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Research Article

Weighting the factors affecting safety of navigation: A case study for the Gulf of İzmit, Türkiye

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Abstract
Cargo transportation is globally carried by sea. The increasing population and associated needs increase the amount and diversity of cargo transported by vessels. The tonnage and number of vessels are also increasing accordingly. Although production and storage points are established in the regions where raw materials are located, they are concentrated in coastal areas in accordance with intermodal transportation. The Gulf of Izmit is the maritime region with the largest maritime facilities in Türkiye due to its location within the Turkish Straits, its dense population, its proximity to production and raw materials, and its strategic location where transportation modes intersect. Vessel Traffic, Pilotage, and Tugboat Services units operate in the region in order to increase the safety of navigation. However, many factors, such as geographical, meteorological, and hydrographic conditions of the region, and critical structures, local traffic, fishing activities, and the presence of dangerous cargo terminals, affect the safety of navigation. In this study, it was decided to use the Analytic Hierarchy Process (AHP) method, one of the Multi-Criteria Decision Making (MCDM) techniques, to identify the factors affecting navigational safety in Gulf of Izmit, to rank them in order of importance and to determine the measures to be taken. In this context, firstly, an extensive literature review was conducted. The data obtained were analyzed by 10 people who are experts in their fields, have academic backgrounds, and work in the region as pilots, vessel traffic operators, port state control officers, and oceangoing masters. Dynamic (variable) and static (unchangeable) risks in the region were identified and a hierarchical structure was obtained. The weights of the factors within the hierarchical structure were determined by making numerical comparisons with each other and the importance ranking was revealed.

1. Introduction

Navigational safety is a critical aspect of maritime operations, ensuring the protection of vessels, their cargo, and the environment from accidents and incidents. The focus on navigational safety is particularly crucial in regions with dense maritime traffic and significant industrial activity. From this point of view, Türkiye is surrounded by seas on three sides, has critical waterways and inland seas, and is located in the Mediterranean-Black Sea basin, where approximately 25 % of the world's maritime trade takes place; military, sportive, and commercial maritime traffic is intense. Located at the center of Türkiye's most important agricultural, commercial, industrial, and technological production, storage, and distribution corridor, the Gulf of İzmit, where many transportation modes coexist, is the maritime area where vessel traffic and cargo handling operations at ports/terminals are the most intense. Considering the data for 2017 - 2023, it is seen that the Gulf of İzmit is the largest port region in Türkiye, and the seventh largest port region in Europe, in terms of vessel movements and cargo handling at ports/terminals in the administrative area of Kocaeli and Yalova Regional Port Authorities (General Directorate of Maritime Affairs, 2022; Landgeist, 2023).

There are 119 coastal facilities within the Gulf of İzmit, including 41 ports and terminals, 36 shipyards, 16 passenger piers, 4 ferry piers, 20 fishing shelters and boatyards, and 3 military facilities. The Gulf of İzmit is 26.36 miles long on the East - West axis. It has a surface area of 161 km^2. A detailed information map of the Gulf of İzmit is shown in **Figure 1**. In general terms, it has;

- 2 Regional Port Authorities (Kocaeli and Yalova Regional Port Authorities)
- 7 Anchorage areas (Yalova 1 - 2, Eskihisar, Hereke, Hereke Barge, Yarımca, İzmit)
- Total 119 coastal facilities
- North-south local traffic lines (Eskihisar-Topçular, Hereke-Karamürsel)
- And the Osmangazi Bridge is located there (General Directorate of Coastal Safety, 2023).

Figure 1 Gulf of İzmit detailed information map.

The Gulf of İzmit is a maritime area where many maritime activities are carried out in military, sportive, economic, and social terms, along with a high intensity of commercial vessel traffic. Local passenger and vehicle transportation, the presence of military facilities, shipyards, fishing activities, sailing and marina activities are the main factors. For this reason, it is important to ensure the safety of navigation, life, property, and the environment, to manage maritime traffic in the most efficient way and to minimize navigational risks. In this direction, 1 Vessel Traffic Service, 3 Pilotage Service, and 6 Tugboat Service units serve in the region. However, the unique geographical, meteorological, and oceanographic elements of the region indicate that navigational risks always exist. In addition, the presence of bridges, underwater pipelines and power lines, location and capacity of traffic separation schemes and anchorages, and location of ports and terminals are risk factors that increase navigational risks, and which indicate that proactive measures are required.

The aim of the study is to identify other risk factors besides the risks that have been put forward in some previous studies in order to determine the priorities of safe navigation risks and to put forward a scientific model that can be easily applied by all units operating in the Gulf of İzmit. The model, in which the AHP method was used, was created specifically for the Gulf of Izmit, which includes all maritime activities. Taking into account the characteristic and active structure of the region, all risk factors affecting the safe navigation of marine vessels have been identified and weighted. In this study, Analytic Hierarchy Process (AHP) is used, as it is one of the multi-criteria decision making methods which enables the comparison of a large number of alternatives for a specific objective through the use of specified criteria.

This manuscript consists of 4 chapters in total. In the second chapter, a background is presented by two sections; a literature review and motivation. In the third section, AHP, consisting of 2 main criteria, 16 sub-criteria, and 48 risk factors, is introduced as the methodology. Findings, results, and discussion are presented in the third section. In the fourth section, a brief conclusion is given.

2. Background

2.1 Literature review

Navigational safety is strongly influenced by various factors related to the characteristics of waterways. These factors include geometric features, hydrographic and hydrometeorological conditions, proximity to infrastructure, traffic density, and technological developments. In addition, the characteristics of waterways significantly affect navigational safety by influencing the maneuverability of vessels, the risk of collisions, and overall navigational efficiency. Building sustainable maritime transportation systems requires effective management of various factors, supported by strong legal and regulatory frameworks. This includes analyzing key elements to improve maritime safety standards and integrating detailed environmental data in accordance with the latest technological advances. The literature review explores how different characteristics of waterways affect navigational safety and draws on a large number of studies to provide a comprehensive understanding of these factors. Academic publications (articles, papers, books, presentations) are at the top of these studies. National and international academic studies were reviewed. Studies on the Turkish Straits and the Gulf of Izmit, other critical waterways, the AHP approach, and navigational safety were examined. In addition, statistical data were followed. The number and locations of vessels, cargo, ports, and maritime accidents were determined, density maps were drawn, and the data were kept up-to-date. Annual reports of public and private sector institutions and organizations were examined. In addition, national and international legislation applied in the region was discussed.

