Risk Assessment Study on Rescue Safe Operation Zone for Dangerous Goods Vessel

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Abstract: This paper proposes the concept of rescue safe operation zone, which helps rescue commanders to scientifically determine the zones and scope of maritime search and rescue operations. First, the functions and characteristics of the rescue safe operation zone are introduced, then the factors and domain values affecting the delineation of the rescue safe operation zone in the process of dangerous goods vessel in distress are studied, and finally, a fuzzy comprehensive evaluation model of the rescue safe operation zone is established based on the fuzzy comprehensive evaluation method.

Keywords: rescue safe operation zone, maritime search and rescue, dangerous goods vessels, fuzzy comprehensive evaluation, analytic hierarchy process

1 Introduction

According to China's National Maritime Search and Rescue Emergency Plan "4.1 Classification of Maritime Emergencies", passenger ship or chemical ship that seriously endangers the life of the ship or personnel is a very large maritime emergency, and its SAR emergency work is usually seen as the focus and difficulty of the maritime SAR work, which is highly valued by all emergency departments.

When disposing of maritime accidents which involves dangerous goods vessel, the SAR commander will usually determine the operating zone by combining various factors at the scene, and arrange for rescuers to take rescue actions within the zone. In order to balance the rescue effect and the safety of rescuers, the SAR commanders must scientifically determine the distance between the rescue ship and the distressed ship, so as to prevent the rescue vessel from being too close to the distressed ship and the safety of rescuers from being endangered; and also to prevent the rescue vessel from being too far away from the distressed ship, which makes it difficult for the rescue extinguishant to function effectively. However, there is a lack of scientific and reasonable research on the determination of this operation zone, which is mainly reflected as follows: the valuable experience from realistic work has not been transformed into general theoretical results, and there is a lack of unified understanding; the scope of the zone delineated for each operation varies greatly, and each time when rescue operations are carried out, it needs to be redefined by SAR commanding, which existing the risk of delaying disposing of accident. Therefore, it is necessary to carry out research on the delineation of rescue safe operation zone for vessels carrying dangerous goods, so that the scope of rescue safe operation zone can be scientifically determined when disposing of maritime accidents involving dangerous goods.

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The Maritime Traffic Safety Law of China sets out the requirements for the delineation, adjustment, and publication of safe operation zones. According to the Law's interpretation, the zone's delineation should consider that "the delineation should be reasonable and feasible, and the coordinates of the boundary control points should be accurate"[1]. In the study of safe operation zone, the current research focuses on construction work on the water and bulk liquid dangerous goods barging operations outside the port, with little involvement in the scope of rescue operation. Zhang Huiqin et al. studied the impact range of explosion of a 50,000-ton dangerous goods ship in dangerous goods anchorage, using empirical formulae to calculate the impact radius of damage caused by instantaneous explosion of three kinds of dangerous goods respectively, and verified the calculation results through simulation, giving the maximum radius of the impact range of explosion as 500m[2]. Combining several cases of ship fire rescue, Cheng Hao introduced the measures for implementing firefighting actions by maritime rescue vessels. In the two accidents involving oil tankers and fishing vessels carrying dangerous chemicals, it was pointed out that certain safe distance should be maintained from the distressed ship[3]. Based on the STAMP model, Yin Jie analyzed the causes of the collision and explosion of the MV Sanchi and the emergency response process, also analyzed the key aspects of the accident, including setting up a 10 n-mile navigation control zone by SAR center to prevent passing ships from entering, and finally made relevant recommendations[4]. Some scholars and organizations abroad have also carried out related studies. W., Rafaqat et al. developed a gas dispersion model for predicting risk zones based on the toxicity risk assessment of chlorine gas in chemical ports and created three different risk zones according to the difference in weather condition[5]. The Handbook for Maritime SAR in HNS incidents issued by the International Maritime Rescue Federation (IMRF) and the Finnish Border Guard states, “In the absence of clear information on HNS in the initial phase, the immediate restricted zone should be at least 2 n miles". This handbook also defines the SAR operation zone centered on the ship in distress and extending at an angle along the wind direction. The zone is divided into a Hot zone, a Warm zone and a Cold zone[6].

