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Optimization of Emergency Rescue Plan for the Transport of Hazardous Chemicals at Sea

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Abstract

Aiming at the problem of the lack of means of disposal of hazardous chemical transportation accidents, combined with various types of hazardous chemical transportation accidents in the emergency rescue disposal process and emergency rescue of hazardous chemical accidents at sea typical case studies. This paper analyzes the causes of hazardous chemical accidents at sea, rescue programs, the use of hierarchical analysis to optimize the rescue program for the transportation of hazardous chemicals at sea than the selection of the accident, to reduce the occurrence of hazardous chemical accidents at sea, and rescue accidents at sea to provide a certain type of factual basis for rescue, to improve the correctness of the decision-making of the emergency rescue of hazardous chemical accidents at sea as well as the efficiency of rescue, to reduce the casualties and property losses of hazardous chemical accidents at sea. and reduce the casualties and property losses in marine hazardous chemical accidents.

Keywords

Hazardous Chemicals; Maritime Transport; Emergency Rescue; Analytic Hierarchy Process.

1. Introduction

With the world's demand for hazardous chemicals increasing year by year, the transportation of hazardous chemicals by sea vessels [1] is gradually becoming an important way of transporting hazardous chemicals, and the amount of hazardous chemicals being transported by sea is also increasing year by year, and most of the hazardous chemicals have physicochemical attributes such as flammability, explosiveness, toxicity, and so on, so that the risk of accidents in hazardous chemicals transported by sea vessels not only affects the safety of the lives of the transported personnel and the safety of the property, but also creates an irreparable harm to the marine environment.

Safety management of hazardous chemicals transportation at sea [2] is increasingly receiving high attention from all mankind due to the mobility of the risk source, the high risk of the industry to which it belongs, the diversity of hazardous chemicals, the complexity of physical and chemical properties, the potentially high danger, and the high hazards of accidents. Due to the special characteristics of the incident environment and transportation carrier, the marine transportation accidents of hazardous chemical ships are obviously different from the emergency rescue of conventional road transportation accidents of hazardous chemicals, and the Rescue Bureau and the Salvage Bureau, as the main force in dealing with the marine transportation accidents of hazardous chemicals, still have some experience deficiencies in responding to this kind of disasters and accidents.

Therefore, in order to effectively strengthen the prevention and supervision of maritime hazardous chemical transportation accidents, improve the emergency response capability of maritime hazardous chemical transportation accidents, and control, reduce or eliminate the serious social hazards caused

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by such accidents [3], this paper analyzes the maritime hazardous chemical transportation accidents, optimizes the decision-making on the maritime emergency response program, and provides effective assistance to deal with the accidents after they occur [4]. Provide effective help.

2. Accident Attribution Analysis

Marine ship accidents are divided into the following categories: collision accidents, grounding accidents, touch damage accidents, wave damage accidents, fire, explosion accidents, wind accidents, self-submergence accidents, operational pollution accidents, and other water transportation accidents that cause casualties and direct economic losses [5].

The main causes of ship accidents lie in two factors [6], which are: human factors and ship equipment and facilities factors. According to the theory of system safety engineering, the factors affecting the occurrence of ship accidents can be macroscopically categorized into human (crew members, ship transportation companies, managers), ship (the ship's own equipment and facilities and hazardous chemicals) and environmental factors.

2.1 Human Factor

Accidents caused by human factors are mainly manifested at the three levels of crew, ship transportation companies and managers. Crews are mainly characterized by weak sense of responsibility, insufficient safety awareness, low level of professional skills, inadequate maintenance of ships and ship equipment and facilities, and operational errors. Managers of ship transportation companies mainly manifest in the unqualified training of crew, insufficient training of ship safety awareness of crew, and imperfect implementation of daily supervision and management of the ship, which will cause major safety hazards. People are the key factors in ship navigation, and good or bad ship condition is directly linked to people. The reason why human factors [7] can be the main cause of ship accidents is that people have instability, including knowledge, skills, responsibility, experience, physiology, psychology, health status, behavioral characteristics and other aspects. At the same time in the management errors, poor maintenance of ship equipment, operational errors, design irrationality and other human controllable factors also occupy a certain proportion, so these factors can be prevented and eliminated by regulating human behavior, to a large extent will reduce the occurrence of ship accidents.