When it comes to determining navigational safety, geometric characteristics of waterways, such as radius of curvature and channel width, are critical. Gao et al. (2019) conducted a study to investigate the influence of flow condition, radius of curvature, operator level, and vessel maneuverability on the importance of navigational safety in the context of inland river bending channels. They concluded that more compact curves make management more difficult, which increases the likelihood of accidents occurring. According to Gao et al., this highlights the importance of considering geometric elements when planning and developing waterways to ensure safe passage at all times (Gao et al., 2019). Similar to the previous study, Hasanspahić et al. (2018) conducted an analysis to identify the factors affecting the safety of tanker navigation on narrow waterways. They found that geometric features, as well as traffic, meteorological, and ship design factors, play an important role in minimizing the risk of grounding and other adverse consequences (Hasanspahić et al., 2018). In addition, natural elements such as hydrographic and hydrometeorological conditions also have a significant impact on navigational safety. Afonin (2018) highlighted the impact of these conditions on navigational safety in marine areas that are part of the Northern Sea Route. According to Afonin, the research presented a model that demonstrates the importance of environmental considerations in navigation design (Afonin, 2018). The model recommends the assessment of navigational conditions and ship states in order to make safety assessments. Li et al. (2013) also emphasized the importance of incorporating environmental data into safety assessments to improve navigation safety by building a navigation environment safety index system based on a Bayesian network analysis of Changjiang River data. This was done to provide a navigation environment safety index system (Li et al., 2013). Baig et al. (2024) explained how to improve maritime safety in five categories and how this could be integrated into the domestic ferry sector (Baig et al., 2024). Nwokedi et al. (2022) examined the performance of port state controls and classification societies in West and Central Africa between 2015 and 2020 and revealed the impact on maritime safety (Nwokedi et al., 2022).

When traveling near buildings, such as bridges, there are various additional safety factors to consider. Li and Zhang (2011) conducted a detailed study on the factors that affect safe navigation near bridges. This included an analysis of the importance of these factors, as well as the interconnection between these factors. Furthermore, a safety assessment model, based on fuzzy mathematical theory, was developed. According to Li and Zhang, this research sheds light on the complications caused by man-made structures and the need to implement additional safety measures (Li et al., 2011). In addition, the density of vessel traffic is another important component to consider when determining navigational safety. Park and Yea (2008) conducted an international collaborative study to investigate the impact of the navigational environment on seafarers' behavioral patterns in avoiding collisions. The findings of the study suggest that increasing traffic density and complex navigation areas have a significant impact on mariners' ship handling capabilities, which in turn requires the development of advanced tactics for traffic management and collision avoidance (Park et al., 2008). Similarly, Gucma et al. (2022) proposed a methodology to assess navigational safety by analyzing relative navigational risk. They emphasized the importance of modifying navigation practices and systems to effectively manage traffic congestion and minimize the probability of accidents (Gucma et al., 2022). Besides these, Singh et al. (2023) analyzed the maritime accident between Helge Ingstad and Sola TS, creating a study case and analyzing the human factor for it. They discussed the crucial human based factors, including environmental, legal, competency, behavioral factors, sense making, and fatigue (Singh et al., 2023).

Furthermore, technological advances have been successful in improving the safety of navigation services. Breedveld (1999) discussed the potential for using GPS or DGPS, electronic navigation charts, river radar, and computer technology to improve navigation safety on Western European inland waterways (Breedveld, 1999). Dalaklis et al. (2020) also emphasized the integration of technological advances for a net-centric collaborative environment for increasing safety at sea (Dalaklis et al., 2020).

On the other hand, there are studies about the legal concepts of safety of navigation, as it is absolutely necessary to enhance and ensure this. Vidan et al, (2012) proposed investigating the factors that lead to accidents, and putting up new regulatory frameworks in order to cut down on the number of accidents. Additionally, the research suggested that existing electronic devices be modified, and that new marking systems be implemented in order to enhance safety on inland waterways (Vidan, 2010). As a consequence of this, the safety of navigation is influenced by a great number of elements that are associated with the characteristics of waterways. Geometric features, hydrographic and hydrometeorological circumstances, physical proximity to structures, traffic density, and technology advancements are some of the factors that fall under this category. The effective control of these aspects, which is supported by powerful legal and regulatory frameworks, is absolutely necessary in order to provide transportation that is both safe and efficient. In the future, research should continue to investigate these difficulties by incorporating cutting-edge technologies and extensive environmental data in order to further improve navigation safety requirements.

The methodologies employed in the studies mentioned above- quantitative analysis, risk assessment models, model-based approaches, fuzzy mathematics, Set Pair Analysis, Bayesian Network Analysis, and technological evaluations- each offer unique strengths and insights. However, this research selected the analytic hierarchy process (AHP) method, mainly because it is, in essence, a theory equipped to deal with intricate and multiple perspectives on complicated topics such as navigational safety. It is a systematic and structured approach to decision making. Analyzing criteria pairwise with AHP will allow the decomposing of the problem into a hierarchy of sub-problems that are easier to understand and analyze separately from one another. This method, which facilitates the integration of various criteria, such as human factors, environmental conditions, and geometric features, is effective in including both quantitative and qualitative factors. By weighting these criteria according to their relative importance, AHP creates a transparent framework for prioritizing various elements that affect navigational safety. Additionally, AHP's capacity to handle subjective judgments and convert them into a series of scores increases its utility in situations where empirical data are scarce or difficult to obtain. This makes AHP a tool that is both versatile and robust, capable of performing a comprehensive and balanced analysis when assessing multi factor based navigational safety.

2.1 Motivation

There are few studies on the Gulf of İzmit in the maritime literature. The studies conducted tend to be in the areas of earth sciences, history, environmental sciences, ecology, and industry. In the maritime field, some studies have been carried out on navigation safety, marine pollution, fisheries, and dangerous cargo transportation.

The most important study on the subject is the Gulf of İzmit PAWSA Workshop, held in 2014, where vessel traffic in the Gulf of İzmit was examined, risky areas were identified, the validity of the safety of navigation measures taken was analyzed, and new measures were discussed. The Gulf of Izmit PAWSA studies, reports, and outputs accepted by IALA and involving all maritime components were examined. In the workshop attended by all maritime units operating in the Gulf of İzmit, various presentations were made about the region, numerical data were shared, and risk maps were prepared (IALA, 2014). In **Figure 2**, the risky navigation areas of the Gulf of İzmit were evaluated and determined in five different categories.

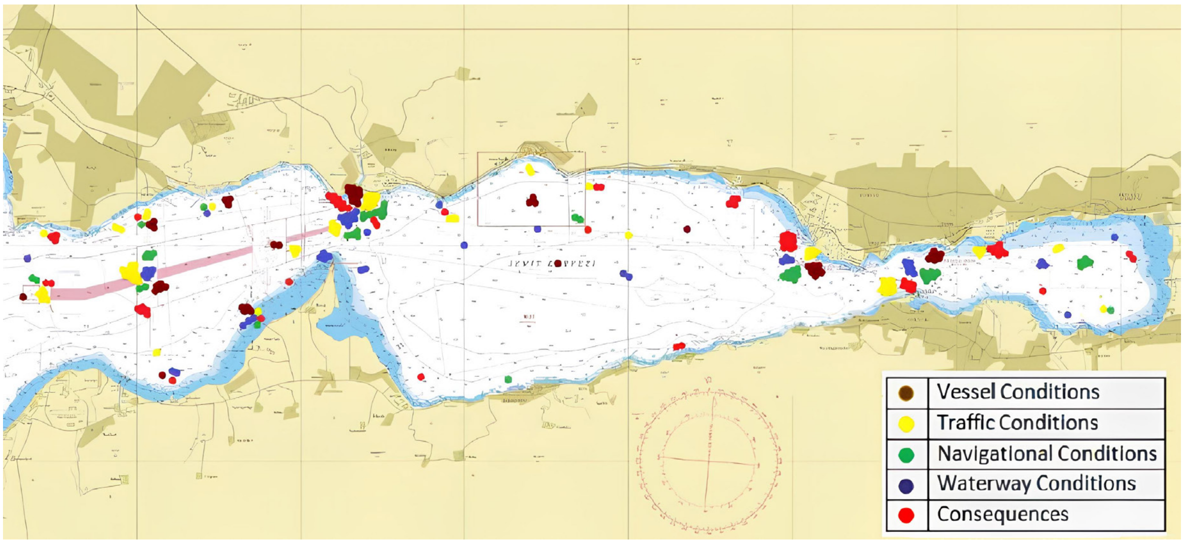

Figure 2 Gulf of İzmit PAWSA risk map (IALA, 2014).

