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RESEARCH ARTICLE

Analysis of Extraction Method for Maritime Traffic Intensity Zone Through Occupancy Rate of Automatic Identification System Data

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ABSTRACT This study addresses the challenges of effectively reflecting maritime traffic flows in Korea's MSP. Maritime traffic intensity zones were identified through a spatio-temporal density analysis and the application of standardization techniques. This study proposes unified extraction standards for maritime traffic intensity zones and provides quantitative indicators for MSP based on the occupancy rates of Automatic Identification System (AIS) data. The results of the spatio-temporal density analysis were polygonized and represented at 10% intervals. A suitable maritime traffic intensity zone was then selected based on the occupancy rates of ship counts and ship points within each polygon, followed by a statistical review. Consequently, the maritime traffic intensity zone with an upper 20% density was identified, and the zone exhibiting an upper 10% density was designated as the primary maritime traffic intensity zone. This approach facilitates improved navigation and port area reflections, as anticipated from the implementation of unified extraction standards and methods for maritime traffic intensity zones established by local governments in Korea.

INDEX TERMS Maritime traffic intensity zone, occupancy rate, spatio-temporal density, automatic identification system (AIS) data, polygonization.

I. INTRODUCTION

Global warming has progressed at the fastest rate over the past 2,000 years due to continuous greenhouse gas emissions [1]. To overcome this, the international community reached its first agreement specifying the transition from fossil fuels at the 28th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) [2]. As a result, the burgeoning renewable energy industry, particularly offshore wind power generation, is garnering significant attention [3]. Ships tend to follow established routes based on historical tracks, and the presence of marine facilities notably influences these patterns [4]. Due to the geographical characteristics of Korea, being surrounded by sea on three sides, maritime logistics serves as a major means of transportation [5]. According to the 5th Long-Term Shipping Industry Development Plan announced by the Ministry of Oceans and Fisheries (MOF), 99.8% of Korea's cargo volume is transported through imports and exports, constituting the majority of transportation [6]. In PIANC [7], when installing an offshore wind farm complex, the separation distance is set at a distance equivalent to six times the maximum vessel length in the target sea area. Meanwhile, the United Nations Convention on the Law of the Sea [8] sets the separation

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TABLE 1. GICOMS traffic concentrated navigation area input parameter and reflection status by local government.

Region	Notice date	Input parameter of Port and Navigation Zone	Occupancy rate	Reflection of traffic flow
Busan	Feb. 03rd 2020.	Top 2 of Class 5	8.30%	
Gyeonggi	Sep. 30th 2021.	Top 3 of Class 5	29.36%	
Incheon	Sep. 30th 2021.	Top 3 of Class 5	4.33%	
Jeju	Dec. 29th 2021.	Arithmetic Mean of 1 year (0 ~ 1)	0.15%	
Gyeongsangnam-do	Dec. 30th 2021.	Top 2 of Class 5	6.79%	
Chungcheongnam-do	Feb. 21st 2022.	Arithmetic Mean of 1 year (0 ~ 1)	8.48%	○
Gwangwon	Apr. 25th 2022.	Arithmetic Mean of 1 year (0 ~ 1)	1.54%	
Ulsan	May. 30th 2022.	Top 3 of Class 5	26.81%	
Jeollanam-do	May. 31st 2022.	Arithmetic Mean of 1 year (0 ~ 1)	1.24%	
Jeollabuk-do	Jun. 29th 2022.	Top 3 of Class 5	4.26%	
Gyeongsangbuk-do	Jun. 30th 2022.	Top 3 of Class 5	9.16%	

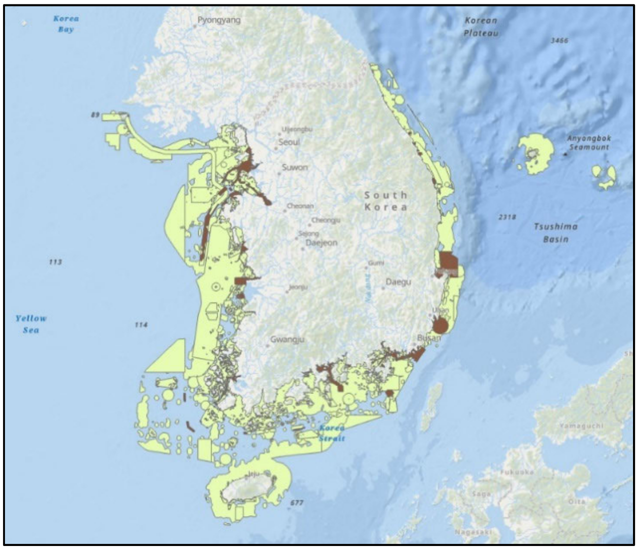


FIGURE 1. Port and navigation zone within the marine spatial planning area in Korea.

distance at 500 m for artificial facilities. Additionally, when a facility is located on the starboard side, the International Ship Collision Prevention Rules (COLREG) established by the International Maritime Organization (IMO) [9] suggest securing a free water area of 0.3 nautical miles. In Korea, regulations are being created and managed to ensure that safety separation distance standards are met through a maritime traffic safety assessment system when installing offshore wind farm sites [10].

In Korea, the Marine Spatial Planning (MSP) Act was enacted and implemented in 2018 to minimize conflicts based on the purpose of using marine space and to enable its effective use [11] (MOF, 2021). Under the MSP Law, nine types of marine use zones have been designated to regulate and manage the use, development, and conservation of marine spaces. The marine use zones related to maritime traffic are the port and navigation zones, which are essential for maintaining port functions and are defined as areas necessary for the safe operation of ships. According to the marine spatial characteristic assessment [12], the core activities of ports and navigation zones include major ports and vessel passages; the evaluation items for major ports are trade ports and coastal ports, which encompass sea routes, traffic safety-specific sea areas, anchorages, traffic separation zones, and the General Information Center on Maritime Safety and Security (GICOMS) maritime traffic intensity zone. The GICOMS represents the national Automatic Identification System (AIS) managed by the Korean government to enhance ship safety and security [13]. In Korea, marine space management plans have been announced in 11 local government jurisdictional waters, starting from Busan in February 2020 to Gyeongsangbuk-do in June 2022 [14]. Table 1 illustrates the evaluation item standards and designation status related to the GICOMS maritime traffic intensity zone, reflecting port and navigation zone designations in Korea. Navigation routes, anchorages, traffic separation zones, and traffic safety-specific sea areas were scored based on their presence or absence (presence $= 1$, absence $= 0$), and these scores were integrated into the marine space management plan. Regarding the GICOMS traffic density, regional variations exist; however, in most cases, it was categorized into five grades, with 1 point assigned to the upper two or three grades. An exception in Chungcheongnam-do's marine space management plan was that the analysis results of the GICOMS traffic-concentrated area were reflected as use zones, and in most areas, ship traffic flow was not efficiently reflected. This inefficiency arises from variations in the interpretation of maritime traffic

