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RANKING THE MAIN RISKS THAT CAN LEAD TO THE POLLUTION OF THE MARINE ENVIRONMENT IN THE BLACK SEA

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ABSTRACT

The aim of this paper is to present the way in which the main risks that can lead to the pollution of the marine environment of the Black Sea can be ranked using multicriteria analysis, based on the AHP process (Analytic Hierarchy Process). This analysis represents a solid basis for the decision-making process. Based on this hierarchy, the decision-makers in the maritime field can easily visualize both the risk assessment criteria and the risks that must be taken into account. The analyzed risks (oil spills, shipwrecks, ship collision, fire explosion) in relation to the considered criteria (bad weather conditions, high-density traffic, human errors, ship age) have been ranked as follows: "ship collision" risk with overall priority = 0.366 is the one that must be considered the most dangerous in relation to the considered criteria, followed in descending order by the risk of "oil spills" with overall priority = 0.303, the risk of "shipwrecks" with overall priority = 0.181 and finally the risk of "fire explosion" with overall priority = 0.150.

Keywords: risks, overall priority, shipwrecks, ship collision, human errors

1. INTRODUCTION

More than 90 percent of goods that are traded internationally are transported by the sea, according to the Organization for Economic Co-operation and Development. This means that by 2050, the volume of maritime trade will triple [34]. However, due to extreme weather episodes (storms becoming more intense due to climate change), the sea trade routes can be severely affected. Therefore, one of the main causes of marine pollution is shipping, which is added to the industrial emissions and accidents between the ships. Even if maritime transport has led, as stated by Mansyur et al., (2021) and Wang et al., (2023), to the increase in the efficiency and the global flow of goods, it inevitably has had a major contribution to various maritime accidents. These accidents have resulted in large fuel spills, with a high weight in water pollution, which, together with accidental spills on board the ship, constitute constant threats that can produce significant damage to the marine environment, seacoasts, and oceans, resulting in, at the same time, economic and social problems [5]. The causes of maritime accidents and their effects have been investigated over time by a series of international organizations and specialized agencies, of which the most well-known, in this direction, is the International Maritime Organization (IMO). All these organizations and international agencies have contributed, through the regulations, conventions, rules, and international standards elaborated, to reducing the frequency and even eradicating maritime accidents [29].

The effects of marine environmental pollution, regardless of their origin, become dramatic because they cause damage to living marine organisms and can also cause anthropogenic climate change [14].

Referring to the Black Sea, which is one of the most contaminated basins of the World Ocean, due to its hydrological characteristics, but also to the anthropic impact, it could be observed over time that the pollution level of this sea is progressing significantly. Among the most dangerous pollutants, oil and oil products can be listed, which, in addition to serious damage to living marine organisms, can break the natural hydrological cycle, which leads to anthropogenic climate change. In this way, the degree of risk increases, especially for coastal areas due to human economic activities carried out [15].

In recent years, because of the increased awareness of the impact of marine environment pollution, several measures have been adopted and implemented with the aim of reducing and even eliminating pollution from maritime transport [6], [14], [16]. Thus, the IMO (International Maritime Organization) introduced new regulations, starting on January 1, 2023, which aim to reduce greenhouse gas emissions and the impact they have on the marine environment [27].

The paper aims to classify the main risks that can lead to the pollution of the marine environment in the Black Sea, using the AHP method.

2. EXTREME EVENTS IN THE BLACK SEA

The role that the Black Sea has for the neighboring countries, from a socio-economic point of view, is of interest to scientific studies, especially in terms of meteorological events that have a negative impact on human activities.

The Black Sea, as a closed basin in which storms predominate, is characterized by a relatively large number of naval accidents. Their main causes are the unfavorable hydrometeorological conditions.

On the other hand, the naval traffic on this important navigation route has grown substantially, as a result of the increase in offshore activities in the area, also generated by the existence of the pan-European transport corridor (Danube-Rhine-Main Canal), which connects the Black Sea with Central European countries [9], [12].