In 2012 and 2014, Yurtören et al. used Automatic Identification System (AIS) data with the Environmental Stress (ES) model to determine the density values in the Gulf of İzmit and the adjacent Istanbul Strait (Yurtören et al., 2012; Yurtören et al., 2014).

In two separate master's theses, prepared by Şahin in 2015 and Aydın in 2017, on the negative effects of increasing vessel traffic in the Gulf of İzmit and risk assessment methods, analysis and determinations were made on vessel traffic, marine pollution, and maritime transportation (Şahin, 2015; Aydın, 2017). In addition, Anıker, who served as a pilot in the Gulf of İzmit, compiled examples from around the world about tugboat, escort, and TSS applications in 2022 and made recommendations for applications in the Gulf of İzmit (Anıker, 2022).

When articles, papers, and academic publications are reviewed, it is determined that the studies on Gulf of İzmit are generally related to earthquakes. Although not directly related, studies on coastal structures, climate, and historical development help to investigate maritime-related issues related to the Gulf of Izmit (Garipağaoğlu et al., 2014; Dönmez et al., 1985; Hergüner, 2015).

Annual maritime sector reports prepared by private sector organizations were scanned and the hinterland of the Gulf of İzmit and cargo handling statistics in ports were examined. In summary, it can be said that the Gulf of İzmit is the region with the most intensive vessel movement, the highest number of cargo handling operations, and the highest number of coastal facilities (Chamber of Shipping, 2023; Shipbuilding Industrialists' Association, 2022; Turkish Port Operators' Association, 2023).

Monthly and annual vessel and cargo statistical data shared by public institutions such as the General Directorate of Maritime Affairs, the General Directorate of Coastal Safety, and the Kocaeli Regional Port Authority under the Ministry of Transport and Infrastructure stand out as important sources in this study. According to official data, 10,035 (6.67 %) of the total 60,195 vessels calling at Turkish ports in 2023 sailed in and called at Gulf of İzmit. Again, 84,610,735 tons (16.24 %) of the total cargo handling amount of 521,079,804 tons and 2,159,162 TEU (17.20 %) of the total container handling amount of 12,556,401 TEU in Turkish ports in 2023 were realized in the ports located in Gulf of İzmit (General Directorate of Coastal Safety, 2023; General Directorate of Maritime Affairs, 2023a; General Directorate of Maritime Affairs, 2023b).

In 2023, the AIS-based vessel movement density map taken from the İzmit VTS database Gatehouse program was as shown in **Figure 3**. East-West movements show the vessels entering the VTS area and the ports of call. North-south directional density shows the local traffic movements within the VTS area.

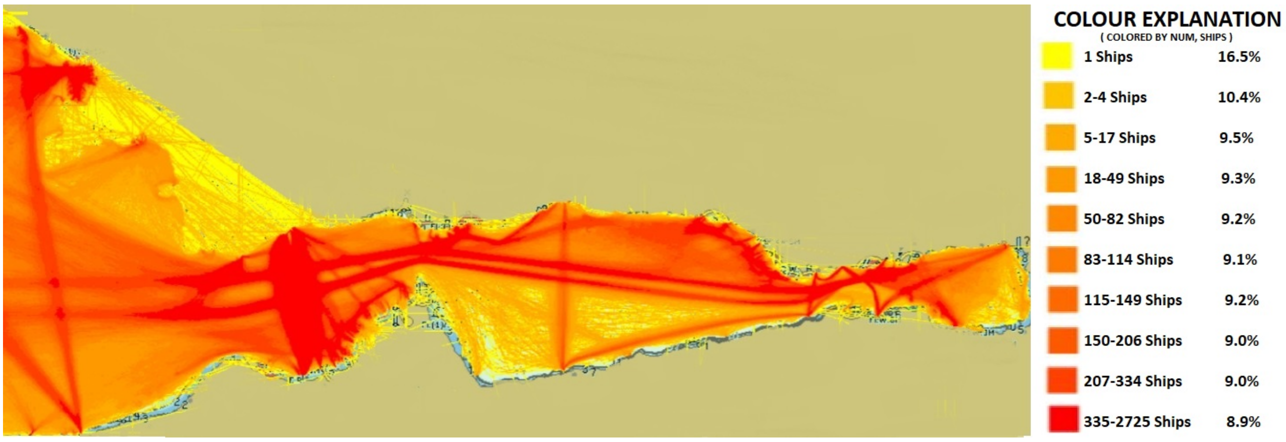

Figure 3 Gulf of İzmit vessel traffic density map (General Directorate of Coastal Safety, 2023).

Accident reports for the last 8 years, prepared by İzmit Vessel Traffic Services, and annual vessel-port density data were also used in the process of determining risk factors. Accident statistics for the last 8 years are shown in **Table 1**. Accordingly, 34 maritime accidents, involving 42 vessels, occurred in the last 8 years. In 2017 and 2018, fatalities, injures and sea pollution occurred in these maritime accidents.

Table 1 Numerical data of accidents occurring in the Gulf of İzmit in the last 8 years.

