

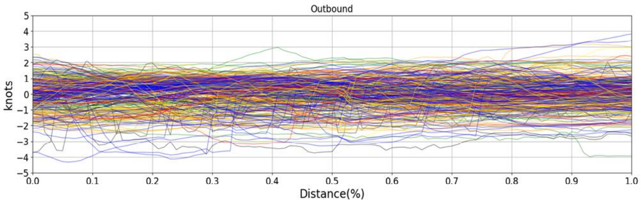


Fig. 12 Dk(v) Analysis Results – Outbound

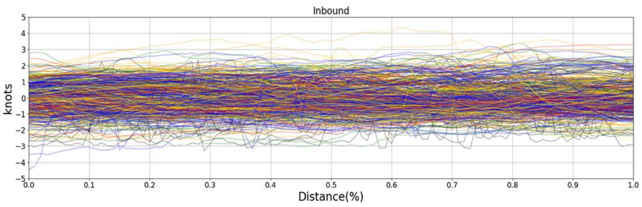


Fig. 13 Dk(v) Analysis Results – Inbound

Table 4 Results of the continuity index

Size	Outbound	Inbound
S1	0.8893	0.7054
S2	0.9297	0.8939
S3	0.9265	0.9094
S4	0.9026	0.9222
S5	0.8902	0.8987
S6	0.9193	0.8961

4.4 CS index analysis

The CS index and maritime traffic flow evaluation results derived from analyzing Dk(Θ) and Dk(v) by vessel size are shown in Table 5. A higher CS index indicates a greater impact on the fluidity of maritime traffic flow, which implies deviation from the Standard Plan.

The evaluation of maritime traffic flow for the approach route to Busan Port revealed that many segments had a CS index between 0.8 and 1.0 (Unstable). This is likely due to the narrowing or widening of the approach route, allowing vessels to select various courses and speeds depending on their destinations. Additionally, environmental factors such as changes in course and speed due to the presence of pilot boarding points and the influence of tugboat assistance are also reflected in these results.

Table 5. summarizes the CS index results, indicating areas with unstable conditions based on deviations from the Standard Plan

Table 5 Results of the CS index

Size	Outbound		Inbound	
S1	0.6 ~ 0.8	Normal	0.6 ~ 0.8	Normal
S2	0.8 ~ 1.0	Unstable	0.8 ~ 1.0	Unstable
S3	0.8 ~ 1.0	Unstable	0.8 ~ 1.0	Unstable
S4	0.6 ~ 0.8	Normal	0.8 ~ 1.0	Unstable
S5	0.8 ~ 1.0	Unstable	0.6 ~ 0.8	Normal
S6	0.8 ~ 1.0	Unstable	0.8 ~ 1.0	Unstable

4.5 Case study

The CS model allows for maritime traffic flow evaluation of entire vessels, vessel sizes, and types of vessels within the evaluation area from a macroscopic perspective, but it also facilitates the evaluation and detailed analysis of specific vessels. While macroscopic analysis can identify general behaviors or trends, it is difficult to precisely analyze the unique behavioral patterns or operational performance of individual vessels. Therefore, a case study on a specific vessel can quantitatively evaluate whether that vessel adheres well to the characteristics of maritime traffic flow, such as spatiality and continuity.

For the case study in the approach route to Busan Port, a vessel from the S4 group was selected as an example for the study case. By analyzing real-time AIS data from the vessel, the CS model can quantitatively assess how well the vessel follows the Standard Plan and responds to changes in the maritime environment. Figures 14 to 17 show the Standard Plan of the S4 group and the course line of the case study vessel.

The case study vessel was entering Busan Port North Harbor through the South Entering Fairway. During navigation, it deviated from the route, made a turn, and then re-entered the route at the midpoint. This deviation and subsequent correction were quantitatively measured by the CS model, allowing for precise evaluation of traffic flow smoothness and identifying the points where traffic congestion or inefficiencies occurred.

