Emergency Management
Science and Technology

ARTICLE

Open Access

https://doi.org/10.48130/emst-0025-0020

Emergency Management Science and Technology **2025**, 5: e022

Evaluation method of shore–ship collaborative rescue capability based on FSV and GRA

Jianing Wang[1], Ying Zhang[1], Ying Chen[2*] and Yue Chen[3*]

[1] *School of Safety Science and Emergency Management, Wuhan University of Technology, Wuhan 430070, China*
[2] *School of Power Engineering, Naval University of Engineering, Wuhan 430033, China*
[3] *School of Resources and Environment , Wuhan Textile University, Wuhan 430200, China*
* Corresponding authors, E-mail: 1661918533@qq.com; chenyue9458@163.com

Abstract

Based on fire scenarios, an evaluation model for ship collaborative firefighting capabilities is constructed to conduct a quantitative analysis of ship collaborative firefighting and rescue fire situations, firefighting and rescue capabilities, and firefighting and rescue action effects. Owing to the characteristics of multiple dangerous sources, such as fuel and cargo on berthed ships, the firefighting and rescue influencing factors on the ship's collaborative firefighting and rescue capabilities are proposed in terms of capabilities, firefighting resource demand, firefighting equipment, firefighting tactical coordination, and firefighting organization and command, and further build an evaluation index system for the ship's collaborative firefighting and rescue capabilities. In the weight determination stage, the fuzzy set value method is used to determine the weight, combined with expert experience and qualitative and quantitative methods; in the scoring stage, a gray whitening weight function is used to standardize the scoring, which eliminates the subjectivity of the scoring to a certain extent. be quickly determined based on the status analysis of the first-level indicators, and actions can be taken in conjunction with the command rescue strategy.

Citation: Wang J, Zhang Y, Chen Y, Chen Y. 2025. Evaluation method of shore–ship collaborative rescue capability based on FSV and GRA. *Emergency Management Science and Technology* 5: e022 https://doi.org/10.48130/emst-0025-0020

Introduction

The port is the intersection of inland rivers, oceans, railways, and highways. It is an important material distribution center with a large throughput, concentrated ships, and the coexistence of land and water. From the design and current status of ports over the years, it can be seen that not only land docks, storage yards, etc. are subject to fire risks, but also water berthing docks and large ships are also subject to fire risks. Dangerous goods (chemicals, oil, and gas fuels, etc.) generally have dangerous characteristics such as combustion and explosion. Once a fire accident occurs in many warehouse (tank) areas, port oil and gas, and chemical companies, it will lead to chain fires and major fire and explosion accidents. There are many dangerous sources, such as fuel oil and cargo on board, and the firefighting resources in the cabin are limited. Fire accidents on berthed ships occur occasionally, and the consequences of fires are usually serious. Accidents with relatively serious losses are shown in Table 1.

The causes of the accidents are mostly due to maintenance and construction errors during the berthing of the ship, illegal operations by the crew, untimely rescue, or weak rescue capabilities that cannot extinguish the fire[1,2]. Therefore, it is necessary to combine the firefighting and rescue capabilities of the onshore firefighting system and the ship's reserve firefighting to rescue sudden fires in ports and berthed ships, that is, shore–ship coordinated firefighting and rescue. However, the current port firefighting and rescue work lacks clear shore–ship coordinated rescue plans and management standards, and cannot mobilize both parties' firefighting and rescue resources well.

Due to the high risk of fire on shore and docked ships, consideration is now being given to fire rescue support from shore to ship and from ship to shore to reduce fire losses. When a fire occurs, the coordinated firefighting and rescue operations between shore and ship can make full use of the firefighting resources of both places, combining the advantages of large reserves, mobilization, and complete equipment of shore firefighting resources and the mobility and strong mobility of ships to control the development of the fire promptly. This is a study on the current low level of coordinated firefighting and rescue capabilities between ships and shores. Quantitative analysis of coordinated firefighting capabilities can support the development of a technology for evaluating the coordinated firefighting capabilities of shore and ships.

Rescue capability assessment methods and techniques

Domestic and foreign scholars have conducted a lot of research on the evaluation of firefighting and rescue combat capability[3]. The main evaluation methods are the fuzzy evaluation method, hierarchical analysis method, grey correlation method, etc.[1−5]. Zhang[4] evaluated the firefighting combat capability from the aspects of personnel and equipment. Shang[5]proposed the concept and method of dynamic evaluation of firefighting and rescue team combat capability. Xia et al.[6] established a three-dimensional firefighting combat capability evaluation system with first-level indicators and adhered to the detailed hierarchical quantitative standards based on practice and scientific theory. Sun et al.[7] established a fuzzy comprehensive evaluation model to evaluate the emergency response capability level of coal storage bases in ports and used the G1 method to determine the index weights. Guo & Qi[8] proposed a new method for emergency response capability evaluation based on the fuzzy analytic hierarchy process (FAHP) and verified the effectiveness of the method through numerical examples. Shang et al.[9] proposed an evaluation index weighting method based on the evaluation index system of large ship support capability, combined with the analytic hierarchy process (AHP) and entropy method, and established a comprehensive weight model based on subjective and objective weights for evaluating the support capability of large ships.