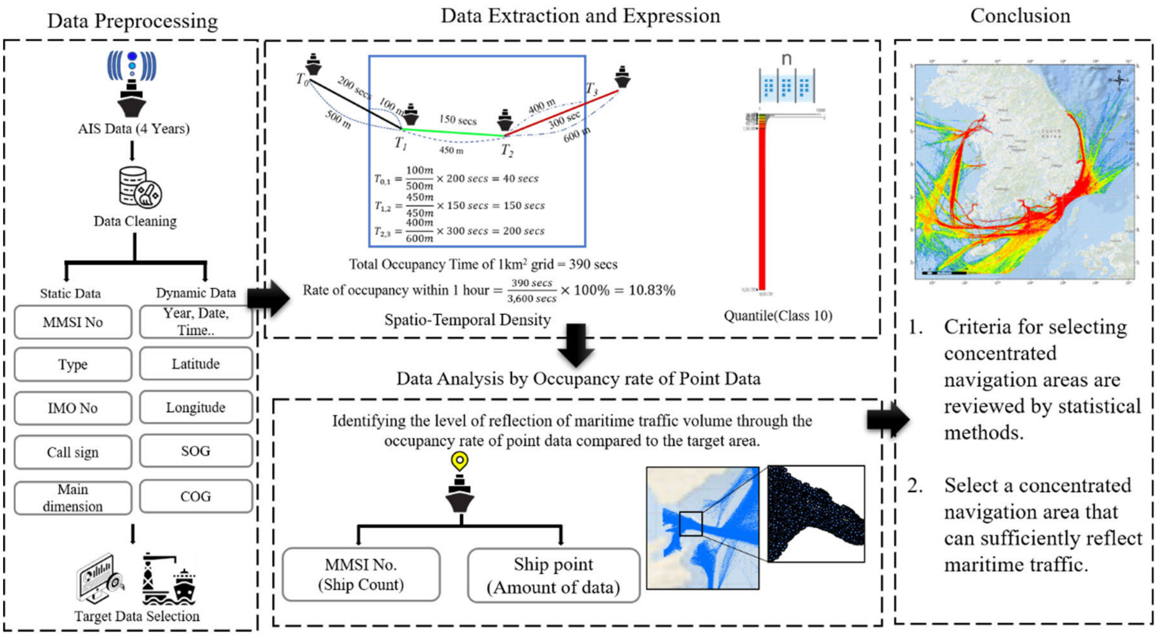


FIGURE 2. Flow chart of this study.

data due to different input standards and analysis techniques across regions.

Figure 1 illustrates the current extent of port and navigation zones in Korea, which comprise a small 4.91% of the total maritime use zone. If the navigation area for commercial ships is not recognized as a designated use area, it may be given lower priority compared to other uses such as energy development, potentially infringing on the right of passage for ships and leading to a reduction in trade. To overcome this issue, there is a need for the standardization and systematization of analysis methods. In addition, to resolve the problem of inefficient reflection of maritime traffic flow due to the high density of ships anchored or moored within port areas, it is necessary to re-establish standards for analyzing maritime traffic density and high-traffic areas that are appropriate to the current maritime traffic conditions in Korea. In this study, an analysis was conducted based on integrated AIS information of cargo ships and oil tankers, which are major ship types engaged in international voyages, with target areas including the Exclusive Economic Zone (EEZ) of the Republic of Korea. Then, using ArcGIS Pro version 3.2, the main passage areas of the target sea area were identified using statistical techniques through AIS data occupancy analysis based on spatio-temporal density analysis [15]. If this study presents a method to standardize appropriate standards and analysis techniques for GICOMS traffic maritime traffic intensity zones, it will be possible to present quantitative indicators that can claim navigation port areas in Korea's maritime spatial planning and identify traffic-dense sea areas. It will also be of great help in establishing ship decarbonization strategies and preparing maritime safety measures.

TABLE 2. AIS data reporting intervals.

Ship's Dynamic Conditions	Reporting Interval
Ships anchored or moored and not moving faster than 3 knots	3 min
Ships anchored or moored and moving faster than 3 knots	10 s
Ships with speeds ranging from 0 to 14 knots	10 s
Ships with speeds ranging from 0 to 14 knots and changing course	3 1/3 s
Ships with speeds ranging from 14 to 23 knots	6 s
Ships with speeds ranging from 14 to 23 knots and changing course	2 s
Ship speed > 23 knots	2 s
Ships with speeds > 23 knots and changing course	2 s

II. METHODS

Figure 2 outlines the overall research flow of this study. Initially, the target area was defined and the relevant AIS data were retrieved. To obtain these data, access was granted to a database containing AIS records spanning four years, from 2018 to 2021. This database holds approximately 4.0 TB of information and encompasses all the AIS data recorded from vessels traversing the South Korean sea area, including the EEZ.

A. AUTOMATIC IDENTIFICATION SYSTEM DATA

Extensive maritime data analysis has traditionally faced challenges due to the limited network size of the shipping industry [16]. However, recent advances in satellite technology have significantly improved communications between ships, resulting in the accumulation of vast data resources.

TABLE 3. Results of monthly review of cargo volume data in Korea from 2018 to 2021 by PORT-MIS.

Month	Year			
	2018	2019	2020	2021
1	342,157,557	359,576,242	343,085,960	343,136,002
2	308,192,649	304,809,291	339,432,263	306,877,331
3	337,299,845	345,716,120	363,562,368	354,265,602
4	337,586,798	343,416,824	335,079,537	337,491,181
5	346,433,261	352,364,746	339,763,514	343,355,720
6	335,398,635	339,601,277	326,826,547	341,300,871
7	341,163,203	344,944,788	345,327,217	349,674,422
8	328,469,406	345,766,466	325,630,552	336,373,172
9	331,050,612	320,979,044	336,873,525	331,833,388
10	342,864,878	353,281,700	336,742,007	360,534,328
11	345,263,702	343,114,120	338,524,468	337,720,102
12	345,220,117	362,879,384	335,533,739	353,542,719
Total	4,041,099,663	4,116,450,002	4,066,381,697	4,096,104,838

TABLE 4. Comparison of AIS data used in the analysis of previous studies.

Category	Lee and Cho [26]	Kim et al. [27]	This study
Period	Seasonal analysis by week 1st –7th March, June, September, December 2018	Seasonal analysis by month March, June, September, December 2018	Seasonal analysis considering maximum cargo volume by month March, June, September, December 2020
Type	Cargo, tanker, towing, passenger		Cargo and tanker
Length	Over the 60 m length overall		No limitation
Speed	No limitation	Over 3 knots	

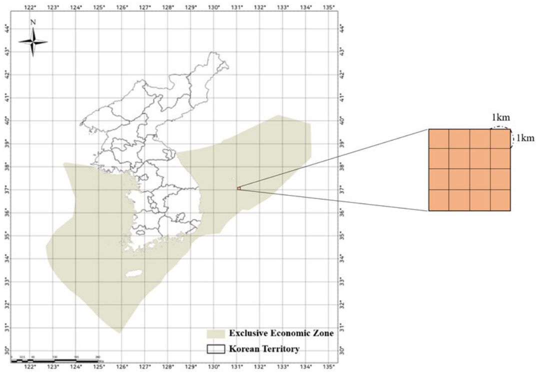
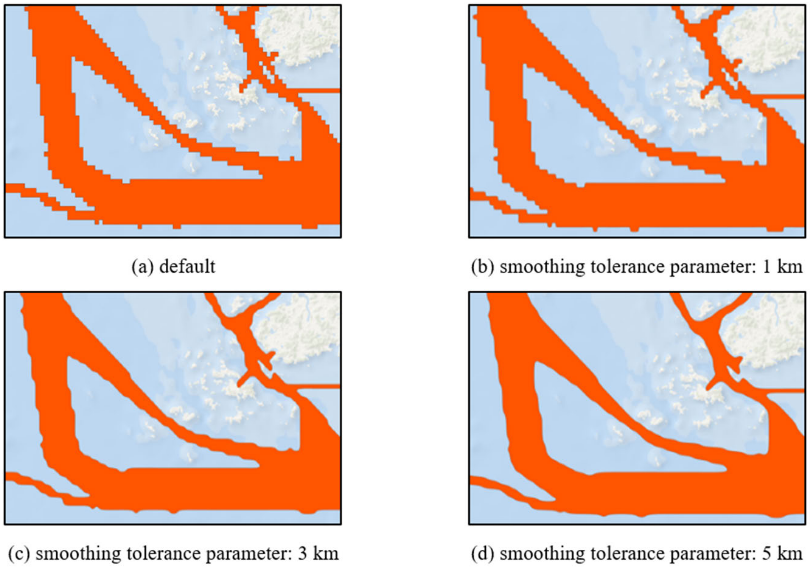