In summary, this paper studies the delineation of rescue safe operation zone of dangerous goods vessel in distress through laws and regulations and practical experience in rescue work. It is necessary to provide a theoretical approach that balances the safety of rescue personnel with the efficiency of rescue operations.

2 Functions and characteristics of rescue safe operation zone

2.1 Functions of rescue safe operation zone

The rescue safe operation zone shall enable the following functions:

(1) Effective rescue: the rescuers can take effective rescue action to dispose the accident.

(2) Safe rescue: the safety of rescue vessel and rescuers must be guaranteed.

(3) Accessibility: the ability to minimize the affection on vessel traffic and surrounding environment.

2.2 Characteristics of the rescue safe operation

(1) Diversified functions. Based on different functions, the rescue safe operation zone can be divided into danger zone (also called core zone), rescue operation zone and alert zone (also called traffic control zone), which compose together and are applied in rescue operations. The danger zone is an area where the lives of people are at risk, with the ship in distress as the center. Rescue vessels and rescuers are strictly prohibited from entering this area; Rescue operation zone is an area outside the danger zone for rescuers to take rescue operations, only ships directly involved in rescue operations can enter this area with restriction; Alert zone is an area outside the rescue operation zone to minimize the potential impact on vessel traffic and to prevent secondary accidents. This zone is restricted to support vessels, guard vessels and pollution control vessels that provide support for rescue operations. The danger zone is built around the distressed ship, the rescue operation zone is built around the danger zone and the alert zone is built around the rescue operation zone. Each zone has different functions and is relatively independent and complementary, ultimately forming the rescue safe operation zone at the scene.

(2) Dynamic area. As the danger level of distressed ship develops continuously over time and the hydro-meteorological situation of the distress locale changes constantly, the rescue safe operation zone is a dynamic area, its boundary range and zone shape are not fixed, which is different from the traditional concept of ship domain or mobile safe zone. For example, when disposing a ship fire accident, the fire will spread and develop downwind due to the wind, the danger zone on the downwind side of the ship will increase and the scope of the rescue operation zone will be reduced, the distance between the rescuers and distressed ship need to be increased.

(3) Complicated causation. There are many factors affecting the scope of rescue safe operation zone, including the situation of dangerous goods, rescue vessels, natural environment, and traffic environment. The situation of dangerous goods mainly refers to the influence of dangerous goods on ship; the situation of rescue vessels mainly refers to the ability of rescue vessels to take rescue operations safely and effectively; the situation of the natural environment mainly refers to the influence of the hydro-meteorological and other environmental factors at the scene that bring uncertain changes to the accident; the situation of the traffic environment mainly refers to the vessel traffic of the location where accident occurred and the measures taken by the maritime authorities to reduce the impact of the accident.

3 Factors and domain values affecting rescue safe operation zone

By summarizing the relevant research results and actual experience of rescue operations, the factors affecting the delineation of rescue safe operation zone for dangerous goods ships are classified into four categories: dangerous goods hazard domain, rescue ship operation domain, natural environment change domain, and traffic environment restriction domain.

3.1 Dangerous goods hazard domain

By analyzing the dangerous goods, it can determine the dangerous boundaries around the distressed ship and prevent rescuers on scene from entering the danger zone. The dangerous goods hazard domain can be divided into the nature of goods, the quantity of goods, and the severity of accident.

(1) Nature of goods

The nature of dangerous goods plays a dominant role in various factors and has a direct effect on the danger zone. Common dangerous goods are divided into nine categories based on their fatalness[7]. In the case of ship fire, for example, the severity of fire accdient and the risk of explosion usually depends on the nature of the dangerous goods on ship. When a fire breaks out on a distressed ship, on the one hand the burn of dangerous goods may produce smoke containing large quantities of toxic gases, on the other hand an explosion of dangerous goods may easily occur. Initial isolation distance and protect distance are determined in terms of the extent of shockwave damage and thermal radiation from the explosion, and thus the boundary of the danger zone can be delimited. Table 1 lists some of the physical and chemical property parameters of three common dangerous goods transported by waterways[8]:

Table 1 Parameter table of some physical and chemical properties of common dangerous goods transported by waterways