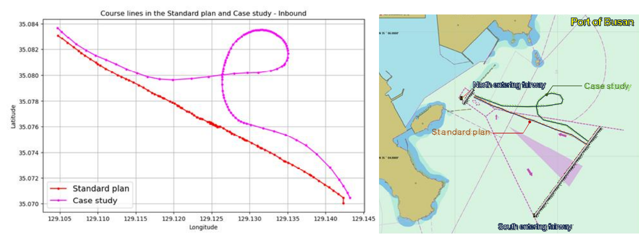


Fig. 14 Course lines in the standard plan and case study

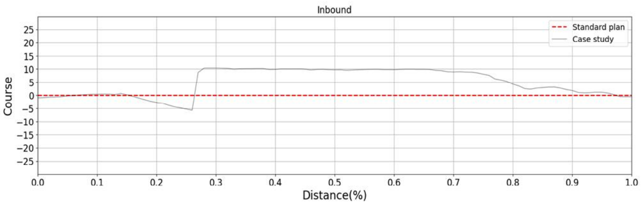


Fig. 15 Dk(Θ) analysis results for case study - inbound

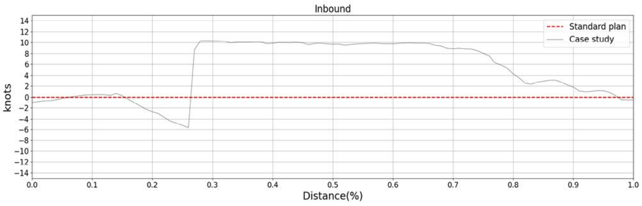


Fig. 16 Dk(v) analysis results for case study - inbound

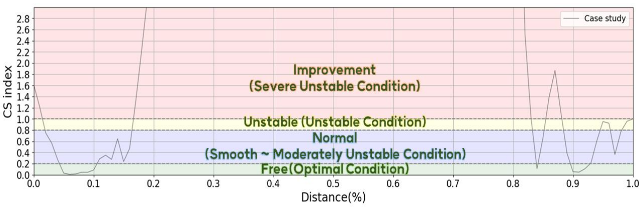


Fig. 17 CS index analysis results for case study

5. Conclusion

This study proposed a model for analyzing and evaluating maritime traffic flow from a macroscopic perspective. The model aims to quantitatively and objectively evaluate the smoothness of maritime traffic flow based on big data generated by the navigation of multiple vessels, providing important information that can be used to improve maritime traffic management. Additionally, it offers the potential to propose optimal routes for autonomous ships and smart navigation technologies, and to serve as a key indicator for predicting secondary behaviors.

Unlike existing models, which rely on the subjective judgment of operators for risk assessment, the CS model developed in this study differentiates itself by providing a more structured and objective tool for analyzing maritime traffic flow based on data such as course and speed. This data-driven approach minimizes subjectivity and allows for a more accurate and reliable evaluation of traffic flow.

The ideal maritime traffic flow evaluation proposed in this study focuses on analyzing maritime traffic flow from a macroscopic perspective and aims for a quantitative evaluation of traffic flow characteristics rather than qualitative assessments based on the subjective judgment of operators.

To develop a new maritime traffic flow evaluation model, the following research procedures were carried out:

First, the characteristics of maritime traffic flow were presented in terms of spatiality and continuity. Spatiality refers to the spatial autonomy and customary navigation patterns, which are significant distinguishing features of maritime traffic compared to other types of traffic flow, while continuity refers to the continuous speed characteristic that results from the nature of the transport means(vessels).

Second, the purpose of evaluating maritime traffic flow was defined. The evaluation aims to assess how well the spatiality and continuity characteristics of maritime traffic flow are maintained. Accordingly, the CS(Course & Speed) model was designed, focusing on course and speed data that vessels change during navigation. Changes in course and speed are the results of decision-making based on the condition of the vessel and the information provided by navigational instruments, which collectively form the passage patterns of maritime traffic flow.

Third, evaluation criteria for the CS model were established. The CS index, derived using the CS model, is calculated based on the Spatiality Index and Continuity Index, each reflecting the degree of adherence to the Standard Plan. The evaluation indicators for the CS index are divided into four statuses: Free, Normal, Unstable, and Improvement, and further classified into six detailed conditions. Fig. 18 shows the overall structure of the CS model developed in this study.