FIGURE 3. Target area of this study.

These data, sourced from AIS transmissions, are promising for enhancing safety measures and supporting diverse research initiatives in maritime navigation. For instance, Dreyer [17] leveraged historical AIS data to model traffic patterns in Norway and derived optimal speeds through regression analysis. Similarly, Lee et al. [18] utilized AIS data to study customary maritime traffic behavior in Korea and established a framework for identifying prevalent maritime routes. Kang et al. [19] conducted a study on congestion in narrow waterways in the Houston ship channels using AIS data. Slaughter et al. [20] explored vessel trajectory prediction using AIS data and a recurrent neural network algorithm. Kim et al. [21] devised an avoidance algorithm for scenarios involving multiple ship encounters and validated their approach using AIS data from real vessels navigating the Strait of Dover. Singh et al. [22] developed a maritime traffic simulator using 4 months of historical AIS data and developed a plan to reduce maritime traffic congestion through multiagent decision-making. Moreover, Itoh [23] focused on predicting future traffic trends and ship encounter probabilities near Fukushima, Japan, using AIS data. Notably, examining traffic characteristics using AIS data serves as a foundational step in comprehensively understanding ship traffic dynamics and conducting thorough data analysis [24].

According to the International Telecom Union [25], the transmission cycle of an AIS varies depending on the operating status of the ship. Table 2 lists the reception periods of the AIS signals. For this analysis, berthing or moored vessels that did not affect maritime traffic flow were excluded. Additionally, data from vessels traveling at three knots or more were filtered to utilize data with a relatively regular reception cycle (2–10 s).

In this study, a basic analysis of one-month data was established as the principle for examining maritime traffic flow of ships in various operational types, influenced by


(a) default

(b) smoothing tolerance parameter: 1 km

(c) smoothing tolerance parameter: 3 km

(d) smoothing tolerance parameter: 5 km

FIGURE 4. Example of PAEK algorithm results according to smoothing tolerance parameter settings.

seasonal sea conditions and changes in cargo. The target period for this study was to review maritime cargo volume in Korea from 2018 to 2021 through the Port Management Information System (PORT-MIS) [26], which provides data on Korea's maritime cargo volumes. The analysis focused on the month with the highest cargo volume. Table 3 displays the total monthly cargo volumes from 2018 to 2022. In March 2020, the cargo volume peaked at 363,562,368 tons, the highest compared to any other month during the entire period. This analysis specifically reviews the traffic volume of March 2020 based on the cargo volume. Additionally, to examine seasonal changes, the months of June, September, and December 2020 were also included in the analysis.

Along the coast of Korea, customary traffic routes have long been established and optimized for vessel operations by type, including domestic and international cargo transportation. Particularly, cargo and tanker ships engaged in international voyages have established customary passage routes between ports, focusing on major trade ports. This study conducted an analysis based on integrated AIS information from cargo ships and oil tankers, the primary ship types engaged in international voyages, with target areas including the EEZ of the Republic of Korea. Table 4 compares the characteristics of our data with those of Lee and Cho [27] and Kim et al. [28]. In this study, we utilized more up-to-date data than previous studies and aimed to more accurately reflect the traffic characteristics of ships engaged in international voyages by focusing solely on tankers and cargo ships. However, as ships engaged in international voyages often exceed 60 m in length, ship size was not separately considered in this analysis.

B. ANALYSIS AREA MODELING

Density analysis necessitates establishing a grid comprising cells of specific sizes within a designated analysis area [29]. The European Marine Observation and Data Network (EMODnet), supported by the EU's integrated maritime policy, adopts 1 × 1 km grid cells to cover all EU waters and certain adjacent regions [30]. In contrast, a marine spatial characteristic assessment in Korea [12] outlines that the grid structure within the territorial sea is $3' \times 3'$ (approximately 5 km^2), and within the EEZ, excluding the territorial sea, it is $15' \times 15'$ (approximately 25 km^2). However, considering the density of marine space usage, the grid size was adjusted to $1'30'' \times 1'30''$ (approximately 2.5 km^2), $30'' \times 30''$ (approximately 1.0 km^2), and $3'' \times 3''$ (approximately 100 m^2). The Maritime Spatial Planning and Management Act mandates organizing the sea area into a grid format for the quantitative analysis of maritime traffic. For this study, a grid size of 1 km × 1 km was selected, as depicted in Figure 3, which illustrates the target area and the 408,566 grids.

C. ANALYSIS DATA MODELING

The maritime traffic intensity zone was extracted and categorized into 10 classes using the quantile-display method, an effective approach for illustrating relative differences between sections [27]. The results were divided into 10% intervals, and the analysis involved polygonizing each segment starting from the lowest 10%. The extracted density in this study was polygonized to facilitate comparative analysis. The smoothing of polygons was performed using the polynomial approximation with exponential kernel (PAEK) algorithm [31]. Figure 4 illustrates an example of the smoothing results for the South Sea of Korea obtained using the PAEK algorithm. As the smoothing tolerance parameter increased, the lines forming the grid became smoother. This adjustment affected the distance between the vertices of the polygon, with smaller parameters yielding a more uneven and rough surface appearance. However, as the smoothing tolerance parameter increases, the polygon's shape becomes larger

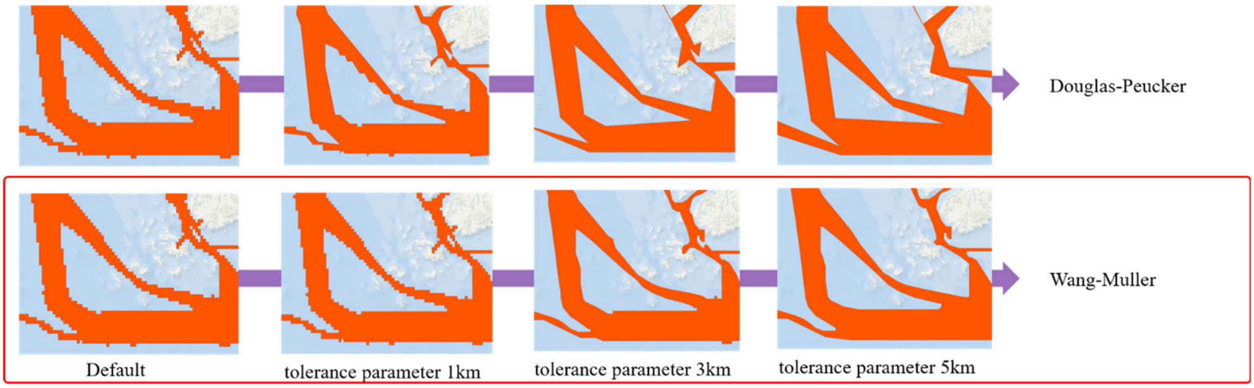


FIGURE 5. **Results of comparative review of polygon simplification.**

and smoother, potentially resulting in numerous coordinates in the curved parts. Thus, caution should be exercised in setting this parameter. For this study, the smoothing tolerance parameter was set at 5 km.