In the Black Sea, wave conditions are considered less energetic compared to the open ocean, but as a result of warmer temperatures and higher sea levels caused by the climate change, the intensity of storms has increased in recent years. Such storms often appear in the Black Sea area, the wave conditions being comparable to those of the ocean [23], [31]. Therefore, in order to prevent maritime and coastal hazards, with very large economic and ecological consequences, a precise forecast of these situations is necessary. Besides this, the Black Sea area is prone to the occurrence of severe meteorological phenomena, either because of the cyclones that can develop in the area or because they just cross the region [30]. According to an estimate made by the High Meadows Environmental Institute, the proportion of category 3 to 5 cyclones has increased, from 1979 to the present, by approximately five percent per decade [13]. An example of an extreme phenomenon, produced in the Kerch Strait on November 11, 2007, is the intense storm, which caused the sinking of four oil tanks [7]. Most oil spill accidents have occurred as a result of strong storms. These extreme weather phenomena can manifest themselves in various forms: strong lightning, floods, heavy rains, snow accumulations, etc., but they all involve strong winds and increased atmospheric humidity, and they can disrupt maritime activities and even be real dangers to navigation and the environment. The association of such phenomena with high wind speed determines a strong impact, both on the marine and coastal environment, but also on the regional economic infrastructure, affecting safety in the marine environment, especially due to floods caused by strong storms that can lead to the loss of human lives [10], [19], [32].

For the operation of the maritime sector at optimal parameters, it is necessary to take into account the internal factors as well as the external factors. Due to maritime routes severely affected by the extreme phenomena, ships are forced to adjust their routes to avoid interruptions or delays and even find solutions to prevent loss of cargo and even ship damage [26], [27].

In order to be able to minimize the risks that arise because of the extreme phenomena, it is necessary to implement safety measures and procedures, which may refer to the consolidation of the infrastructure, the equipping of ships, ports, and terminals with equipment to prevent the occurrence of disasters, up to the monitoring of environmental conditions [17].

Based on literature studies [1], [2], [8], [24], [25], [20], [21], [22], analyzing the various causes that have led to accidents in the Black Sea basin, it has been found that along with the main causes (unfavorable hydro-meteorological conditions and technical faults of the ships), a number of subjective factors intervene, such as the poor training of the crew, their stress and fatigue. By superimposing storms, strong winds, and big waves on top of human errors, serious naval accidents can occur in the Black Sea basin.

3. RESEARCH METHODOLOGY

In order to evaluate the main risks that can lead to the pollution of the marine environment in the Black Sea, the AHP method has been applied in three stages:

1. Building the hierarchical structure of decision analysis (Fig. 1).
2. The derivation of the criteria (calculation of the weights) involves the pairwise comparison of the criteria (the decision matrix). It results in the number of the compared pairs N(N-1)/2 (where N-number of criteria). Following pairwise comparisons, the relative weights of the criteria result, which form the vector of these weights (W), the criterion with the highest weight being the most important [11].
3. From the decision matrix, the normalized matrix is obtained, each entry in this matrix is obtained by dividing the entries in the decision matrix by the sum of the columns.

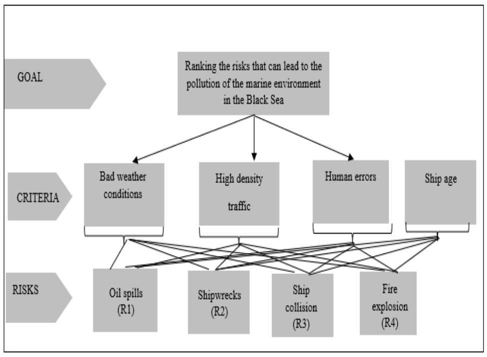

Fig. 1. The hierarchical structure of decision analysis

The weight vector (W) is an N-dimensional column vector, which was obtained by calculating the average of the entries on each row of the normalized matrix.

To establish the relative importance of two criteria, relative scores according to Saaty's scale are used (1 for the case when i and j are equally as important; 3 for the case when i is slightly more important than j; 5 for the case when i is more important than j; 7 for the case when i is strongly more important than j; 9 for the case when i is absolutely more important than j) [3].

The verification of the coherence of the judgments made by the decision-makers selected for the assessment of marine risks and the establishment of their importance was achieved by calculating the consistency ratio

(CR=CI/RI). In this sense, the consistency index (CI) containing the judgments of the decision-makers, and the random consistency index (RI), using a random matrix [28], were used. The consistency indices for the randomly generated matrix are presented in Table 1 (n-number of elements compared). According to [3], if CR ≤ 0.1 the AHP analysis can continue.

Table 1 Consistency indices based on the random matrix [3]

n	3	4	5	6
RI	0.58	0.9	1.12	1.24

The calculation of CR is done using the matrix that includes the comparisons by criteria, multiplying each element in the columns of this matrix by the weight of the corresponding criterion to finally obtain the weighted sums, by adding up the values on each row of the matrix. The elements of the weighted sum vector are divided by the weight corresponding to each criterion, thus calculating the average of the obtained values, denoted by ʎmax (the largest eigenvalue), to then calculate CI = (ʎmax-n)/(n-1) [4].