Table 1. Fire accidents on berthed ships.

Event	Time	Accident ship	Cause of fire	Fire situation
1	2020	Bonhomme Richard	During scheduled maintenance at the dock, the fire extinguishing system was temporarily shut down, and sparks from the construction ignited the vehicle in the deck compartment.	The fire burned for 4 d, with an estimated loss of US $1 billion and several crew members injured.
2	2014	Kerch	A fire broke out during the berthing period. The crew used a diesel generator to dry clothes in violation of regulations.	It took three fireboats several hours to put out the fire.
3	2022	Carney	During the base maintenance process, a circuit failure occurred and a fire occurred, which caused the hazardous source loaded on the hull to explode.	Six people were sent to the hospital, the extent of damage to the hull is unknown.
4	2012	Tokiwa	The fire originated from a generator in the engine room near the bottom of the ship, and the fuel caused the fire to spread.	No casualties.
5	2012	Miami	During berthing, a fire was set in the restaurant.	Hull damage, economic losses of US $700 million.

When evaluating each indicator, it is difficult for AHP to accurately describe the situation of each indicator through quantitative analysis. Compared with the general evaluation process, such as fuzzy comprehensive evaluation, when there are more evaluation index factors (> 9), the workload of the scoring scale is too large and complicated, which will cause dissatisfaction and confusion among scale experts. In the hierarchical analysis method, there are more discussions on the consistency of the judgment matrix, but not enough consideration of the rationality of the judgment matrix, which is a lack of consideration of the quality of expert experience.

Under this urgent need, fuzzy set theory, which can well handle the uncertainty of decision-making problems, came into being[10,11]. Fuzzy sets[12,13] use membership as a single scale to reflect the support and opposition of decision information to objective things. However, in the face of complex evaluation objects, it is difficult to accurately describe the uncertainty of objective things by fuzzy sets alone. Based on this, Bulgarian professor Atanassov proposed the concept of intuitionistic fuzzy sets (IFS) in the 1980s[14]. Membership and non-membership are used to express the support, opposition, and hesitation of decision information. Compared with fuzzy sets, IFS can more accurately describe the natural attributes of objective things[15,16]. In the fuzzy set value method, the overall importance of each indicator is comprehensively measured and divided into intervals. At the same time, multiple experts are invited to divide the importance of expert opinions according to their experience and level[17]. The importance of expert opinions is added to the weight calculation process, which is suitable for fire rescue scenarios such as ship and shore-coordinated firefighting that require experienced judgment. This allows an accurate assessment of firefighting and rescue decision-making effectiveness, achieving a scientific and reasonable evaluation.

Grey theory is mainly used to process grey systems, i.e., fuzzy information systems. For 'poor information' and 'uncertain information', grey-to-white processing is performed through whitening weight functions to improve the certainty of information. Generally speaking, information is different, which is inevitable. In the evaluation of firefighting combat capability, the information provided is necessarily different, and grey theory can fully develop 'minimum information' under such fuzzy conditions. Li et al.[18] constructed a decision model based on intuitive fuzzy cross entropy and a comprehensive grey correlation analysis algorithm, and solved the problem of sorting shelters. The objective environment of the fire scene, some highly certain information, and some force composition in the command are all 'minimum information' that can be possessed. Grey whitening weight clustering is used to calculate each clustering object, and the grey classes can be clearly distinguished according to the whitening weights of different indicators[19,20].

The fuzzy set value and grey correlation method are used to evaluate the coordinated rescue capabilities of shore and ships. After analyzing the factors affecting the coordinated rescue capabilities, an index system for capability evaluation is obtained, experience and objective data are balanced, uncertainty indicators are quantified, and the coordinated rescue capabilities are evaluated.

Analysis of collaborative rescue capabilities between ships and shore scenarios and construction of an index system

Selection of primary indicators for the collaborative firefighting and rescue capability assessment system

By statistically analyzing the primary indicators in relevant specifications, standards, and literature, we can obtain the following results:

(1) Firefighting personnel management and facilities and equipment management are selected as first-level indicators in many standards and documents. Therefore, firefighting rescue personnel and firefighting equipment and materials are selected as first-level indicators.

(2) Although the first-level indicators, such as 'building fire protection', 'building fire protection design', and 'building internal conditions' have different names, the contents of the three-level indicators they cover are the same. They all consider the fire rescue capability from the perspective of the ship itself. Here, the communication environment and fire protection soft environment of the ship are added and summarized as the fire rescue environment as the first-level indicator.

(3) Most documents or standards regarding organization and command are regarded as a first-level indicator, and a small number of documents regard it as a second or third-level indicator. To reflect the importance of organization and command in the fire safety system of ship premises and facilitate the analysis of fire rescue capabilities, fire organization and command are selected as a first-level indicator.