In order to standardize the ship safety management [8], and the establishment of the ship safety management system is a management specification for the shipping company. Ship transportation companies should strengthen the construction of safety culture, so that the ship and shore to form a good safety atmosphere, to promote the quality of safety education and the cultivation of crew safety awareness, so that the safety management system is fully operated from the top down, to a certain extent, but also to the occurrence of accidents on board the ship to play a preventive role.

2.2 Marine Equipment Failure

Failure of ship equipment and facilities is mainly caused by the following aspects:

① Material and ship structure design defects

Defects in the material quality of ship parts will directly or indirectly cause the failure of the relevant parts in use and lead to failure. Defects in the design of ship structure will directly or indirectly lead to accidents during transportation.

②Abnormal operation of equipment and facilities

These abnormalities usually include: poor fuel combustion, poor lubrication between related structures, leakage, high temperature, overload, and long running time. Generally, it is caused by the defects of ship parts and materials or the irregular behavior of ship's personnel, which leads to the abnormal working of the equipment and thus causes the failure.

③Abnormal operation and management

These abnormalities usually include: poor processing of ship parts, poor installation of ship parts, poor sealing of airtight containers, poor fuel purification, poor lubrication oil purification, as well as operational errors and mismanagement and other factors. These behavioral errors can indirectly lead to ship failures, but are often important influencing factors that lead to failures of equipment and facilities on ships. Many of these factors are only superficially related to the ship's equipment and facilities, but they are all linked to the human factor.

2.3 Environmental Factor

Environmental factors are often directly related to the safety of ship operation, so it is necessary to ensure that the ship is in a good operating environment and navigation conditions [9]. The natural environment includes: hydrological, meteorological and geographical factors. The impact of environmental factors on ships is mainly reflected in:

① Reduced visibility

Due to the influence of meteorological conditions, such as rain, snow, fog, night navigation and other factors caused by reduced visibility, obstructed line of sight, to the ship driver for the navigation conditions of judgment errors or operational errors, resulting in ship accidents.

② bad weather conditions

Bad weather conditions, such as thunderstorms, windy weather, cold wave weather and other factors, these factors will bring adverse effects to the ship navigation and transportation. High wind and wave weather will make it more difficult to drive the ship due to the wind and waves at sea, and the possibility of ship accidents will also increase.

③Complex hydrological conditions

Hydrographic conditions mainly refer to: sea reefs, sea reefs, sea ice floes, shoals and obstacles in the water. Reefs in the sea can lead to the occurrence of ship reefing accidents [10], should be known in advance before sailing whether there are reefs and other unclear factors in the sailing area. Ice floes and obstacles in the water and other factors have a certain degree of chance, although the possibility of occurrence is relatively small, but navigation in the northern sea area or winter navigation should pay attention to, and the ship personnel should pay close attention to the abnormalities of the radar on the ship, to avoid the occurrence of accidents caused by human factors.

The navigational environment includes two aspects: traffic conditions and navigational aids [11]. Traffic conditions mainly refer to the density of ship traffic in the waters and the size of the traffic volume. In the case of navigating dense waters, it will increase the difficulty of ships in navigation. Aids to navigation facilities lead to accidents mainly in the failure of maritime lighthouses and route markers, the failure of maritime navigational data, and the damage of navigational aids.

3. Optimization of Emergency Response Solutions

Emergency rescue methods can be divided into: intelligent rescue system [12], self-rescue, ship, helicopter and other rescue methods.

Self-rescue [13] of the basic rescue principles are: ① different types of marine to take different self-rescue measures; ② ship self-rescue focuses on ship to ship; ③ ship self-rescue organization, should be rapid and accurate investigation of the damage to the ship as the basis; ④ seize the moment, according to the contingency deployment of rescue; ⑤ ship self-rescue implementation of the organization should be carried out according to the emergency deployment table.

The basic principle of ship rescue [14] is that the ship duty standby is ready to rescue, it must meet the standby regulations in terms of personnel, equipment, rescue equipment, oil and water, staple and sideline food reserves and ship certificates, books and materials, etc., and those who do not comply with the regulations are not allowed to serve as duty standby tasks. Where the designated rescue duty standby ship, must be designated by the Bureau of Rescue time and place standby, without the

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approval of the Bureau of Rescue, standby ship shall not serve as other tasks, the crew is not allowed to leave the ship without authorization.

The basic principle of helicopter rescue [15] is mainly measured by the distance from the shore, and the search and rescue radius of the rescue helicopters of the coastal rescue bases and the near-shore fast rescue vessels is determined, and the functions of the more distant search and rescue tasks rely on the search and rescue programs of large ocean-going rescue vessels as well as shipborne rescue helicopters.