Types of dangerous goods	Explosion limit	Calorific value	Closed Cup Flash Point	autoignition temperature
Petrol	1.2% to 7.2%	4.4×10^{7}J/kg	40°C	415~530°C
Toluene	1.1% to 7.1%	4.094×10^{5}J/kg	4°C	480°C
Liquefied Petroleum Gas	2.3%~9.5%	4.5217×10^{7}~4.6055×10^{7}J/kg	-80 to -60°C	426~537°C

(2) Quantity of goods

The larger the quantity of dangerous goods a ship carries, the more dangerous it will be in the event of an accident. Dangerous goods of the same nature, with different amounts of leakage, will result in different levels of danger. According to the theory of explosion damage, the energy generated by the explosion of dangerous goods can be calculated using the following formula[2]:

$$E_0 = m \times k \times H_c \quad (1)$$

Where E_0 is the total energy of the explosion of the dangerous goods (J). m is the mass of the dangerous goods (kg).k is the upper explosive limit of the dangerous goods. H_c is the calorific value of the dangerous goods (J/kg).

The upper limit of the amount of dangerous goods a ship can carry is determined by the ship type. The bigger the ship is, the larger the amount of dangerous goods ship can carry and the more dangerous it will be in the event of an accident. Take oil tankers for example, the common oil tanker types are shown in Table 2.

Table 2 Common types of oil tankers

General tanker	Less than 10,000 tons
Handy max tanker	10,000 - 50,000 tones
Panamax tanker	60,000-80,000 tons
Aframax	80,000 - 120,000 tons
Suezmax	120,000 - 200,000 tons
VLCC	200,000 - 300,000 tons
ULCC	Over 300,000 tons

(3) Severity of accident

The severity of accidents varies from one type to another. According to the experience of the rescue operation, fire and explosion on a dangerous goods ship is the most sever accident, followed by leakage of dangerous goods. If a ship fire is not controlled in time, the fire will spread to the cargo hold area, which will easily ignite the dangerous goods in the cargo hold and cause an explosion; after a ship collision/grounding/touching accident, the hull breakage will easily cause the dangerous goods in the cargo hold to leak and spread, which will adversely affect the people and environment at the scene.

3.2 Rescue ship operation domain

To ensure the safety of a rescue vessel, it is essential to ensure that it can operate in a safe area as far as possible and it can evacuate quickly to avoid danger in an accident. The manoeuvrability of the rescue vessel, especially the emergency manoeuvrability, has a strong influence on the determination of the rescue operation zone. The main considerations are stopping performance and turning performance[9].

(1) Stopping performance

Stopping performance refers to the performance of a ship making sternway to stop the ship at any headway speed, and is an index to measure the inertia of longitudinal movement of the ship, generally measured by stopping distance and stopping time. When the distress on board suddenly expands and threatens the safety of the rescue vessel, the rescue vessel should immediately stop approaching the distressed ship and take full astern until the ship's speed is zero, this stopping performance is called emergency stopping performance. According to MSC.137(76) "Manoeuvrability of Ships", the requirement for the ship's ability to stop is that the track travel measured in a full speed reverse stop test should not exceed 15 times the length of the ship and should not exceed a maximum of 20 times the length of the ship. In such cases, the rescue vessel usually approaches the vessel in distress by the bow.

There are many factors affecting the emergency stopping distance, mainly including the ship's displacement, initial speed, main engine astern power, speed and time, the type of propulsion, the degree of fouled bottom of the hull and the external conditions. The following formulae can be used to estimate the emergency stopping distance and stopping time[10]:

$$t = 0.00089\frac{W \cdot v_0}{R_0} \tag{2}$$

$$s = 0.0121\frac{W \cdot v_0^2}{R_0} \tag{3}$$

Where t is the astern time (min). s is the emergency stopping distance (m); W is the actual displacement of the ship (t). R_0 is the ship's resistance at speed v_0 (t). v_0 is the speed of the ship before astern (kn).

(2) Turning performance

Turning performance is the ability of ship’s full steering to turning movement, it is an indicator that measures the size of the minimum water area occupied by the ship's slewing motion and the rapidity of turning. When the situation cannot be controlled and poses a serious threat to rescuers, the rescue vessel will need to immediately evacuate by turning back. In such cases, the rescue vessel usually approaches the distressed vessel on the port or starboard side. Table 3 gives the range of relative tactical diameter for common participating SAR vessels.