In the last stage, the derivation of the local priorities, called scores, for the risks that must be prioritized, which consists of their pairwise comparisons, for each criterion are made. If M is the number of risks being compared, a real matrix of the (M x M) type, of the pairwise comparisons of these risks, is constructed for each criterion N, i = 1, ..., N. Pairwise comparisons are made on the same principle as in the case of criteria, each entry in the matrix of the (M x M) type representing the assessment of one risk with another in relation to each criterion, using Saaty's numerical scale [3]. The score matrix of the compared risks is thus constructed, denoted by T= [t(i)..... t(N)], which is a real M × N matrix [11]. The calculation of the global priorities/scores for the evaluated risks is based on the weight vector (W) of the criteria and the score matrix (T) of the compared risks, making the product T x W=V. The vector of global scores/priorities for the compared risks is thus obtained. Based on these global priorities of the compared risks, they are ranked in descending order of the global scores [4].

4. RESULTS AND DISCUSSIONS

For the pairwise comparisons of the four considered criteria (bad weather conditions, high traffic density, human errors, ship age) (Tables 2÷5), but also of the risks addressed (oil spills, shipwrecks, ship collision, fire explosion) (Tables 6÷9), discussions with representatives of the port authorities in the Black Sea were held, who expressed their opinion regarding the importance of these criteria and risks, which could lead to the pollution of the marine environment, in case of a naval accident.

Table 2 Priorities of the selected criteria and consistency ratio based on the decision matrix

Criteria	Bad weather conditions	High-density traffic	Human errors	Ship age	Priority of the criteria
Bad weather conditions	1	7	5	7	0.623
High-density traffic	0.143	1	0.333	3	0.106
Human errors	0.2	3	1	5	0.216
Ship age	0.143	3	0.2	1	0.055
CR = 0.091					

Table 3 Normalized matrix

Criteria	Bad weather conditions	High-density traffic	Human errors	Ship age
Bad weather conditions	0.673	0.618	0.765	0.438
High-density traffic	0.096	0.088	0.051	0.188
Human errors	0.135	0.265	0.153	0.313
Ship age	0.096	0.029	0.031	0.063

Table 4 Calculus of the weighted sum

Criteria	Bad weather conditions	High-density traffic	Human errors	Ship age	Weighted sum
Bad weather conditions	0.623	0.740	1.081	0.383	2.827
High-density traffic	0.089	0.106	0.072	0.164	0.431
Human errors	0.125	0.317	0.216	0.273	0.931
Ship age	0.089	0.035	0.043	0.055	0.222

Table 5 Calculus of the largest eigenvalue (ʎmax)

Weighted sum	Priority of the criteria	Weighted sum/priority of the criteria
2.827	0.623	4.535
0.431	0.106	4.075
0.931	0.216	4.308
0.222	0.055	4.065
	Total	16.983
	ʎmax	4.246

Table 2 presents the weights of the criteria, which were used to obtain the weighted sum (Table 4). Table 5 shows the calculation method of ʎmax, which has been used to calculate CI=(4.246-4)/(4-1)=0.082 and CR=0.082/0.9= 0.091≤0.1. Based on the value obtained for CR, it can be concluded that the decision-making factors' judgment is reasonably consistent, which allows the continuation of the decision-making process, using AHP.

In the second stage, the local priorities (scores) are determined for the four risks that are compared to be ranked and involve similar calculations to the first stage, contained in Tables 6÷9. The local priorities obtained for the four risks show which is the greatest risk of pollution of the marine environment, in the case of each criterion. For this, we considered that:

- In relation to Bad weather conditions (the first criterion), R1 is much more important than R2 and R1 is equally important with R3, but slightly more important than R4 (Table 6):

Table 6 Local priorities in relation to bad weather conditions (first criterion)

Bad weather conditions	oil spills	shipwrecks	ship collision	fire explosion	Priority
oil spills	1	5	1	3	0.399
shipwrecks	0.2	1	0.333	0.333	0.083
ship collision	1	3	1	3	0.357
fire explosion	0.333	3	0.333	1	0.161
CR=0.043					

- In relation to High-density traffic (the second criterion), R2 and R3 are slightly more important than R1, while R1 and R4 are equally important (Table 7):

Table 7 Local priorities in relation to High-density traffic (second criterion)

High-density traffic	oil spills	shipwrecks	ship collision	fire explosion	Priority
oil spills	1	0.333	0.333	1	0.122
shipwrecks	3	1	0.333	3	0.283
ship collision	3	3	1	3	0.473
fire explosion	1	0.333	0.333	1	0.122
CR=0.057					

- In relation to Human errors (the third criterion), R2 is slightly more important than R1 and R1 slightly more important than R4, while R3 is much more important than R1 (Table 8):

Table 8 Local priorities in relation to Human errors (third criterion)

Human errors	oil spills	shipwrecks	ship collision	fire explosion	Priority
oil spills	1	0.333	0.333	3	0.172
shipwrecks	3	1	1	3	0.365
ship collision	3	1	1	3	0.365
fire explosion	0.333	0.333	0.333	1	0.099
CR=0.059					

- In relation to Ship age (fourth criterion), R2 and R4 are slightly more important than R1 and R3 is much more important than R1 (Table 9).