The Douglas–Peucker and Wang–Muller methods are primarily used for polygon simplification techniques, which are crucial for simplifying the edges of smoothed traffic routes. The Douglas–Peucker method focuses on retaining key points while simplifying the overall shape [32], whereas the Wang–Muller method is designed to preserve and simplify the critical curve sections of the route [33]. Figure 5 presents a comparison of the results from the simplification analysis using both the Douglas–Peucker and Wang–Muller methods. It was observed that the Wang–Muller method more accurately reflects the traffic route without distorting it, compared to the Douglas–Peucker method, which might oversimplify, potentially losing important route details.

D. SPATIO-TEMPORAL DENSITY ANALYSIS

Although there is no universally accepted definition of density or standardized methodology for analyzing maritime traffic fields, it is commonly understood as the number of ships per unit area [34]. However, since all maritime traffic density analyses rely on historical AIS data, various analyses can be conducted depending on the data type and method, potentially yielding different outcomes.

Point density calculates the density of point features within the vicinity of each output cell. The neighborhood, which represents the search radius, is defined around each cell center, and the number of points within this neighborhood is summed and divided by the area of the neighborhood. However, this method may not be suitable for assessing maritime traffic flows because it can result in inflated density readings, particularly for anchored or moored ships. Line density defines the density of linear features within the vicinity of each output cell. It is expressed as the length per unit area and is calculated using Equation (1).

$$Line\ density = \frac{(L_n \times V_n) + (L_{n+1} \times V_{n+1})}{Area\ of\ Unit} \tag{1}$$

where Ln represents the length of the portion of each line within the circle and Vn represents the corresponding weight, which could be a ship attribute value. However, due to the variability in both the line density and the reception period of AIS data, accurately predicting the density of the lines connecting points can be challenging. To address these challenges, this study introduces a novel approach to calculating maritime traffic density based on occupancy time, defined as the duration during which a ship traverses a unit area. This method draws inspiration from the updated methodology outlined in the EU vessel density map detailed by EMODnet Human Activities [30]. By aggregating occupancy times over one month, density is quantified as the occupancy time in hours per square kilometer per month. This innovative analysis method offers several advantages over traditional approaches. First, it mitigates the limitations posed by temporal variations in AIS data, where different ships are sampled at varying intervals. Second, unlike conventional methods, which may overlook variations in ship speed, this approach accounts for ship velocity, thereby providing a more accurate reflection of the actual traffic environment, even when multiple vessels traverse the same route or cover identical distances. Spatio-temporal density is calculated using Equation (2).

$$D_i = \sum_{j=1}^{n} \frac{S_j}{L_j} \times T_j \tag{2}$$

Here, Dj represents the vessel density (measured in hours) within cell i. Lj denotes the total length (in kilometers) of a specific line, while Sj refers to the partial length of that line j intersecting cell i. Tj represents the total time (in hours) spent along line j, and n indicates the number of lines associated with the cell. Essentially, this formula computes the density as the collective time spent by each ship (in hours) within a given cell over the entire duration. Figure 6 illustrates the concept of the calculation for spatio-temporal density. When a vessel passes through a 1 km^2 grid from point (x_0, y_0) to (x_3, y_3), the time spent navigating within that grid is converted to the length of the voyage. In this scenario, the total duration of the

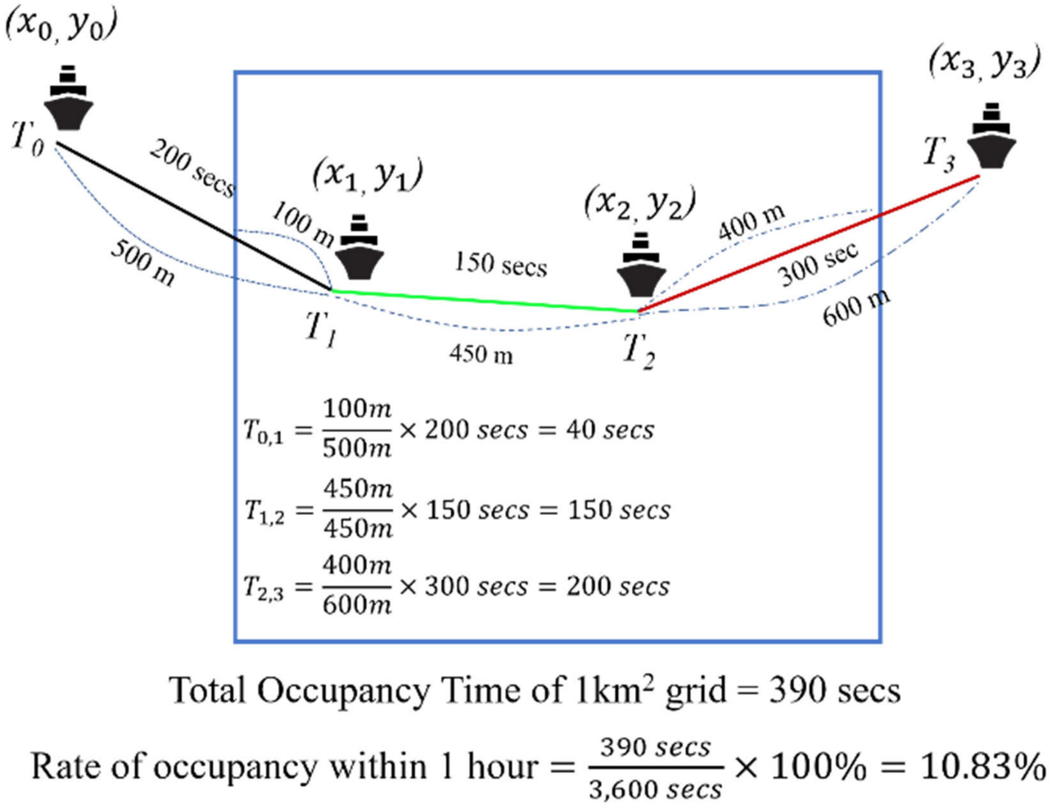


FIGURE 6. Concept of spatio-temporal density analysis method.

voyage is 390 s. Additionally, the portion of the grid occupied by the ship during this one-hour period is determined to be 10.83%.