3.1 Preferred Decision-making Algorithm

In this section, the Maritime Emergency Rescue Program will be improved by preparing a decision-making algorithm for development model selection. Selecting an emergency rescue program is a multi-objective decision-making process due to the many factors affecting the development program. The indicators such as feasibility, technical readiness, flexibility, manufacturing and installation, cost and expense, operability, and HSE risk are considered comprehensively, and the weights of the indicators are firstly determined by using hierarchical analysis [16], and then the fuzzy comprehensive evaluation method is utilized to obtain the preferred ranking of the development model.

1) Determination of indicator weights

Hierarchical analysis is one of the commonly used methods for calculating the weights of indicators. It combines qualitative and quantitative analysis, compares the indicators two by two, and quantifies them using the numbers 1-9. The scale values for levels 1-9 are shown in Table 1.

Table 1. Scale values for levels 1-9

Qualitative results	Quantitative results
A_i has the same impact as A_j	$a_{ij} = 1$
A_i has a slightly stronger effect than A_j	$a_{ij} = 3$
A_i has a stronger impact than A_j	$a_{ij} = 5$
A_i has a significantly stronger effect than A_j	$a_{ij} = 7$
The impact of A_i is definitely stronger than that of A_j	$a_{ij} = 9$
The impacts of A_i and A_j are between the two levels mentioned above	$a_{ij} = 2,4,6,8$
The effects of A_i and A_j are the opposite of those described above	$a_{ij} = 1, 1/2, \cdots, 1/9$

As a result, the pairwise comparison matrix is obtained through expert scoring, and using the pairwise comparison matrix, the eigenvector corresponding to its largest eigenvalue can be calculated, which is its initial weight vector. The specific process is shown in Figure 1.

Let CI be the consistency parameter associated with the eigenvalue method, which is calculated as:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

Where $\lambda_{\max}$ is the maximum eigenvalue and n is the number of indicators.

The consistency ratio CR is obtained from the ratio of the consistency index CI and the randomness index RI and is calculated as follows:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{2}$$

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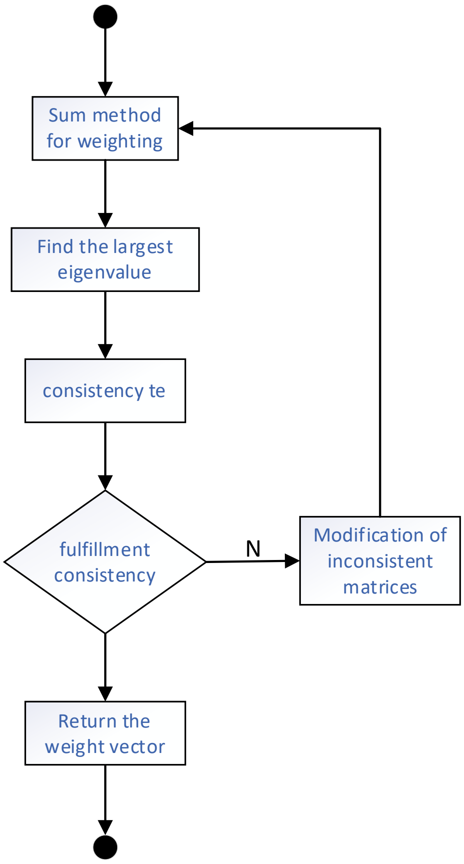

Figure 1. Main process of Analytic Hierarchy process

The random index, RI, can be found in Table 2, and the matrix can be considered to have acceptable consistency if the CR is less than 10%. After normalization, the weight vector is derived. If it does not pass, the inconsistency matrix needs to be corrected.

Table 2. Stochastic indices

n	3	4	5	6	7	8	9	10	11
RI(n)	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.52

In summary, the weight vector obtained by using hierarchical analysis is $\vec{w} = \{w_1, w_2, \cdots, w_m\}$, where $w_i \geq 0, \sum_{i=1}^{m} w_i = 1$.