Table 3 Values for the relative tactical diameter of some types of ships

Type of vessel	Large cargo ships	Small and medium sized cargo ships	Tugs
Relative tactical diameter	5~6.5	4~5	1.5 to 3

It is possible to determine indirectly the turning performance of a ship by using the Nomoto model. Assuming the initial conditions $t = 0$ and $r = 0$, and irrespective of the steering time, and solving the first-order vessel manoeuvring equation of motion, the instantaneous angular velocity during the turning motion is expressed as

$$r = K\delta\left(1 - e^{-\frac{t}{T}}\right) \quad (4)$$

Where r is the angular velocity of the ship's turning back (rad/s). δ is the ship's steering rudder angle (rad). K is the turning index ($1/s$). t is the turning time (s). T is the tracing ability index (s).

Thus, for a given rudder angle, the turning angular speed r depends on the manoeuvrability index K, T. The analysis of the indexes can be used to determine the strength or weakness of the ship's manoeuvrability. When K is large T is small, the ship's turning performance is good.

3.3 Natural environment change domain

The natural environment at sea has a significant impact on the determination of rescue safe operation zone. As wind and currents can affect both the movement of a ship causing it to drift and the extent of accident, thus the scope of rescue safe operation zone is determined by considering the effects of wind and currents, taking into account other environmental factors.

(1) Impact of wind

The Hughes formula can be used to directly calculate the magnitude of the combined wind power force, which facilitates qualitative analysis of the forces and laws of motion of the ship, with the following expressions.

$$F_a = q \times C_a \times (A_T \times cos^2\theta + A_L \times sin^2\theta) \quad (5)$$

Where F_a is the wind power (N). q is the wind pressure (N/m^2). C_a is the wind power coefficient, related to the ship's draft and the shape and area distribution of the ship's superstructure. A_T is the area of the ship's positive projection above the waterline (m^2). A_L is the area of the side projection above the waterline of the ship (m^2). θ is the relative windward angle.

Based on practical experience in rescue work, wind plays a major role in affecting the fire and its smoke intensity. A change in wind direction will lead to a change in the direction of fire spread and the direction of toxic smoke dispersion; a change in wind speed will lead to a change in the rate of fire spread and the rate of toxic smoke dispersion. The Gaussian plume model has been widely used to calculate the effect of wind on the diffusion of gases, The equation is as follows[11]:

$$q(x,y,z) = \frac{Q}{\pi u \sigma_y \sigma_z} \times exp\left(-\frac{y^2}{2\sigma_y^2}\right) exp\left(-\frac{z^2}{2\sigma_z^2}\right) \tag{6}$$

Where $q(x,y,z)$ is any point in space (x,y,z) the mass concentration of the toxic substance in the air (mg/m^3). Q is the rate of pollutant release (mg/s). u is the average wind speed (m/s). x,y,z represents the downwind distance, the side wind distance and the vertical wind distance (m).σ_y, σ_z are the horizontal/vertical distribution coefficients of pollutants.

(2) Impact of current

Currents mainly affect the extent to which dangerous goods drift and spread over the sea surface. Dangerous goods will continue to drift and spread to the surrounding area with the movement of current, threatening to the rescuers and causing environmental pollution. Currently the oil particle model is representative and has been widely used in predicting the dynamics of oil spill drift at sea, with the velocity equation[12]:

$$U_t = C_w U_w + U_s \tag{7}$$

Where U_t is the total velocity of the drifting motion (m/s). C_w is the wind drift coefficient. U_w is the wind speed at 10 m above the sea surface (m/s). U_s is the surface velocity (m/s).

(3) Other factors

Other environmental factors have an impact on the determination of the rescue safe operation zone. For example, waves can effect on the stability and manoeuvrability of the ship, temperature and humidity can have an influence on the nature of dangerous goods, and visibility can affect significantly on the ability of the ship's pilot to look out and maintain a safe distance.

3.4 Traffic environment restriction domain

The maritime traffic accident emergency response has a greater impact on the traffic environment in the accident waters and needs to be considered in the delineation of the rescue safe operation zone, with the main factors contain being the busyness of the waters and traffic control measures.