E. OCCUPANCY RATE OF POINT DATA

The spatio-temporal density analysis results obtained through this method were expressed as quantiles ranging from 0% to 100%. In this study, the results were segmented into 10% intervals, and an analysis was performed on the upper density from 10% to 50% to identify the maritime traffic intensity zone. When delineating a section based on upper-density thresholds ranging from 10% to 50%, it is crucial to examine the actual data occupancy rate within a specified range. This review ensures that the outcomes obtained through density-based extraction accurately reflect the traffic volume in the area under consideration. AIS data primarily consist of location information represented as points. Therefore, the occupancy rate of point data is a crucial metric for assessing maritime traffic volume by comparing the actual data occupancy to the total area. In this study, the occupancy rate was analyzed using two main approaches: Maritime Mobile Service Identity (MMSI) and AIS Point occupancy analyses. The MMSI occupancy analysis involves tracking the number of ships passing through a specific area within a month. Conversely, the AIS Point occupancy analysis quantifies the rate of AIS points within a designated polygon area relative to the entire sea area. This approach provides insight into the actual extent of ship occupancy within a sea area. The occupancy rate was calculated using Equation (3).

$$O_{ratio} = \frac{P_d}{T_p} \tag{3}$$

where O_{ratio} indicates the occupancy rate, P_d denotes the number of ship points by density (MMSI and AIS points), and T_p denotes the total number of points in the target area. This involves determining both the total number of vessels passing through and the AIS Point occupancy rate compared to the entire sea area over a one-month period. The results were assessed using statistical techniques [35] to ensure validity and reliability. Figure 7 illustrates the concept and flow of the occupancy rate in ship point analysis.

III. RESULTS

A. EXTRACTION OF POLYGON BASED ON MARITIME TRAFFIC DENSITY

1) ANALYSIS RESULT OF SPATIO-TEMPORAL DENSITY

Vessel traffic flow aims to ensure safe navigation while incorporating economic factors to establish customary routes. Identifying areas of customary concentrated navigation flows and sea areas where major traffic is concentrated provides the foundation for establishing maritime traffic routes [36]. The results of the spatio-temporal density analysis conducted

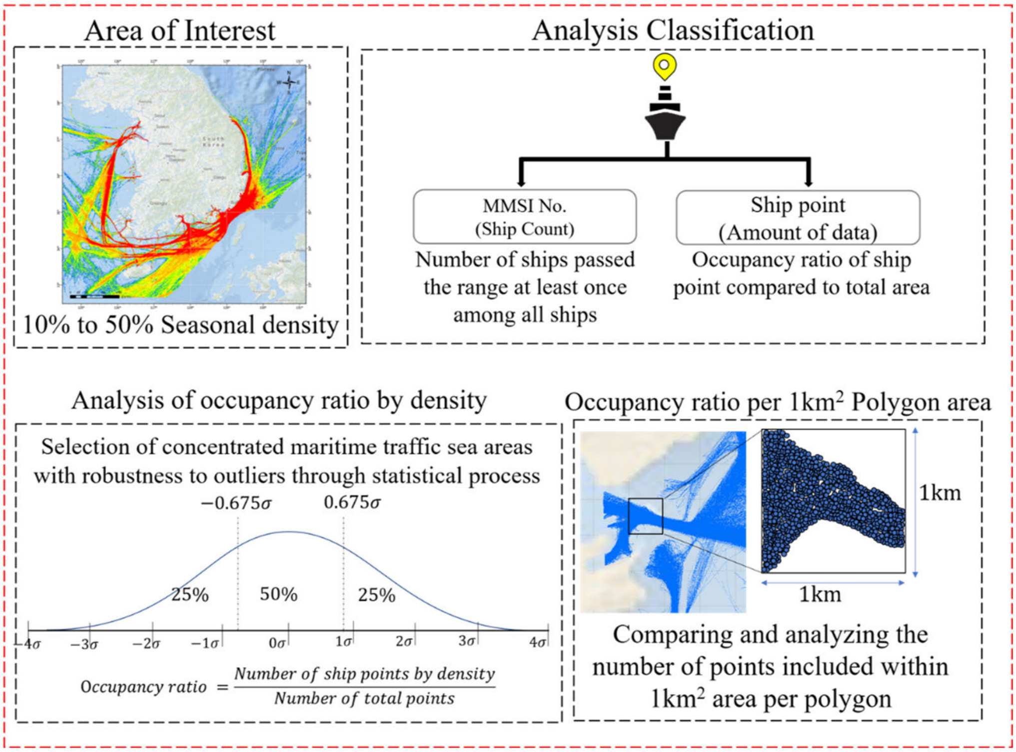
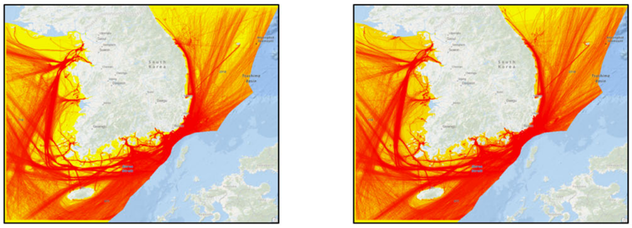


FIGURE 7. Concept and flow for occupancy rate of ship point analysis.


(a) March 2020 (b) June 2020

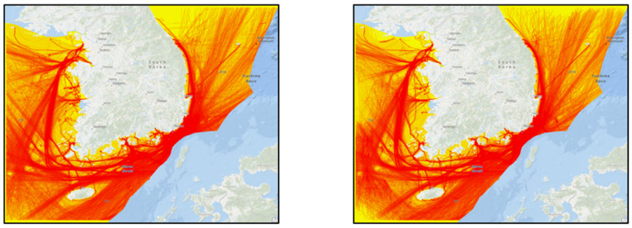

(c) September 2020 (d) December 2020

FIGURE 8. Results of spatio-temporal density in Korea.

on cargo ships and tankers, which primarily utilize major domestic trade ports, are displayed in Figure 8. The analysis revealed no significant differences due to seasonal changes. It identified the main flows as those passing along the coast of Korea and the traffic heading to China or Taiwan via Korea.

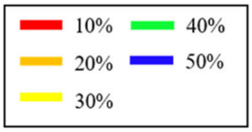
2) POLYGONIZATION OF MARITIME TRAFFIC DENSITY

Figure 9 displays the results of density polygonization by quantile from the upper 10% to 50% of the integrated spatio-temporal density of cargo ships and tankers, calculated for each month at 10% intervals. Consequently, when the density of the upper 10%, expressed as a frequency, is polygonized, it proves effective for exploring the efficient range of wide-area transportation routes that encompass Korea's coastal waters. Additionally, maritime traffic routes used for international navigation were identified at a density of the upper 20%. The upper 30% was considered indicative of a more extensive international traffic route, but densities at the upper 40% and above were found to encroach on most of the sea area near Korea.