Table 9 Local priorities in relation to Ship age (fourth criterion)

Ship age	oil spills	shipwrecks	ship collision	fire explosion	Priority
oil spills	1	0.333	0.2	0.333	0.087
shipwrecks	3	1	3	1	0.375
ship collision	5	0.333	1	1	0.258
fire explosion	3	1	1	1	0.279
CR=0.098					

Knowing the local priorities for the four analyzed risks (oil spills, shipwrecks, ship collision, fire explosion), in relation to the considered criteria (bad weather conditions, high-density traffic, human errors, ship age), calculated in Tables 6÷9 and taking into account the weights of each criterion, determined in Table 2, given in the form of the vector $W_{criteria\ weights}$, the overall priorities of the risks can be determined (Table 10), based on which their ranking can be achieved. The obtained criteria weight vector is:

$$W_{\text{criteria weights}} = \begin{bmatrix} 0.623 \\ 0.106 \\ 0.216 \\ 0.055 \end{bmatrix}$$

Table 10 Overall priorities of the risks

Risks / Criteria	Bad weather conditions	High-density traffic	Human errors	Ship age	Overall priority
Criteria weights	**0.623**	**0.106**	**0.216**	**0.055**	
R1 (oil spills)	0.249	0.013	0.037	0.005	0.303
R2 (shipwrecks)	0.052	0.030	0.079	0.021	0.181
R3 (ship collision)	0.222	0.050	0.079	0.014	0.366
R4 (fire explosion)	0.100	0.013	0.021	0.015	0.150

The order of the risks is given by the vector $V_{\text{global priorities of the risks}}$ obtained by multiplying the vector $W_{\text{criteria weights}}$ with the score matrix of the compared risks (T), which is a weighted sum of the local priorities of the risks, in relation to the four considered criteria, with the weights obtained for the four criteria.

$$V_{\text{global priorities of the risks}} = \begin{bmatrix} 0.303 \\ 0.181 \\ 0.366 \\ 0.150 \end{bmatrix}$$

Based on the vector $V_{\text{global priorities of the risks}}$, the four risks can be classified, in descending order of overall priorities. Thus, risk R3 (ship collision) with overall priority = 0.366 is the one that must be considered first, being the most dangerous in relation to the considered criteria, followed by risk R1 (oil spills) with overall priority = 0.303, then R2 (shipwrecks) with overall priority = 0.181 and risk R4 (fire explosion) with overall priority = 0.150.

5. CONCLUDING REMARKS

The AHP process is an important approach when it is necessary to adopt a decision-making process with multiple criteria, based on the preferences of decision-makers. Decision-makers can visualize the entire decision-making process in a hierarchy, which includes the purpose of this process, the evaluation criteria, and the variants (risks) analyzed.

The first step in this analysis consisted of pairwise comparisons of the criteria established by the stakeholders to determine the weights of these criteria, which were further used to rank the risks, which were compared in pairs in relation to each criterion. Using the AHP model, the weights of the criteria and the scores obtained for the risks can be combined, finally determining the global score. This global score is a sum weighted with the scores of the criteria, based on which the decision-makers can structure the decision-making process, achieving a classification of the most important risks that must be addressed to avoid pollution of the marine environment. Saaty's relative measurement scale was used to make the pairwise comparisons.

Using the AHP method, in order to rank the four risks, considered to be the most dangerous in relation to the criteria selected by the decision-makers in the maritime field, the following were obtained:

- the weights of the four criteria (bad weather conditions-0.623; high-density traffic-0.106; human errors-0.216; ship age-0.055) following their pairwise comparisons;
- the local priorities of the evaluated risks (Table 11), following their pairwise comparisons, in relation to the considered criteria;

Table 11 Local priorities of the analyzed risks

Risks / Criteria	Bad weather conditions	High-density traffic	Human errors	Ship age
Oil spills	0.399	0.122	0.172	0.087
Shipwrecks	0.083	0.283	0.365	0.375
Ship collision	0.357	0.473	0.365	0.258
Fire explosion	0.161	0.122	0.099	0.279

- the global scores of the analyzed risks, based on which they have been classified in descending order, are: "ship collision" (0.366), "oil spills" (0.303), "shipwrecks" (0.181), "fire explosion" (0.150).

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