(1) Busyness of the waters

When an accident occurs in a channel, anchorage, wharf, customary route, and other areas with dense traffic flow or concentrated distribution of vessels, the impact of the vessel in distress and rescue operations on passing vessels should be fully considered, so the setting of the alert zone should tend to be reasonable and avoid the delineation of too large to affect the normal sailing of passing vessels; when an accident occurs in a breeding area, environmentally sensitive area and other areas not conducive to rescue operations, the safety of the rescue vessel should be ensured first, and the delineation of the rescue operation zone should be appropriately increased.

(2) Traffic control measures

Traffic control measures are measures taken by the VTS center in the area where the accident occurred to prevent the normal sailing of passing vessels from being affected by the accident. At the beginning of an accident, the traffic control measures are equivalent to an alert zone, after which the scope of the alert zone and other subzones are defined according to the development of the accident.

4 Safety evaluation model of rescue safe operation zone based on fuzzy comprehensive evaluation method

The fuzzy comprehensive evaluation method is a comprehensive evaluation method based on fuzzy mathematics, and the evaluated object is usually a complex system composed of many factors with fuzziness. According to the analysis in the previous chapters, there are many factors affecting the delineation of the rescue safe operation zone, which can be divided into 4 primary indicators and 10 secondary indicators. There is a certain degree of fuzziness in each factor, and the evaluation of these factors is also fuzzy, so this paper is suitable to adopt the fuzzy comprehensive evaluation method for the safety evaluation of the rescue safe operation zone.

4.1 Establish indicator system

Based on the previous study, a safety evaluation index system for rescue safe operation zone is established as shown in Figure 1, and the set of factors is determined according to this index system U which contains 4 subsets of 10 evaluation indicators.

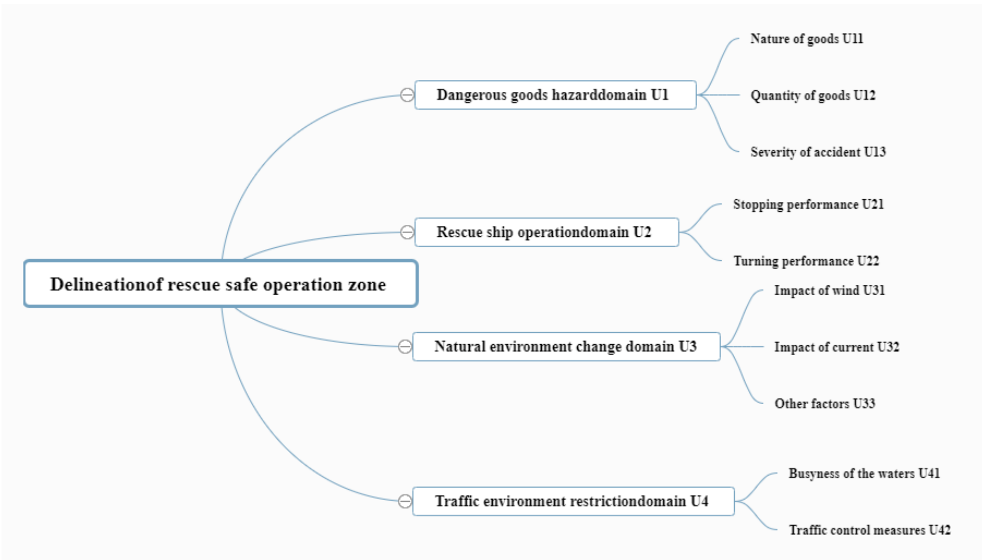

Figure 1 Evaluation index system for the delineation of rescue safe operation zone

4.2 Calculation of indicator weights

The common methods for determining the importance of factors are Delphi, expert survey, and Analytic Hierarchy Process (AHP), among which the AHP is more flexible, concise, and widely used, so it is proposed to use this method to calculate the weight values of the obtained indicators.

Firstly, the safety evaluation matrix of the rescue safe operation zone was constructed and experts in the field were invited to assign values to the judgment matrix using the 1~9 scale method to obtain the initial judgment matrix, as shown in Table 4~Table 8.