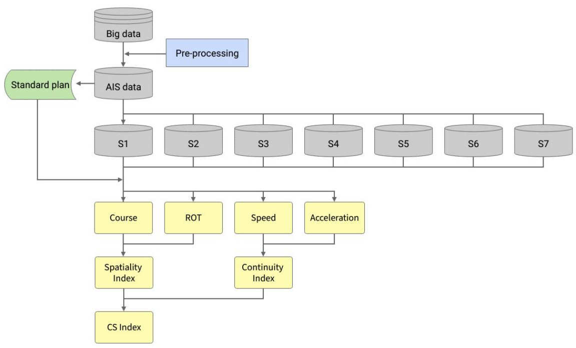


Fig. 18 CS Model Procedures

For the evaluation and application of the CS model developed in this study, the approach route to Busan Port, a major domestic port entry route, was analyzed. The results indicated that, although there were differences depending on vessel size and flow direction, many segments had a CS index between 0.8 and 1.0, indicating an unstable condition. Therefore, maritime traffic flow was analyzed as being in an unstable state.

Nonetheless, there are some limitations to this study. First, the analysis was based on big data collected over a specific period, which means it did not reflect the characteristics of maritime traffic flow over diverse timescales. As maritime traffic flow characteristics can change over time, future research should consider longer periods (over a year) or various timeframes (annual, seasonal, hourly, etc.).

Additionally, the evaluation area was limited to domestic port entry routes and coastal passage routes. Although these areas have high traffic volumes and feature a wide range of vessel sizes and types, maritime traffic tends to follow linear routes. Therefore, the spatiality and continuity indices of the CS model may be analyzed more stably.

Hence, future studies will explore visualization methods, including real-time use and verification, to effectively utilize the results of maritime traffic flow evaluation using the CS model in maritime traffic management systems. Furthermore, emphasis will be placed on developing evaluation methods that provide alternatives for improving maritime traffic management and predict maritime traffic flow in response to future cargo volumes.

Acknowledgements

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References

[1] BIMCO(2023), Container Shipping Market Overview & Outlook Q4 2023.

[2] Clarkson PLC(2023), 2023 Annual Report.

[3] Do, C. U.(2017), Transportation Engineering.

[4] Gazis, Denos C.(2006), Traffic Theory, Springer Science & Business Media, Vol. 50.

[5] Grech, Michelle, T. Horberry, and T. Koester(2008), Human Factors in the Maritime Domain, CRC Press.

[6] Kim, J. K., Ahn, Y. J., Kim, S. W. and Lee, Y. S.(2016), “A Normal Distribution Test of Passing Main Fairway for Dangerous Goods Tanker on Busan Port”, The Korean Society of Marine Environment & Safety, Vol. 11.

[7] Lee, E. J.(2024), “A Study of Development a Big Data-based CS Model for Maritime Traffic Assessment”, Korea Maritime and Ocean University, Department of Coast Guards Studies Graduate School, PhD Dissertation.

[8] Lee, E. J., Kim, H. S., Lee, E. K., Kim, K. S., Yu, Y. U. and Lee, Y. S.(2023), “Improving the Maritime Traffic Evaluation with the Course and Speed Model”, Applied Sciences, Vol. 13, No. 23, p. 12955.

[9] Ministry of Land, Transport and Maritime Affairs and Korea Institute of Marine Science and Technology Promotion(2009), Planning Research for the Development of Maritime Traffic Safety Evaluation Model and Integrated Risk Assessment and Analysis Technology for Coastal Waters.

[10] Ministry of Oceans and Fisheries(2024), Maritime Traffic Safety Act, Enforcement Decree of the Maritime Traffic Safety Act, Enforcement Rules of the Maritime Traffic Safety Act, Guidelines for Implementing Maritime Traffic Safety Diagnostics.

[11] Mitsui & Co(2019), Maritime Autonomous Surface Ships: Development Trends and Prospects.

[12] Freightwaves, “Tidal Wave of New Container Ships: 2023-24 Deliveries to Break Record”, https://www.freightwaves.com/news/tidal-wave-of-new-container-ships-2023-24-deliveries-to-break-record.

[13] United Nations Conference on Trade and Development (2023), Review of Maritime Transport 2023, Geneva, Switzerland.

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