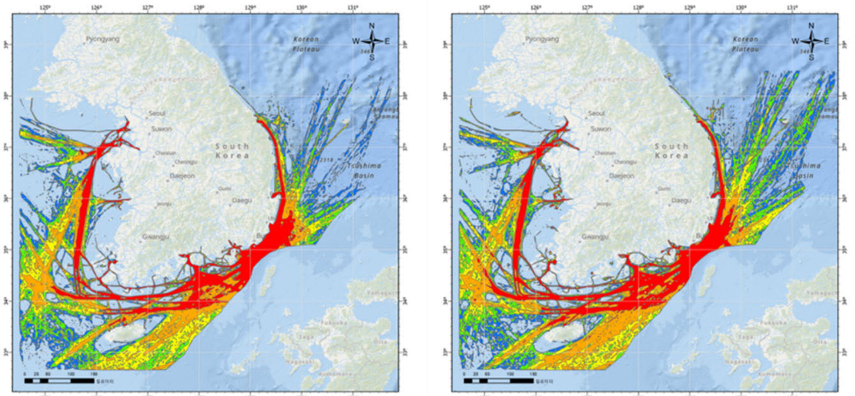
B. ANALYSIS RESULTS OF OCCUPANCY RATE OF SHIP POINT

1) SEASONAL ANALYSIS OF OCCUPANCY RATE OF SHIP COUNTS

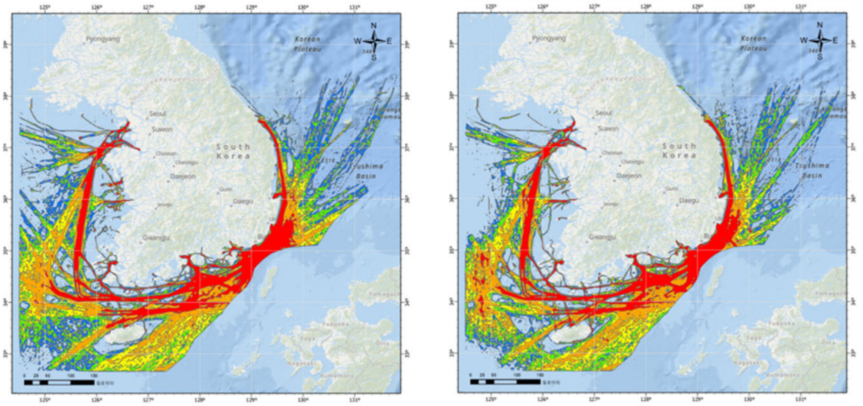
Table 5 displays the analysis results for ship count occupancy rates across the four seasons. This represents the total number of ships that passed through the polygon area at least once during the data analysis period (one month). The seasonal variation showed that approximately 300 more ships passed in March (Spring) and June (Summer) compared to September (Fall) and December (Winter). This is believed to be due to a decrease in vessel traffic caused by typhoons in the early fall in Korea and Siberian pressure during the winter [37]. The analysis of ship numbers according to the MMSI data revealed that during the month, 90.25% of the upper 10%, 95.02% of the upper 20%, 96.49% of the upper 30%,



(a) legend



(b) March 2020 (c) June 2020



(d) September 2020 (e) December 2020

FIGURE 9. Results of spatio-temporal density in Korea.

97.40% of the upper 40%, and 97.85% of the upper 50% of ships passed through more than once. In the upper 10%, 9 out of 10 ships navigated through waters under the jurisdiction of Korea in a month, and in the upper 20%, approximately 9.5 out of 10 ships used it more than once. Beyond these percentages, the utility is judged to be low owing to the occupancy relative to the area.

2) SEASONAL ANALYSIS OF OCCUPANCY RATE OF SHIP POINTS

Table 6 presents the analysis results for ship point occupancy rates across the four seasons, representing the total amount and rate of data points occupying each polygon section. The analysis highlights that the volume of traffic data was highest in March 2020, corresponding with the maximum cargo volume as analyzed based on PORT-MIS (refer to Table 2). Furthermore, the variation in occupancy rate across the seasons was not significant. In addition, the data reveals that approximately 6.0 out of 10 ships in the upper 10% and 7.6 out of 10 ships in the upper 20% occupied the sea area. Beyond the upper 30%, the increase in market share is considered relatively small compared to the size of the polygon. Figure 10 illustrates a graph of market share trends by density based on the ship point (amount of data) and MMSI number (count of ships).

3) SELECTION OF MARITIME TRAFFIC INTENSITY ZONE ACCORDING TO STATISTICAL VERIFICATION

To summarize the analysis results from Section III-B, when the occupancy rate of ship counts exceeds 20%, the increasing trend decelerates from approximately 5% to about 1% or less. Based on the AIS points, the increasing trend slowed by approximately 0.6 times with each 10% interval increase. In this study, the maritime traffic intensity zone was defined

TABLE 5. Seasonal analysis results for occupancy rate of ship counts.

Classification		Upper 10%	Upper 20%	Upper 30%	Upper 40%	Upper 50%
March 2020	Counts	4,221	4,498	4,562	4,625	4,646
	Occupancy rate	88.64%	94.46%	95.80%	97.12%	97.56%
June 2020	Counts	4,344	4,546	4,633	4,670	4,684
	Occupancy rate	90.56%	94.77%	96.58%	97.35%	97.64%
September 2020	Counts	3,978	4,205	4,253	4,291	4,323
	Occupancy rate	90.22%	95.37%	96.46%	97.32%	98.05%
December 2020	Counts	3,927	4,091	4,160	4,189	4,203
	Occupancy rate	91.73%	95.56%	97.17%	97.85%	98.18%
Total	Counts	16,470	17,340	17,608	17,775	17,856
	Occupancy rate	90.25%	95.02%	96.49%	97.40%	97.85%

TABLE 6. Seasonal analysis results for occupancy rate of ship points.

Classification		Upper 10%	Upper 20%	Upper 30%	Upper 40%	Upper 50%
March 2020	Counts	55,793,725	71,181,832	79,913,572	84,972,939	88,078,189
	Occupancy rate	58.09%	74.11%	83.20%	88.46%	91.70%
June 2020	Counts	41,345,126	52,008,383	57,725,084	61,275,192	63,493,802
	Occupancy rate	60.13%	75.63%	83.95%	89.11%	92.34%
September 2020	Counts	37,394,221	46,459,845	51,556,517	54,545,275	56,504,095
	Occupancy rate	61.65%	76.60%	85.00%	89.93%	93.16%
December 2020	Counts	39,573,605	48,273,109	53,287,464	56,307,704	57,890,655
	Occupancy rate	64.04%	78.12%	86.24%	91.13%	93.69%
Total	Counts	174,106,677	217,923,169	242,482,637	257,101,110	265,966,741
	Occupancy rate	60.61%	75.86%	84.41%	89.50%	92.59%

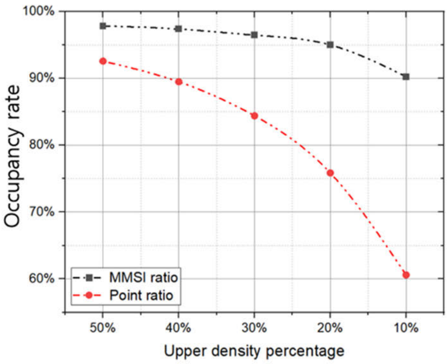
based on the total area under the jurisdiction of Korea, which adequately reflects the traffic volume of ships without occupying an excessive area. Table 7 presents the results of the review of the occupancy rate in Korea's jurisdictional waters by polygon. Consequently, as the density increased by 10%, the area of jurisdictional waters expanded by approximately 5%. This steady increase was a result of the extraction method, which utilized a consistent grid size (1 km^2), thereby showing a constant rate of increase.

Figure 11 illustrates the results of analyzing the number of points contained within an area of 1km2. Approximately 2,640 points were included in the 10% density category, and approximately 1,661 points in the 20% category. Based on the 10% figure, the relative density at 20% was approximately 0.63 times, and the relative density at 50% was about 0.31 times. Indeed, the analysis indicates that as the density increases toward the upper 10%, the density of the AIS points relative to the area also increases, showing a clear trend of concentration as the density categories ascend.