Year	Collision	Fire	Flooding	Grounding	MOB	Sinking	Total
2016		1					1
2017		2	1	3			6
2018	1	1			1		3
2019	3						3
2020	1	2					3
2021			1	1			2
2022	2	2		1	4		9
2023	2	1	1	1	1	1	7
Total	**9**	**9**	**3**	**6**	**6**	**1**	**34**

The length of the Eskihisar-Topçular ferry line is approximately 4.5 nautical miles, of which 1.4 nautical miles is within the Gulf of İzmit Traffic Separation Scheme. A ferry line cuts the traffic separation scheme perpendicularly. Considering the local traffic near the shore (fishing, tugboat, service boat), Eskihisar anchorage area, and Altınova shipyards area, there is also a heavy vessel traffic interaction in the part outside the traffic separation scheme. Data obtained from the PAWSA risk analysis reports for Gulf of İzmit vessel traffic and İzmit VTS database reveal the fact that this line poses a great risk to the existing vessel traffic. It has been determined that there is an average of 20 mutual ferry voyages per hour on the Eskihisar-Topçular line, and it has been observed that the number of voyages is much higher than this average (26 - 27 voyages/hour) when the activity is more intense, such as on weekends and holidays. When the technical specifications and ages of the ferries serving on this line are examined, it is seen that their average length is 75 meters, average speed is 10 knots, and average age is around 30 years. Considering the current traffic density, there is a mutual ferry movement every 3 minutes, and considering the length and speed values, the ferries form an almost uninterrupted line on the route that the vessels entering and exiting the Gulf of İzmit have to follow. In addition to this situation, the high number of vessels entering and exiting the Gulf of İzmit, the fact that most of these vessels carry dangerous/harmful cargo, the fact that some of these vessels are sub-standard, and the age and technical characteristics of the ferries operating on this line pose a serious risk to navigation safety. A total of 21,489,307 passengers and 3,871,747 vehicles were transported in Gulf of İzmit in 2022 (General Directorate of Maritime Affairs, 2023c). In the light of all of these data, the factors affecting the navigational safety in the Gulf of İzmit were analyzed using the AHP method.

3. Methodology

3.1 Analytic hierarchy process (AHP)

AHP is a mathematical theory within the scope of Multiple Criteria Decision Making (MCDM) techniques, used for comparing, measuring, and determining the superiority of a large number of alternatives through the criteria determined for a certain purpose. It was developed in 1977 by Thomas L. Saaty (Saaty, 2008).

Other MCDM techniques are called SAW (Simple Additive Weighting), ELECTRE (Elimination Et Choice Translating Reality), TOPSIS (Technique of Order Preference by Similarity of Ideal Solution), VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje), and PROMETHE (Preference Ranking Organization Methods for Enrichment Evaluation) (Pham et al., 2024; Cil et al., 2022; Özdemir, 2016).

AHP method has many applications in real life, especially in business and maritime (Polat et al., 2020; Tunçel et al., 2023; Canımoğlu et al., 2021). This method helps to make analytical and accurate decisions in many areas, such as software selection, project and portfolio selection, vendor and resource selection, planning and budgeting, market research, performance and risk assessment, cause and effect research, and training. AHP can be used in every situation and environment where selection criteria can be determined and preference rankings can be made. AHP application steps consist of 4 steps in summary, and will be explained in detail in Sections 3.2, 3.3, and 3.4. These steps are;

- Step 1: Creating the Hierarchical Structure.
- Step 2: Pairwise Comparison Matrices and Determination of Superiorities.
- Step 3: Determination of the Eigen Vector (Relative Importance Vector).
- Step 4: Calculating the Consistency Ratio of the Eigenvector (Sipahioğlu, 2008).

3.2 Hierarchical structure

After determining the purpose of the study and conducting an extensive literature review, the steps of the AHP method are applied. A decision hierarchy is created, starting from the top with the decision objective. There are criteria at the middle level and alternatives at the lowest level. In the hierarchical structure, each set of factors forms a hierarchy level. The hierarchy should be constructed very carefully and meticulously to best represent the problem. In particular, it is very important to determine the number of factors that will affect the result and at which level of 1the hierarchy they will be located, and to define each factor down to the finest details, in order to make consistent pairwise comparisons. While determining the criteria, sub-criteria, and alternatives, it is an important step in order to make the right choice to benefit from the opinions of different institutions, organizations and experts, publications, surveys, and academic research (Akyüz, 2015). In our study, 2 main criteria, 16 sub-criteria, and 48 risk factors that may affect navigation safety were identified. The hierarchy structure according to the criteria, sub-criteria, and alternatives is shown in **Table 2**.

Table 2 AHP hierarchical structure.

Purpose	Criteria	Sub-Criteria	Navigation Risks
Analysis of Factors Affecting Safety of Navigation in the Gulf of İzmit by AHP Method	Static Risks (S)	S1 - Gulf of İzmit Entrance TSS Deficiency	S11 - Disruption of traffic organization
			S12 - Vessels reaching the pilotage point at the same time/close to the pilotage point
			S13 - Encounter of inbound and outbound traffic
		S2 - Pilot Pick up / Drop off Points	S21 - Reduced/lost maneuverability of intercepting vessels
			S22 - Uncontrolled maneuvering / operational difficulties in bad weather conditions
			S23 - Proximity of Yalova - Kocaeli pilotage service points to each other
		S3 - Eskihisar - Topçular Ferry Line	S31 - Intense and irregular movement
			S32 - Conflicts over right of way
			S33 - Overlap of the ferry line with Eskihisar anchorage area
		S4 - Bridge Zone	S41 - Adjacency to Dilovası port area and Eskihisar anchorage area
			S42 - Maneuvering / navigational difficulties due to speed and overtaking restrictions
			S43 - Air draft restriction (60 meters)
		S5 - Narrowest Navigation Area	S51 - Pilot change operations for Derince Port
			S52 - Presence of military installations and maritime space
			S53 - Underwater pipe / power lines
		S6 - Anchorage Areas	S61 - Adjacency / Proximity (Dangerous cargo, Ferry line, Local traffic, Pipeline, Port)
			S62 - Seabed structure / Depth inappropriateness
			S63 - Insufficient anchorage space
		S7 - Geographical Conditions	S71 - Shoals, wrecks and other coastal navigation obstacles
			S72 - Irregular installation / location of port facilities within the Gulf
			S73 - Location of the resident population close to terminals handling dangerous cargo
		S8 - Current TSS	S81 - Navigational risks of joining/leaving TSS
			S82 - Vessels entering and leaving Yalova cannot use current TSS
			S83 - Contacts to vessels within the TSS
	Dynamic Risks (D)	D1 - Local Traffic	D11 - Difficulty monitoring local traffic
			D12 - Navigation in maneuvering areas of commercial vessels
			D13 - Failure to establish local traffic VHF contact
		D2 - Naval Activities	D21 - Failure to receive data from navy vessels

Table 2 (continued) AHP hierarchical structure.

Analysis of Factors Affecting Safety of Navigation in the Gulf of İzmit by AHP Method	Dynamic Risks (D)		D22 - Failure to report navy vessel movements
			D23 - Drill / Ceremony
		D3 - Fishing Activities	D31 - Illegal Fishing Activities (Mussel, Trawling)
			D32 - Failure to establish VHF contact with fishing boats
			D33 - Fishing in prohibited areas (TSS, anchorage area, ferry line, in front of the ports)
		D4 - Sportive / Special Activities	D41 - Unauthorized / uninformed activities
			D42 - Failure to establish VHF contact with yacht/sailboat
			D43 - Obligation for partial or total suspension of business activities
		D5 - Commercial Traffic without Pilot	D51 - Presence of substandard vessels
			D52 - Incompetent and uninformed crew
			D53 - Failure to establish VHF contact with Coaster
		D6 - Meteorological Conditions	D61 - Wind
			D62 - Restricted Visibility
			D63 - Heavy rain / snow / blizzard / hail
		D7 - Oceanographic Conditions	D71 - Current
			D72 - Tide
			D73 - Stream / River / Lake impacts
		D8 - Shipyard Activities	D81 - Sea trial and towing activities
			D82 - Frequent failure of vessels (Defect on arrival, new construction, repair period)
			D83 - Irregular anchoring in front of Yalova Shipyard

3.3 Matrix information

The pairwise comparison matrix is formed by comparing the criteria at one level in the hierarchical structure with each other in the context of a higher factor. In AHP, the evaluation of factors is determined with the pairwise comparison judgment *aij* by considering many criteria. The pairwise comparison judgment *aij* determines the relative importance of criteria *i* and *j* with respect to the factor at the next higher level. In other words, the value *aij is* the answer to the question to what extent criterion *i* should be preferred over another criterion *j* in the context of the factor under consideration. The comparison of the options is done separately according to each criterion and, as a result, pairwise comparison matrices are created. In the construction of these matrices, the 1 - 9 comparison scale proposed by Saaty, shown in **Table 3**, is used (Tzeng & Huang, 2011).