Table 4 U Calculated values for the weight of the evaluation indicators

Indicators	U_1	U_2	U_3	U_4
U_1	1	4	7/2	6
U_2	1/4	1	2/3	2
U_3	2/7	3/2	1	3/2
U_4	1/6	1/2	2/3	1

Table 5 U_1 Calculated values for the weighting of the evaluation indicators

Indicators	u_{11}	u_{12}	u_{13}
u_{11}	1	8/3	8/5
u_{12}	3/8	1	5/12
u_{13}	5/8	12/5	1

Table 6 U_2 Calculated values for the weighting of the evaluation indicators

Indicators	u_{21}	u_{22}
u_{21}	1	2/3
u_{22}	3/2	1

Table 7 U_3 Calculated values for the weighting of the evaluation indicators

Indicators	u_{31}	u_{32}	u_{33}
u_{31}	1	5/2	9/2
u_{32}	2/5	1	5/2
u_{33}	2/9	2/5	1

Table 8 U_4 Calculated values for the weighting of the evaluation indicators

Indicators	u_{41}	u_{42}
u_{41}	1	3
u_{42}	1/3	1

After the initial judgment matrix is obtained, the corresponding eigenvectors need to be calculated $W = (W_1, W_2, \cdots, W_n)^T$. Common methods of calculation are summation, square root, eigen root and least squares[13]. In this paper, the square root method is used, the calculation formula is:

$$W_i = \frac{\left(\prod u_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} u_{ij}\right)^{\frac{1}{n}}} (i, j = 1,2, \cdots, n) \tag{8}$$

The eigenvectors of $\boldsymbol{U}$ is $A = [0.58578\ 0.14702\ 0.17326\ 0.093939]$

The eigenvectors of $\boldsymbol{U_1}$ is $A_1 = [0.49071\ 0.16296\ 0.34633]$

The eigenvectors of $\boldsymbol{U_2}$ is $A_2 = [0.4\ 0.6]$

The eigenvectors of $\boldsymbol{U_3}$ is $A_3 = [0.60773\ 0.27122\ 0.12104]$

The eigenvectors of $\boldsymbol{U_4}$ is $A_4 = [0.75\ 0.25]$

Based on the obtained eigenvectors, the maximum eigenvalue of the judgment matrix can be approximated and calculated as

$$\lambda_{max} \approx \frac{1}{n}\sum_{i=1}^{n}\frac{(UW)_i}{W_i} \tag{9}$$

The maximum eigenvalue of $\boldsymbol{U}$ is $\lambda_A = 4.04$

The maximum eigenvalue of $\boldsymbol{U_1}$ is $\lambda_{A1} = 3.01$

The maximum eigenvalue of $\boldsymbol{U_2}$ is $\lambda_{A2} = 2.00$

The maximum eigenvalue of $\boldsymbol{U_3}$ is $\lambda_{A3} = 3.01$

The maximum eigenvalue of $\boldsymbol{U_4}$ is $\lambda_{A4} = 2.00$

In the judgment matrix obtained, the importance judgments of the elements in the judgment matrix should be consistent and no contradiction should occur, so the consistency test needs to be carried out on the obtained judgment matrix, and the consistency index is calculated as:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{10}$$

Where λ_{max} is the maximum eigenvalue of the judgement matrix. n is the order of the judgment matrix. The smaller the CI value is, the better the consistency of the judgment matrix is, and when $CI = 0$, the judgment matrix is fully consistent. But in actual problem, it is difficult to achieve complete consistency, so we need to introduce the consistency ratio CR The calculation formula is:

$$CR = \frac{CI}{RI} \tag{11}$$

Where RI is the average random consistency index, taking values related to the order of the judgment matrix, as shown in Table 9.

Table 9 RI Relationship with matrix order$n$ relationship table

n	1	2	3	4	5	6	7
RI	0	0	0.52	0.89	1.12	1.26	1.37

When$CR < 0.1$, the judgment matrix is considered to have satisfactory consistency and the elements in the feature vector are the weight values of each evaluation indicator; when $CR \geq 0.1$, the judgment matrix is considered inconsistent and needs to be adjusted to meet the requirements.