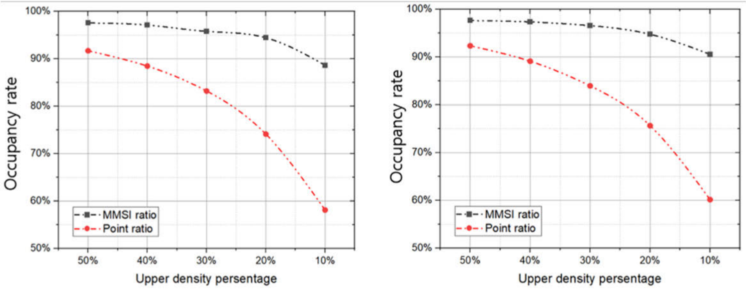
TABLE 7. Occupancy rate of Korean jurisdiction waters by density extraction results.

Classification	Occupied area (km^2)	Compared to that under jurisdiction of Korea
Upper 10%	21,136.88	4.83%
Upper 20%	42,848.53	9.78%
Upper 30%	64,738.37	14.78%
Upper 40%	85,410.87	19.50%
Upper 50%	107,058.98	24.44%

The normal distribution is a universally and widely used method. It exhibits a bell-curved shape on both sides, centered

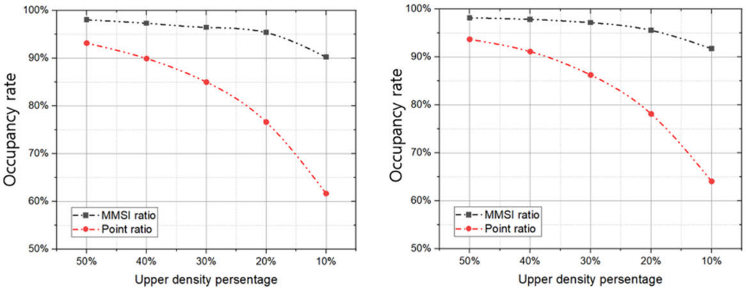


(a) total



(b) March 2020

(c) June 2020



(d) September 2020

(e) December 2020

FIGURE 10. **Occupancy rate of ship points and counts trend by each upper density (10% to 50%).**

around the arithmetic mean, which is the most common indicator of the central tendency of data. The overall distribution typically falls within the range of ±1 standard deviation (σ) on both sides. Approximately 68% of the data falls within this range, about 95% are distributed within the $\pm 2\sigma$ range, and roughly 99.7% within the $\pm 3\sigma$ range [38]. The traffic distribution in fairways is assumed to be normally distributed [39]. However, since the data in this study were analyzed for all the jurisdictional waters of Korea, they are unlikely to follow a normal distribution. Therefore, to assess the robustness and efficiency against potentially unclean data, statistics were computed using measures such as the center value and Interquartile Range (IQR). This approach is effective in reviewing data integrity [40]. The median, or second quantile, known for its high robustness, indicates the central tendency and remains relatively stable even when outliers or extreme values are included. The median divides the data into two halves, with half of the data falling between the 1st and 3rd quantiles, known as the IQR. The upper quantile (3rd quantile), representing 75% of the data, corresponds to the highest value within this range, providing a robust representation of statistical values. The results of this study show that the upper 20% density encompasses more than 75% of the ship points, and 95% of the ships transit through this area at least once a month. This corresponds to the 3rd quartile level of the total data. Consequently, the maritime traffic intensity zone was designated as a polygon with the upper 20% density, while the polygon with the upper 10% density was selected as the primary maritime traffic intensity zone. Figure 12 illustrates the extraction results for the traffic-concentrated sea areas presented in this study.

IV. DISCUSSION

The MSP Act was enacted to ensure the efficient use and management of marine resources, aiming to prevent conflicts between uses. However, in the case of the port and navigation

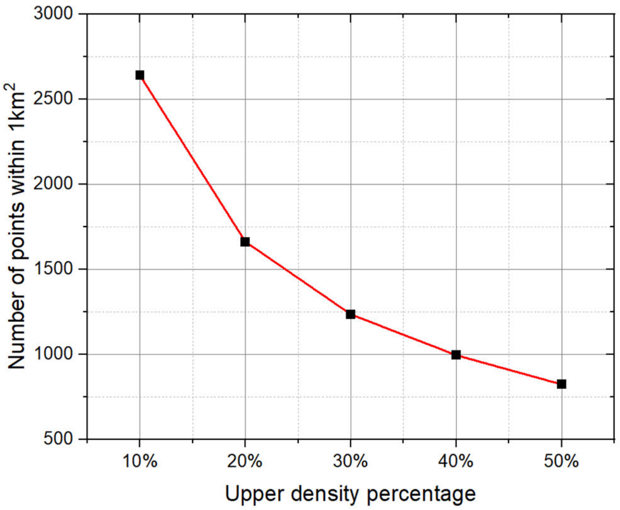
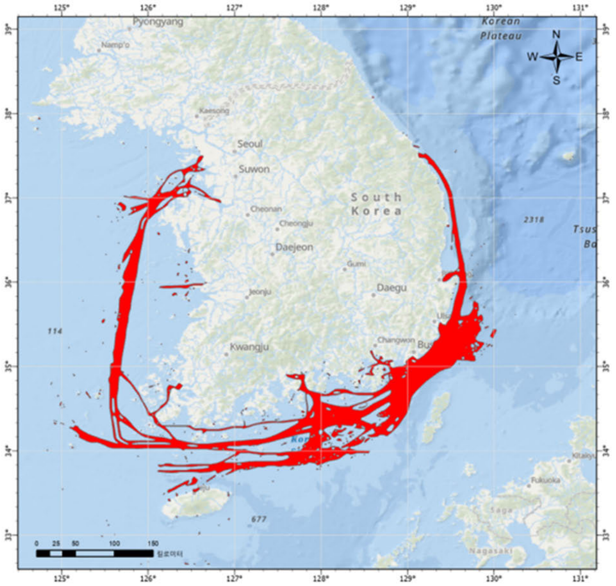
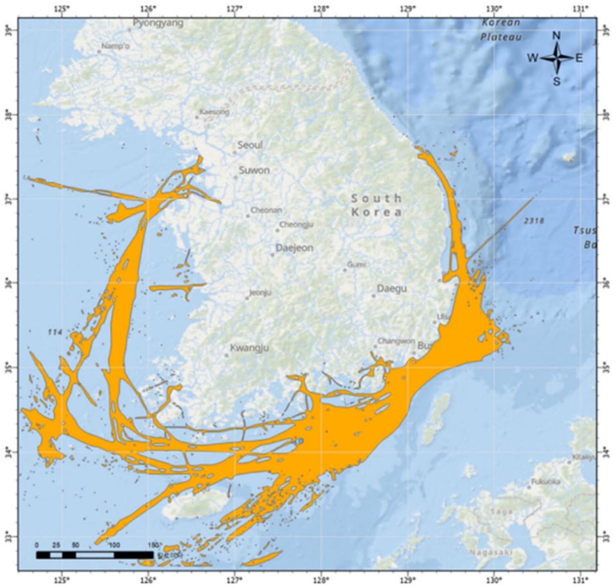


FIGURE 11. Number of AIS points within 1 km^2 area by each density.