3.4 Application

The process flow while creating pairwise comparison matrices in the decision model was as follows:

- Comparison to determine the impact of the main criteria on the outcome (1 matrix).
- Comparison of sub-criteria under each main criterion to determine their impact on the main criterion (16 in total, one for each main criterion).
- Comparisons to determine the impact of options on sub-criteria (48 in total).

In the AHP methodology applied in this study, the evaluation process began with 10 experts (1 person who conducted the study, 3 Pilots, 4 VTS Operators, 1 Maritime Survey Engineer, 1 active Oceangoing Master) individually scoring each criterion. These individual scores were then aggregated to obtain an average score for each criterion, which served as the input for the pairwise comparison matrix. The use of average scores in this manner allowed the incorporation of the collective expertise of the panel while adhering to the AHP framework. There were no extreme values observed for the comparison scoring of the experts. This ensured that the transition from individual scoring to pairwise comparison was both systematic and representative of the panel's overall assessment.

After the pairwise comparison matrices are created, each element in the matrix is normalized by dividing by its column sum according to the relevant formula. Each column sum of the normalized matrix becomes 1. Then, the sum of each row of the normalized matrix according to the relevant formula is divided by the size of the matrix, and the average is taken. These calculated values are the importance weights for each factor. These weights are called the priority vector. After creating the pairwise comparison matrix with the values determined as a result of the comparison judgment between the factors, it is checked whether these comparisons are consistent or not. In order to determine whether a matrix formed as a result of pairwise comparison calculations is consistent or not, the coefficient called the consistency index (CI: Consistency Index), which is one of the many methods, is calculated. If the consistency index value is below 0.10, the comparison matrix is judged to be consistent. If this ratio is exceeded,the matrix is considered to be inconsistent, and the pairwise comparison matrix should be rearranged with different values (Tian et al., 2013; Özbek et al., 2013).

3.5 Findings

In order to find the eigenvalue of each risk factor and to rank them, the weight of the main criterion, the weight of the sub-criteria, and the weight of the relevant option are multiplied by each other. The hierarchical structure, including the results of the relevant normalization, consistency, and eigenvalue calculations, is shown in **Table 4**.

The eigenvalues (degrees of importance) of the 48 risk factors affecting navigation safety are calculated and determined separately by following the AHP calculation steps and using the relevant formulas and then ranked. **Table 5** shows the ranking of the risk factors according to their eigenvalues and percentage importance weights.

According to the data in **Table 5**, the biggest risk factor is the difficulty in monitoring the local traffic in the region, with 9.73 %. The lowest risk factor, with 0.08 %, is the tidal phenomenon, which is an oceanographic risk factor that is almost never encountered in the region, but is only rarely created by the rivers located in the harbor mouths. The ranked % values of all risk factors are also shown graphically in **Figures 4** and **5**.

Table 3 Importance scale (Tzeng & Huang, 2011).

Value	Description
1	Elements are of equal importance or there is no difference between them
3	Item 1 is slightly more important or slightly more preferred than item 2
5	Item 1 is important or preferred over item 2
7	Item 1 is too important or too much preferred over item 2
9	Item 1 is extremely important or extremely preferred over item 2
2, 4, 6, 8	Intermediate values

Table 4 Hierarchical structure (Computational).

Purpose	Criteria	Sub-Criteria	Norm.	Navigation Risks	Norm.	C.I.	Eigen Value
Analysis of Factors Affecting Safety of Navigation in the Gulf of İzmit by Ahp Method	Static Risks (S) Norm. : 0.36 Cons. Index: 0.021834	S1 - Gulf of İzmit Entrance TSS Deficiency	0.13	S11 - Disruption of traffic organization	0.26	0.00267	0.01185
				S12 - Vessels reaching the pilotage point at the same time/close to the pilotage point	0.28		0.01304
				S13 - Encounter of inbound and outbound traffic	0.46		0.02153
		S2 - Pilot Pick up / Drop off Points	0.24	S21 - Reduced/lost maneuverability of intercepting vessels	0.41	0.00267	0.03486
				S22 - Uncontrolled maneuvering / operational difficulties in bad weather conditions	0.37		0.03167
				S23 - Proximity of Yalova - Kocaeli pilotage service points to each other	0.22		0.01918
		S3 - Eskihisar - Topçular Ferry Line	0.14	S31 - Intense and irregular movement	0.49	0.00161	0.02466
				S32 - Conflicts over right of way	0.35		0.01771
				S33 - Overlap of the ferry line with Eskihisar anchorage area	0.15		0.00763
		S4 - Bridge Zone (Critical zone)	0.09	S41 - Adjacency to Dilovası port area and Eskihisar anchorage area	0.62	0.00077	0.01978
				S42 - Maneuvering / navigational difficulties due to speed and overtaking restrictions	0.29		0.00939
				S43 - Air draft restriction (60 meters)	0.09		0.00297
		S5 - Narrowest Navigation Area (Derince-Gölcük)	0.07	S51 - Pilot change operations for Derince Port	0.12	0.00530	0.00300
				S52 - Presence of military installations and maritime space	0.56		0.01400
				S53 - Underwater pipe / power lines	0.32		0.00800
		S6 - Anchorage Areas	0.23	S61 - Adjacency / Proximity (Dangerous cargo, Ferry line, Local traffic, Pipeline, Port)	0.52	0.00045	0.04248
				S62 - Seabed structure / Depth inappropriateness	0.12		0.01021
				S63 - Insufficient anchorage space	0.36		0.02945
		S7 - Geographical Conditions	0.05	S71 - Shoals, wrecks and other coastal navigation obstacles	0.09	0.00204	0.00157
				S72 - Irregular installation / location of port facilities within the Gulf	0.67		0.01195
				S73 - Location of the resident population close to ports/terminals handling dangerous cargo	0.24		0.00433
		S8 - Current TSS	0.05	S81 - Navigational risks of joining/leaving TSS	0.66	0.02329	0.01170
				S82 - Vessels entering and leaving Yalova cannot use current TSS	0.29		0.00517
				S83 - Contacts to vessels within the TSS	0.05		0.00098

Table 4 (continued) Hierarchical structure (Computational).