As calculated, The CR values of $\boldsymbol{U}$, $\boldsymbol{U_1}$, $\boldsymbol{U_3}$ meet the requirements of the consistency test. Since the order of $\boldsymbol{U_2}$, $\boldsymbol{U_4}$ is low, it is straightforward to calculate CI value to verify. As calculated, CI values are all zero, which clearly meets the consistency test requirements.

4.3 Fuzzy integrated evaluation

First, establish the set of evaluation indicators V .

Set $V = \{v_1, v_2, v_3, v_4\} =$ {regular rescue, discreet rescue, dangerous rescue, restricted rescue}.

Regular rescue means that the rescue team takes regular rescue action according to the SAR plan; Based on regular rescue, discreet rescue means that more attention is paid to the safety of rescuers at the scene and more cautious and conservative rescue actions are taken; Based on discreet rescue, dangerous rescue means that rescuers are required to carry out rescue actions under the premise of ensuring their own safety first. Restricted rescue means that the accident is so sever that rescuers are unable to carry out rescue activities, except in exceptional circumstances, rescuers should stop rescuing and resume rescue operations when the extent of danger has been reduced.

Let R be the evaluation matrix, which can be obtained by means of an expert survey. Table 10 gives the evaluation criteria for the rescue safe operation zone indicators, where

The dangerous goods section refers to the International Dangerous Goods Code (IMDG Code), the Dangerous Goods Emergency Response Manual and experts.

Rescue ships section refers to references[14], Natural environment section refers to references[15, 16].

The traffic environment section is classified qualitatively by consulting experts and using fuzzy language.

Table 10 Criteria for evaluating indicators of rescue safe operation zone

Risk level	Restricted rescue	Dangerous rescue	Discreet rescue	Regular rescue
Nature of goods	Category 1	Category 2.1 Category 2.3 Category 3	Category 2.2 Category 4	Category 5 Category 9
Cargo mass/ 10k tons	> 20	10-20	5-10	< 5
Level of risk	Explosion Fire	Collision Reefing	Stranded Out of control	Injuries and illnesses Other accident
Stopping performance	16~20L	13~16L	10~13L	6~10L
Turning performance	9-10L	7-9L	5-7L	1.5-5L
Wind speed/class	≥8	6~7	4~5	2~3
Current rate/knot	> 1.6	(1.2,1.6]	(0.8,1.2]	(0,0.8]
Visibility	Very poor	Not good	Common	Good
Water busyness	Busy	Less busy	Normal	Clear
Traffic control measures	No measures taken	Zoning control measures in place	Zoning control measures and VTS manning	Adopt zoning control measures and arrange VTS watch and on-site marine patrol vessels to keep watching

The final fuzzy set B which calculated by the formula is:

$$B = W \circ R = (b_1, b_2, \cdots, b_n)(i = 1,2, \cdots, n) \tag{12}$$

Then the fuzzy set B is the result of the fuzzy comprehensive evaluation of the fuzzy set of factors U, Then, the weighted average method can be used to determine the corresponding evaluation indexes, and the result obtained is the safety evaluation result of the rescue safe operation zone.

$$A = \frac{\sum_{j=1}^{n} b_j v_j}{\sum_{j=1}^{n} b_j} \tag{13}$$

5 Conclusion

In terms of the importance of each factor, according to the weighting calculation, the Dangerous Goods Hazards domain > Natural Environmental change domain > Rescue ship Operation domain > Traffic Environmental restriction domain.

In a specific rescue operation, rescuers can calculate the fuzzy comprehensive evaluation result according to equation (12) after determining the basic danger information on the scene, and then determine the rescue method to be adopted according to the result obtained from equation (13).

It is recommended that rescuers and commanders at the scene should pay particular attention to the potential risks posed by dangerous goods, especially as the nature of the dangerous goods has a direct impact on the delineation of the rescue safe operation zone. Attention should also be paid to the impact of the natural environment on rescue operations on site, particularly changes of wind. On this basis, the performance of the rescue vessel and the impact on vessel traffic in the waters where the incident occurred should be taken into account. SAR commanders can refer to the findings of this paper when delineating the scope of the rescue safe operation zone, and make the delineation according to the actual situation.

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