(a) primary maritime traffic intensity zone

(upper 10%)



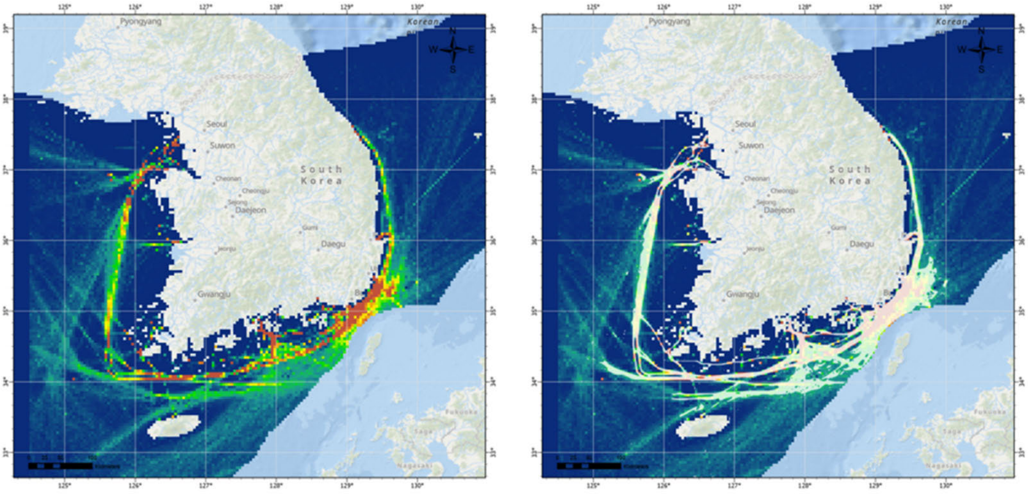
(b) maritime traffic intensity zone

(upper 20%)

FIGURE 12. Extraction results of maritime traffic intensity zone.

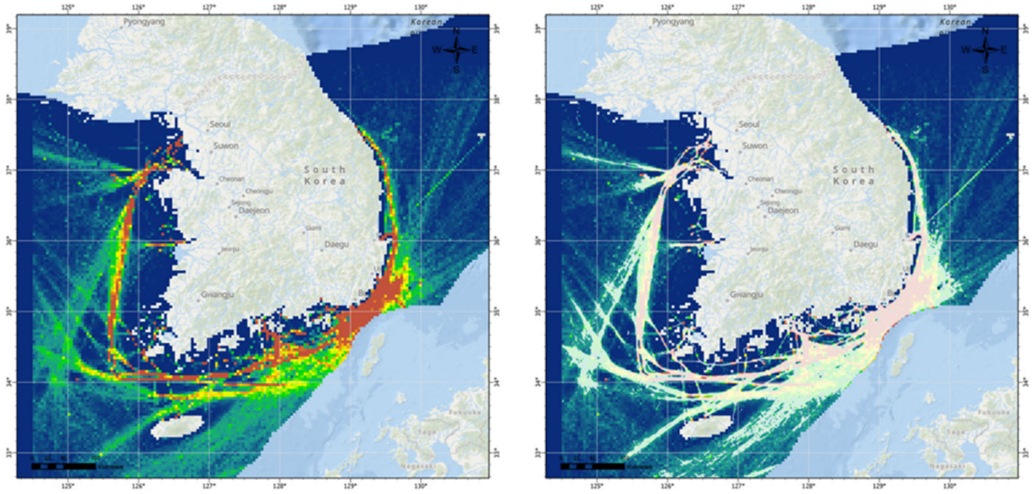
zones in Korea, the effective maritime traffic flow is not adequately reflected due to variations in application standards and analysis methods for GICOMS traffic-concentrated areas by local governments. In this study, we selected the month with the highest cargo volume for each of the four years from 2018 to 2021 and conducted a spatio-temporal density analysis, considering seasonal factors. The target period was determined to be March, June, September, and December 2020. The detected spatio-temporal density was then polygonized and classified based on the upper 10% density. The level of data represented by the occupancy rate of ship points within the detected polygons was assessed. Subsequently, the maritime traffic intensity zone was identified as the polygon with the upper 20% density, while the polygon with the upper 10% density was designated as the primary maritime traffic intensity zone. By applying the stretch function, a raster-based visualization method, the maritime traffic intensity zone can be verified [41]. The stretch function represents the range of polygon values expressed as raster data and improves the displayed image by adjusting and extending the range of the expressed values. This is not a method of classifying each section of the legend but rather a method of displaying the entire legend as an extension along a single-color ramp. The standard deviation method was used, specifying the number of standard deviations utilized to emphasize the variation in feature values from the mean. For example, when applying a σ of 1, values below -σ are interpolated to 0 based on the mean, values of $+\sigma$ to 255, and values above that are set to 0, effectively using guessing techniques for comparative visualization. Figure 13 displays the results of a stretch according to the standard deviation settings and provides a comparison of the overlapping results in the maritime traffic intensity zone. In Figure 13(b), a σ of 2 was applied, facilitating the identification of traffic areas while excluding the top and bottom 5% of the traffic distribution. Upon overlapping and comparing this with the primary maritime traffic intensity zone depicted in Figure 13(c), it was observed that this method effectively reflected the upper-density area. In Figure 13(d), a standard deviation of 1 is applied, representing the densest value of the traffic distribution. Upon overlapping and comparing this with the maritime traffic intensity zone depicted in Figure 13(e), it was found that it effectively reflects the upper-density area. This study anticipates that an efficient reflection of navigation and port areas will be achieved by employing unified extraction standards and methods for

(a) Legend



(b) Stretch function standard deviation: 2

(c) Overlapped Figure 13(a) and primary maritime traffic intensity zone (white color)



(d) Stretch function standard deviation: 1

(e) Overlapped Figure 13(c) and maritime traffic intensity zone (white color)

FIGURE 13. **Results of stretch function according to standard deviation settings and overlapping comparison results in maritime traffic intensity zone.**

GICOMS traffic-concentrated areas, as established by local governments.

V. CONCLUSION

This study addressed the challenges of efficiently reflecting maritime traffic flows in Korea's MSP. Maritime traffic intensity zones were identified through spatio-temporal density analysis and standardization techniques. The study proposed unified extraction standards for GICOMS traffic-concentrated areas and provided quantitative indicators for maritime spatial planning. The results from the spatio-temporal density analysis were polygonized and represented at 10% intervals. A suitable maritime traffic intensity zone was then chosen based on the occupancy rate of ship counts and ship points within each polygon, followed by a statistical review. Consequently, the maritime traffic intensity zone was identified as a polygon with an upper 20% density, and the polygon exhibiting an upper 10% density was designated as the primary maritime traffic intensity zone. This approach aided in enhancing navigation and port area reflection, as expected from the implementation of unified extraction standards and methods for GICOMS traffic-concentrated areas established by local governments. This study is expected to be highly useful as it identifies high-risk areas, the traffic risk of marine ecosystem hotspot areas, and the safety of maritime traffic by identifying traffic intensity zones [42]. One limitation of this study was the restriction of ship types to cargo ships and tankers, which potentially overlooked other vessel categories. Furthermore, for the broader applicability of the research outcomes, further examination is required in global waters beyond Korea. Future research could yield improved results by expanding the scope to encompass a wider range of vessel types and conducting analyses on a more comprehensive scale.

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