Purpose	Criteria	Sub-Criteria	Norm.	Navigation Risks	Norm.	C.I.	Eigen Value
Analysis of Factors Affecting Safety of Navigation in the Gulf of İzmit by Ahp Method	Dynamic Risks (D) Norm.: 0.64 Cons. Index: 0.03441	D1 - Local Traffic	0.28	D11 - Difficulty monitoring local traffic	0.54	0.00036	0.09725
				D12 - Navigation in maneuvering areas of commercial vessels	0.35		0.06260
				D13 - Failure to establish local traffic VHF contact	0.11		0.02015
		D2 - Naval Activities	0.10	D21 - Failure to receive data from navy vessels	0.62	0.00077	0.03955
				D22 - Failure to report navy vessel movements	0.29		0.01879
				D23 - Drill / Ceremony	0.09		0.00595
		D3 - Fishing Activities	0.15	D31 - Illegal Fishing Activities (Mussel, Trawling)	0.37	0.00267	0.03563
				D32 - Failure to establish VHF contact with fishing boats	0.22		0.02158
				D33 - Fishing in prohibited areas (TSS, anchorage area, ferry line, in front of the ports)	0.41		0.03922
		D4 - Sportive / Special Activities	0.03	D41 - Unauthorized / uninformed activities	0.29	0.00077	0.00564
				D42 - Failure to establish VHF contact with yacht/sailboat	0.62		0.01187
				D43 - Obligation for partial or total suspension of business activities	0.09		0.00178
		D5 - Commercial Traffic without Pilot	0.21	D51 - Presence of substandard vessels	0.44	0.00107	0.05882
				D52 - Incompetent and uninformed crew	0.41		0.05535
				D53 - Failure to establish VHF contact with Coaster	0.15		0.02083
		D6 - Meteorological Conditions	0.07	D61 - Wind	0.58	0.00107	0.02617
				D62 - Restricted Visibility	0.31		0.01390
				D63 - Heavy rain / snow / blizzard / hail	0.11		0.00493
		D7 - Oceanographic Conditions	0.02	D71 - Current	0.81	0.03933	0.01039
				D72 - Tide	0.06		0.00080
				D73 - Stream / River / Lake impacts	0.13		0.00167
		D8 - Shipyard Activities	0.14	D81 - Sea trial and towing activities	0.43	0.00843	0.03883
				D82 - Frequent failure of vessels (Defective on arrival, New construction, Long repair period	0.36		0.03275
				D83 - Irregular anchoring in front of Yalova shipyard	0.20		0.01842

Table 5 Importance ranking of navigational risks after AHP analysis.

Rank	Navigation Risks	Eigen Value	Percentage
1	D11 - Difficulty monitoring local traffic	0.09725	9.73
2	D12 - Navigation in maneuvering areas of commercial vessels	0.06260	6.26
3	D51 - Presence of substandard vessels	0.05882	5.88
4	D52 - Incompetent and uninformed crew	0.05535	5.53
5	S61 - Adjacency / Proximity (Dangerous cargo, Ferry line, Local traffic, Pipeline, Port)	0.04248	4.25
6	D21 - Failure to receive data from navy vessels	0.03955	3.96
7	D33 - Fishing in prohibited areas (TSS, anchorage area, ferry line, in front of the ports)	0.03922	3.92
8	D81 - Sea trial and towing activities	0.03883	3.88
9	D31 - Illegal Fishing Activities (Mussel, Trawling)	0.03563	3.56
10	S21 - Reduced/lost maneuverability of intercepting vessels	0.03486	3.49
11	D82 - Frequent failure of vessels (Defect on arrival, New construction, Long repair period	0.03275	3.28
12	S22 - Uncontrolled maneuvering / operational difficulties in bad weather conditions	0.03167	3.17
13	S63 - Insufficient anchorage space	0.02945	2.95
14	D61 - Wind	0.02617	2.62
15	S31 - Intense and irregular movement	0.02466	2.47
16	D32 - Failure to establish VHF contact with fishing boats	0.02158	2.16
17	S13 - Encounter of inbound and outbound traffic	0.02153	2.15
18	D53 - Failure to establish VHF contact with Coaster	0.02083	2.08
19	D13 - Failure to establish local traffic VHF contact	0.02015	2.01
20	S41 - Adjacency to Dilovası port area and Eskihisar anchorage area	0.01978	1.98
21	S23 - Proximity of Yalova - Kocaeli pilotage service points to each other	0.01918	1.92
22	D22 - Failure to report navy vessel movements	0.01879	1.88
23	D83 - Irregular anchoring in front of Yalova shipyard	0.01842	1.84
24	S32 - Conflicts over right of way	0.01771	1.77

Table 5 (continued) Importance ranking of navigational risks after AHP analysis.

Rank	Navigation Risks	Eigen Value	Percentage
25	S52 - Presence of military installations and maritime space	0.01400	1.40
26	D62 - Restricted Visibility	0.01390	1.39
27	S12 - Vessels reaching the pilotage point at the same time/close to the pilotage point	0.01304	1.30
28	S72 - Irregular installation / location of port facilities within the Gulf	0.01195	1.20
29	D42 - Failure to establish VHF contact with yacht/sailboat	0.01187	1.19
30	S11 - Disruption of traffic organization	0.01185	1.19
31	S81 - Navigational risks of joining/leaving TSS	0.01170	1.17
32	D71 - Current	0.01039	1.04
33	S62 - Seabed structure / Depth inappropriateness	0.01021	1.02
34	S42 - Maneuvering / navigational difficulties due to speed and overtaking restrictions	0.00939	0.94
35	S53 - Underwater pipe / power lines	0.00800	0.80
36	S33 - Overlap of the ferry line with Eskihisar anchorage area	0.00763	0.76
37	D23 - Drill / Ceremony	0.00595	0.59
38	D41 - Unauthorized / uninformed activities	0.00564	0.56
39	S82 - Vessels entering and leaving Yalova cannot use current TSS	0.00517	0.52
40	D63 - Heavy rain / snow / blizzard / hail	0.00493	0.49
41	S73 - Location of the resident population close to ports/terminals handling dangerous cargo	0.00433	0.43
42	S51 - Pilot change operations for Derince Port	0.00300	0.30
43	S43 - Air draft restriction (60 meters)	0.00297	0.30
44	D43 - Obligation for partial or total suspension of business activities	0.00178	0.18
45	D73 - Stream / River / Lake impacts	0.00167	0.17
46	S71 - Shoals, wrecks and other coastal navigation obstacles	0.00157	0.16
47	S83 - Contacts to vessels within the TSS	0.00098	0.10
48	D72 - Tide	0.00080	0.08