2) Determine program sequencing

Indicator weights can be obtained by hierarchical analysis method, but to get the results of the preferred ranking of the development model also need to use the fuzzy comprehensive evaluation method. According to the fuzzy set theory, the relative affiliation matrix is R, and r_{ij} represents the evaluation value of indicator $X_i$on programu_j.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (3)$$

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The weight vector and relative affiliation matrix are considered together, where the weight vector $\vec{w} = \{w_1, w_2, \cdots, w_m\}$, where, $w_i \geq 0, \sum_{i=1}^{m} w_i = 1$. Applying the fuzzy relationship operation, the multi-objective fuzzy comprehensive evaluation model can be obtained as:

$$B = w \cdot R = \{b_1, b_2, \cdots, b_n\} \quad (4)$$

By the principle of maximum affiliation, the scheme corresponding to $Maxmun\{b_1, b_2, \cdots, b_n\}$ is the optimal value scheme for comprehensive evaluation.

3) Comparison of Emergency Response Programs

Comprehensive comparison of the following development models Scenario 1: "Intelligent Rescue System", Scenario 2: "Self-Rescue", Scenario 3: "Ship" and Scenario 4: " Helicopter". For the four development modes, the feasibility, technical readiness, flexibility, manufacturing and installation, cost, operability, HSE risk and other indicators are considered comprehensively, and the weights of the indicators are determined by using the hierarchical analysis method, and then the fuzzy comprehensive evaluation method is used to get the preferred ranking of the development modes.

Firstly, the qualitative and quantitative analyses are combined to compare the indicators two by two and quantify them by using the numbers 1-9. As a result, the pairwise comparison matrix is obtained through expert scoring, and the eigenvector corresponding to its largest eigenvalue can be calculated by using the pairwise comparison matrix, which is the initial weight vector. The pairwise comparison matrix is obtained by expert scoring, as shown in Table 3.

Table 3. Symmetric matrices

Factors	feasibility	technical preparation	dexterity	Manufacturing and Installation	cost	operability	HSE risk
feasibility	1	3	4	7	2	3	1
technical preparation	1/3	1	1/2	2	3	2	1/3
dexterity	1/4	2	1	2	2	3	1/2
Manufacturing and Installation	1/7	1/2	1/2	1	1/2	1/3	1/5
cost	1/2	1/3	1/2	2	1	2	1/2
operability	1/3	1/2	1/3	3	1/2	1	1/3
HSE risk	1	3	2	5	2	3	1

After performing consistency test and normalization, the weight vector is obtained as w, as shown in Table 4.

Table 4. Indicator weights

norm	feasibility	technical preparation	dexterity	Manufacturing and Installation	Cost	operability	HSE risk
weights	0.28	0.12	0.14	0.04	0.11	0.07	0.24

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The fuzzy comprehensive evaluation method is used to comprehensively evaluate the development model. According to the fuzzy set theory, the relative affiliation matrix is R, and r_{ij} represents the evaluation value of indicator X_i on program u_j. As far as the feasibility is concerned, 60% of the judges consider it as excellent, 15% as better, 15% as worse and 10% as poor. The feasibility evaluation is then: r1 = {0.6, 0.15, 0.15, 0.1}. Similarly, technical readiness r2 = {0.5, 0.1, 0.2, 0.2}; flexibility r3 = {0.6, 0.2, 0.1, 0.1}; fabrication and installation r4 = {0.3, 0.2, 0.2, 0.3}; costs and fees r5 = {0.5, 0.1, 0.1, 0.3}; and operability r6 = {0.7, 0.1, 0.1, 0.1}; HSE risk r7 = {0.4, 0.2, 0.2, 0.2}. The evaluation matrix R is:

$$R = \begin{bmatrix} 0.4 & 0.25 & 0.15 & 0.2 \\ 0.3 & 0.3 & 0.2 & 0.2 \\ 0.1 & 0.2 & 0.3 & 0.4 \\ 0.3 & 0.2 & 0.3 & 0.2 \\ 0.4 & 0.2 & 0.2 & 0.2 \\ 0.3 & 0.2 & 0.2 & 0.3 \\ 0.2 & 0.3 & 0.3 & 0.2 \end{bmatrix}$$

Considering the weight vector as well as the relative affiliation matrix and applying the fuzzy relationship operation, the multi-objective fuzzy comprehensive evaluation model can be obtained. Where, the weight vector $\vec{w} = \{w_1, w_2, \cdots, w_m\} = \{0.28\ 0.12\ 0.14\ 0.04\ 0.11\ 0.07\ 0.24\}$, $w_i \geq 0, \sum_{i=1}^{m} w_i = 1$. Applied to this program preference, the multi-objective fuzzy comprehensive evaluation results are:

$$B = w \cdot R = \{b_1, b_2, \cdots, b_n\} = \{0.3290\ 0.2500\ 0.2390\ 0.1820\}$$

Table 5. Program evaluation results

typology	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Evaluation results	0.2870	0.2500	0.2390	0.2240

According to the principle of maximum optimization, the preferred solution is "Intelligent rescue system", followed by "Self-rescue" and "Ship", "Helicopter" is an inferior program and should not be used. The ranking of the programs derived from the multi-objective fuzzy decision analysis is basically consistent with the order of the programs derived from the qualitative analysis in the initial development model.