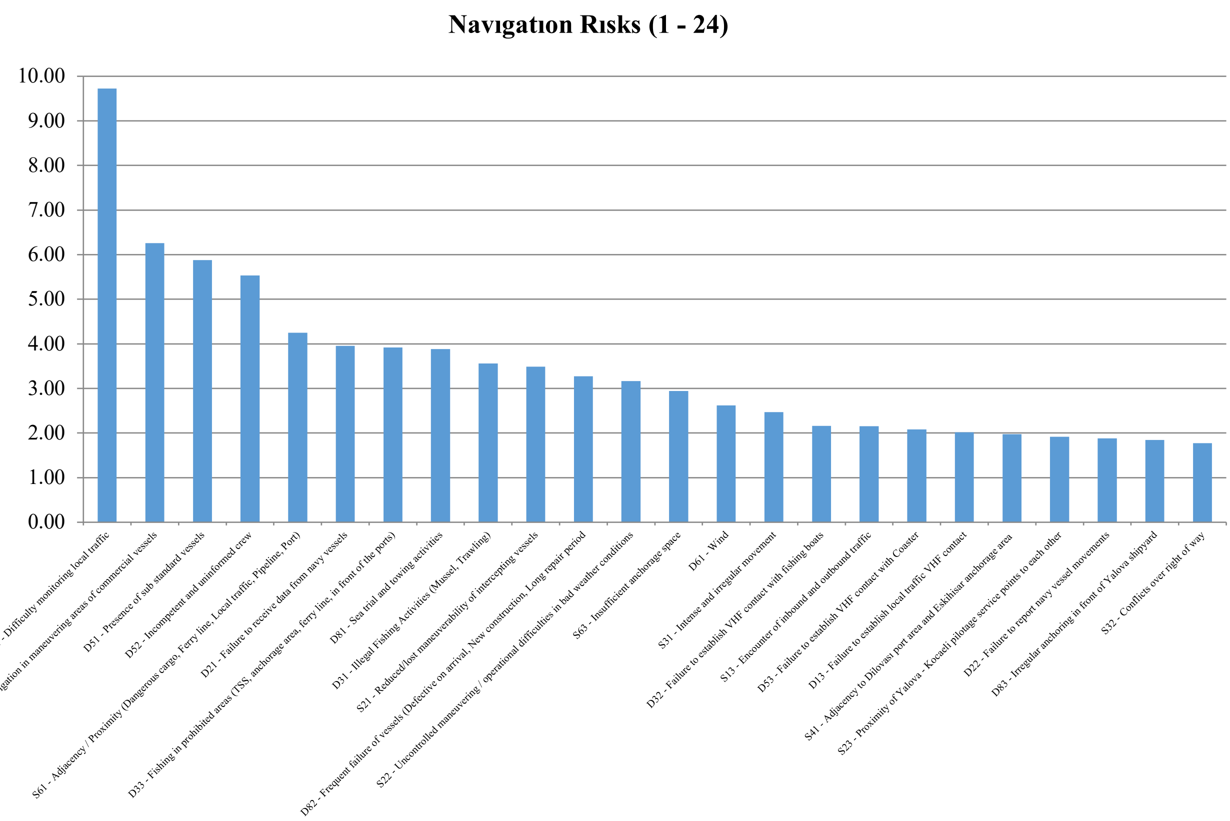

Figure 4 Importance ranking of navigational risks after AHP analysis (1 to 24).

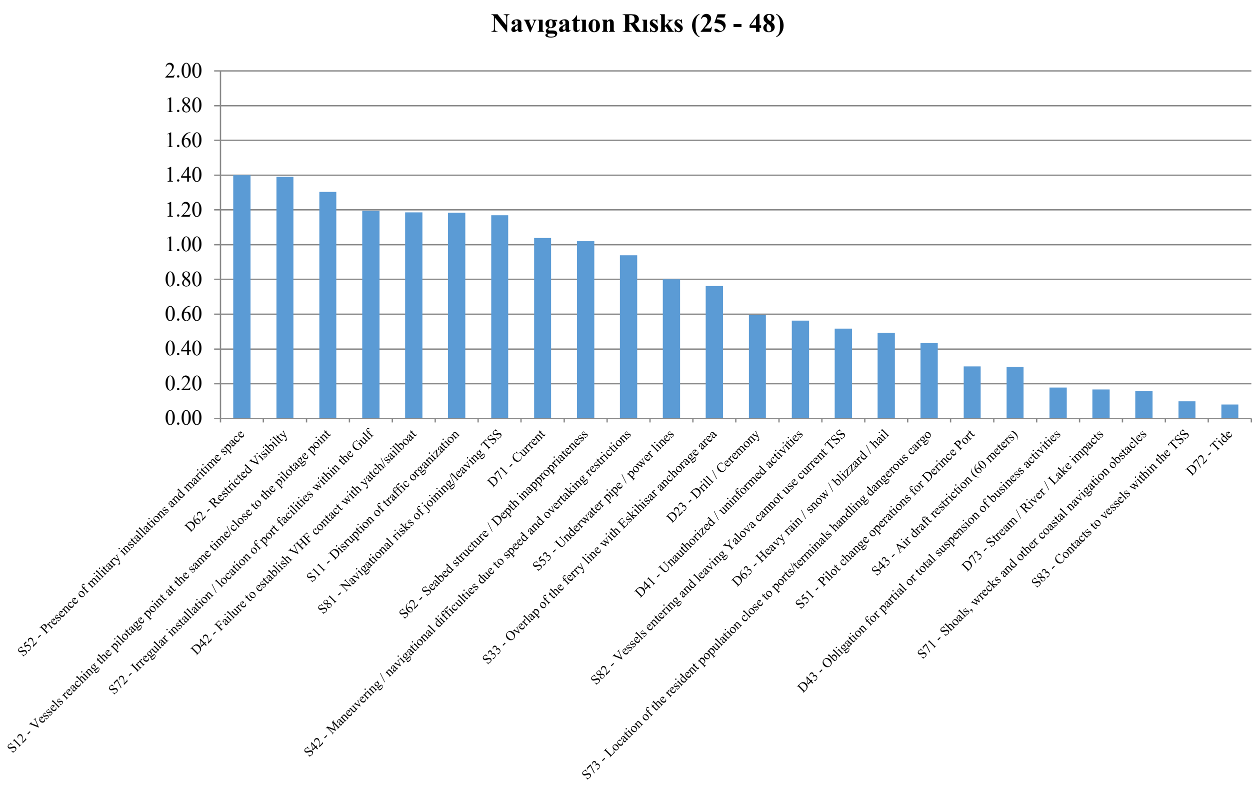

Figure 5 Importance ranking of navigational risks after AHP analysis (25 to 48).

4. Results and discussion

The first two risk factors are risks related to local traffic. The Gulf of İzmit has dense local traffic on the north-south axis and in a narrow area. It is a necessity that local traffic lines should be separated from pilot stations, anchorages, and port maneuvering areas and be at safe distances, because it is a serious risk in itself for a vessel that will be guided at the pilot station, or a vessel that will land its pilot for a short time, and Eskihisar-Topçular local traffic to interact, and for this interaction to take place within the 1.4 mile wide Traffic Separation Scheme (TSS). Of the 48 risk factors identified and weighted;

- The first 5 risk factors account for 31.65 % of the total.
- The first 10 risk factors account for 50.46 % of the total.
- The last 15 risk factors account for only 6.72 % of the total.

Among the static risk factors, the biggest risk factor is that the anchorages are adjacent to each other, coastal areas, coastal structures, heavy local traffic lines, and underwater energy lines, with a rate of 4.25 %. It is clear that relevant mapping and legislative studies should be carried out by the relevant parties to make the anchorages in the Gulf of İzmit clearer. By taking the opinions of all parties, the areas of existing anchorages can be expanded, and alternative anchorage areas can be created.

As a continuation of the existing TSS at the entrance of the Gulf of İzmit, a TSS should be added at a range of 2 to 3 miles, especially to ensure that the inbound traffic arrives at the pilotage points with a fixed route and to prevent vessels from meeting in a narrow area. In addition, the existing TSS 90 - 270 route between Körfez and Değirmendere can be extended by 2 miles in order for the vessels navigating within the TSS to pass through the Tüpraş Platform and Yarımca anchorage at a safer distance.

In addition, a new TSS and pilotage pick-up/drop-off point should be established south of the existing TSS for vessels arriving at the Yalova Port Authority administrative area. Considering the operational and administrative integrity of the Gulf of İzmit, it would be more beneficial to add the sea area east of Osmangazi Bridge, which is located in the administrative area of Yalova Regional Port Authority, to the administrative area of Kocaeli Regional Port Authority. Thus, the use of the existing TSS, in violation of the legislation by all units (vessels, pilotage, tugboats, etc.) operating in the Yalova administrative area, can be prevented.

Escort services in the Gulf of İzmit are limited to high-draft vessels passing through the Osmangazi Bridge. It will be beneficial for safe navigation and for public interest to implement an escort service throughout the Gulf of İzmit for LPG, LNG, and passenger vessels, as well as in the bridge area and east of the Halıdere sea area for vessels with a high air draft and deep water draft.

Shipyard activities carried out in the Gulf of İzmit are mostly realized in the Yalova Altınova region.In the region, there are intensive trial voyages, towing voyages, and breakdown/ damage/ inadequate vessel voyages. This situation has a total rate of 9 % among the risk factors in this study. Determining the anchorages in front of the Yalova shipyard and emergency anchorages will minimize the related risk factors.

In the hierarchical structure created with AHP, many criteria, sub-criteria, or alternatives can be included. This causes the number of pairwise comparisons to be made to be too high and, thus, it becomes complex.

The importance scale in the AHP method is limited. Especially in expert evaluations based on numerical data, intermediate values and fractional values can be used in the importance scale. Although it is thought that going beyond the importance scale may affect consistency, the use of intermediate values is frequently preferred.

There is a possibility that the results may be inconsistent due to the indecision experienced by the experts when using the scale. For this reason, the matrix scores to be given by the experts must be evaluated by calculating the consistency.

Only one risk assessment method (AHP) was used in the study. In this respect, the results are not conclusive, or at the closest level to the truth. The literature review data obtained and the expert comments made in this direction should be used with other analysis methods, and should be developed with different expert opinions with wider participation.

Especially, dynamic risk factors are open to change (increase-decrease). Therefore, future forecasts / determinations / targets should be determined in a simulation environment, and the risk factors and importance weights obtained in the study should be updated in the long term.

5. Conclusions and recommendations

In order to increase navigational safety and minimize accident risks in all maritime area, it is necessary to know the risk factors and characteristics of the area very well. The study stands out because it includes all risk factors predicted for the Gulf of İzmit, indicates the order of importance, and will contribute to risk analysis studies to be carried out in the future.

The results will contribute to the risk analysis studies of all relevant public and private sector units serving in the region. This will be useful in terms of preliminary evaluation and feasibility in other studies to be carried out in the Gulf of İzmit.

In order to present the risks in a clearer and more detailed manner, it is important that the records of accidents, near misses, and all incidents that pose a risk are kept by all units in a timely and complete manner, and that information is provided and maintained in a timely manner. The relevant records should be periodically backed up and stored under the management and coordination of the maritime units of the public authority, and stored in a different and secure environment under adequate physical and cyber security measures in case of an unexpected adverse situation. Related records can be used as a study case in training and can be effective in system improvements. Also, this will enable a proactive approach to navigational risks and more detailed risk assessments.

The port facilities in the Gulf of İzmit are mostly clustered on the northern shores and, at certain points, the port areas are irregularly structured in a way that makes it difficult for vessels to maneuver. Moreover, according to the cargo category, ports and terminals are mixed, except for the Tüpraş area. For example, contrary to global examples, container terminals in the Gulf of İzmit, which are among the largest container terminals in Türkiye, are located in different areas. In some port areas, hazardous cargo (chemical, LPG), dry cargo, containers, and Ro-Ro operations are carried out at the same time, posing risks. In addition, there are adjacent ports to the east and west of the Osman Gazi Bridge, posing risks for vessels maneuvering and navigating in the region. In the long term, efforts should be made to separate port and terminal locations according to the cargo handled (such as hazardous, bulk, container) and to gather terminals with the same characteristics in one region. Legislation on the planning and establishment of port/terminal structures should be updated, and the limitations and requirements between related structures should be determined. In addition, during the coastal facility and settlement planning phase, identification of the medium and long-term environmental impact and social impact and cost-benefit analyses should be conducted by the relevant units of the public authority, and action should be taken according to the outputs of the analyses.

Vessels operating in the region within the scope of local traffic and their employees are substandard. Therefore, regular inspection of fishing vessels, vessels under 1,000 GRT, and vessels subject to local traffic and periodic monitoring of the certification, and the training and mental levels of their personnel, should be carried out. Periodic inspections and training should be conducted by the maritime units of the public authority and port authorities. A blacklist database covering the vessels and employees who do not follow the rules and who are inadequate can be created, and the vessels and employees on the list can be inspected more frequently. In case of repetition, work permits and certificates can be canceled.

Especially, fishing boats, sailboats, and local traffic fail to continuously listen to the relevant VHF channels and fail to display visual and auditory navigation signs related to their operations clearly, posing risk to safe navigation. In order to strengthen the deterrence of administrative sanctions, legislative studies should be carried out, and relevant units should increase their inspections.

Placing remote sensing measurement devices at certain points in the Gulf to obtain current and pollution data will minimize the formation of environmental pollution and contribute to anti-pollution operations. In this context, systems that can record instantaneous data continuously and completely, and that can back up data periodically, at least annually, should be preferred. In terms of installation, operation, maintenance costs, and information security, systems produced with domestic resources will be more beneficial. The data obtained can be used in academic and sectoral studies. They can also be presented as a resource in various training.

Measures that can be taken in practice, according to the weights and importance of the identified factors, should be prioritized under the leadership of the public authority and by a committee consisting of experts working in the region; cost-benefit analyses should be made, and it should be ensured that they are implemented in the short, medium, and long term.

Although the Gulf of Izmit is a narrow and small waterway in terms of area, it contains many maritime units. The proposed navigational safety practices in the region will set an example for similar waterways around the world. Suggestions such as speed limitations in the bridge area, escort applications, and safe distances of traffic separation schemes in critical areas and anchorages can be applied in other waterways by using appropriate decision-making techniques and evaluations.

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