4. Conclusion

In summary, this paper compiles a decision-making algorithm for development mode selection, which comprehensively considers the indicators of feasibility, technical readiness, flexibility, manufacturing and installation, cost, operability, and HSE risk. Firstly, the weights of indicators are determined by hierarchical analysis method, and then the fuzzy comprehensive evaluation method is used to get the preferred ranking of the development mode. From the results of the preference ranking, the "Intelligent Rescue System" is the optimal solution. It further reduces the occurrence of maritime hazardous chemical accidents, provides rescue basis for maritime rescue accidents, improves the correctness of emergency rescue decision-making and rescue efficiency, and reduces casualties and property losses in maritime hazardous chemical accidents.

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References

[1] Author F T I S, Author K M S F. Onshore preparedness for hazardous chemical marine vessel accidents : a case study : original research[J]. Jamba : Journal of Disaster Risk Studies, 2016(No.1):1-7.

[2] Jea G. A study on the IMO regulatory instruments concerning the evaluation of safety and pollution hazards of chemicals in bulk transported by sea (based on MARPOL Annex II and IBC Code)[D]. World Maritime University, 2011.

[3] Ugurlu H, Cicek I. Analysis and assessment of ship collision accidents using Fault Tree and Multiple Correspondence Analysis.[J]. Ocean Engineering, 2022(No.0):110514.

[4] Bogalecka M. Mitigation of sea accident consequences[J]. IOP Conference Series: Earth and Environmental Science, 2021:12011.

[5] Fu S, Yu Y, Chen J, et al. A framework for quantitative analysis of the causation of grounding accidents in arctic shipping[J]. Reliability Engineering & System Safety, 2022:108706.

[6] Chen J A C C, Bian W A O C, Wan Z A Z W, et al. Identifying factors influencing total-loss marine accidents in the world: Analysis and evaluation based on ship types and sea regions.[J]. Ocean Engineering, 2019(No.0):106495.

[7] Kim D, Kwak S. Evaluation of Human Factors in Ship Accidents in the Domestic Sea[J]. Journal of the Ergonomics Society of Kore, 2011(No.1):87-98.

[8] Gerigk M. Priorities in the risk assessment and risk management during the ship accident at sea(Article)[J]. Journal of Konbin, 2012(No.1):5-16.

[9] Popek M. Factors influencing on the environment during hazardous goods transportation by the sea[J]. IOP Conference Series: Earth and Environmental Science, 2019(Conference 1):12052.

[10] Yamamoto K, Kitamura T, Shibata K, et al. Study of the Accident Environment During Sea Transport of Nuclear Material: Analysis of An Engine-Room Fire on a Purpose-Built Ship[J]. Packaging, Transport, Storage and Security of Radioactive Material, 2000(No.3):203-216.

[11] Wang K, Jiang X, Yan X, et al. PSO-based method for safe sailing route and efficient speeds decision-support for sea-going ships encountering accidents[C]//: 2017 IEEE 14th International Conference on Networking, Sensing and Control (ICNSC), Calabria, Italy, 2017.

[12] Bellantuono N, Camarda P, Lisi S. Emergency Management at Sea: A Decision Support System for Search and Rescue Operations[J]. Journal of Organizational Management Studies, 2016.

[13] Gibson S, Gibson B A, Ibrahim A. Method and System for Providing a Self-Rescue Plan in an Emergency:

[14] Li L. Rescue vessel location modelling[D]. Dalhousie University (Canada), 2006.

[15] Vinnem J E, Røed W. Risk Based Emergency Response Planning[J]. Springer Series in Reliability Engineering, 2020:253-270.

[16] Yu C, Liu W, Fei Y, et al. Influencing Factors of Online Furniture Purchase Behavior Based on Analytic Hierarchy Process[J]. BioResources, 2023(No.2):2857-2873.