(4) The priority of ship fire rescue is different from that of ordinary fire rescue. In combat situations, it is necessary to fully consider the conflict between military operations and fire rescue tasks. Now, considering the conflict of coordination, the coordinated rescue capability of ships is comprehensively evaluated, and fire tactical coordination is taken as the first-level indicator.

In summary, five first-level indicators are selected, including fire rescue personnel, fire equipment and equipment, fire rescue environment, fire organization and command, and fire tactical coordination.

Collaborative firefighting and rescue capability assessment system

Concerning relevant standards such as 'General Code for Building Fire Protection', 'General Code for Firefighting Facilities', 'Fire Safety

Management in Crowded Places', 'Design Code for Fire Communication Command System', 'Fire Safety Engineering', and 'General Principles of Fire Emergency Rescue', and taking into account firefighting equipment, firefighting tactical coordination, firefighting organization and command, firefighting and rescue capabilities, and the demand for firefighting resources, five first-level indicators, 12 second-level indicators, and 59 third-level indicators were finally determined. The coordinated firefighting and rescue capability evaluation index system was established, as shown in Table 2.

Method details

Based on the index system established above, fuzzy set value and the grey correlation method are used to evaluate the collaborative rescue capabilities of the shore and ship. At the same time, expert weights are introduced to balance experience bias, quantify uncertainty in the entire chain, and obtain objective evaluation results.

Step 1: Weight interval scoring

First, establish an expert scoring table for indicator formulation, and select experienced authoritative experts who have handled firefighting and rescue tasks to score the weight range of each indicator. Suppose indicator $A = \{B_1, B_2, \dots, B_m, \dots, B_n\}$, sub-indicator B_a of indicator $B = \{C_{a1}, C_{a2}, \dots, C_{am}, \dots, C_{an}\}$, sub-indicator C_{ab} of indicator $C = \{D_{ab1}, D_{ab2}, \dots, D_{abm}, \dots, D_{abn}\}$, The weight score ranges from 0 to 1, and the expert scoring summary table is shown in Table 3.

Among them, [w_{abmr}^-, w_{abmr}^+] represents the lower limit and upper limit of the weight range of indicator w_{abm} given by the rth expert; the subscript 'a' represents the number of first-level indicators, the subscript 'b' represents the number of second-level indicators, the subscript 'm' represents the number of third-level indicators, and the subscript 'r' represents the rth expert. The subscript 'n' in the table represents the total number of third-level indicators, and 'p' represents the total number of experts. The symbols '+/−' above represent the upper/lower limits of the range assigned by a certain expert to this indicator.

Step 2: Weight calculation

Based on the scoring range, calculate the relative weight of each indicator:

$$\overline{w}_{abm} = \frac{\frac{1}{2}\sum_{r=1}^{p}\left(w_{abmr^+}^2 - w_{abmr^-}^2\right)}{\sum_{r=1}^{p}(w_{abmr^+} - w_{abmr^-})} \tag{1}$$

Step 3: Evaluate expert weighting considerations

Table 2. Index system.

Indicator system	First level indicator	Secondary indicators	Level 3 indicators
Firefighting and rescue capabilities of ships and shores	Fire rescue personnel	Number of staff	Rescue area per capita; Number of mobile rescue personnel
		Fire and rescue combat capability	Skills assessment pass rate; Fire scene information analysis capability; Physical training compliance rate; Average number of rescues; Number of firefighters with certificates
	Fire fighting equipment	Fire protection system	Automatic sprinkler system normal rate; Fire alarm system availability; Water supply pipeline status; Fire protection facilities' integrity rate; Fire host status; Fire lane clear; Status of smoke prevention and exhaust systems
		Firefighting equipment	Average rescue area of fire trucks; Fire extinguishing agent type configuration; Fire extinguishing agent reserve; Special equipment reserves; Fire hydrant control pump status; Water pressure of the fire hydrant at the most unfavorable point; Position of handheld firefighting equipment; Protective clothing reserves
	Fire rescue environment	Intrinsic safety	Hazard source distribution; Density of fire escape routes in buildings; Power station layout; Material station layout; Fire water supply source; Number of fire stations; High voltage line safety; Airport fire inspection and acceptance
		Communication environment	Wireless network coverage area; Fire alarm reception line; Number of fire fighting machines; Number of communication command vehicles; Centrally control the number of devices; Number of broadcast devices; Dispatch command voice recording equipment
		Government attention	Fire protection publicity and popularization Punishment
	Firefighting organization command	Principles of organization and command	Clarity of personnel authority; Current fire priority; Command object task status; Command and coordination personnel power; Implementation of personnel responsibilities
		Organizational command level	Education; Fire situation analysis and processing capabilities; Fire environment familiarity; Familiarity with facilities and equipment; Age limit for fire commander
		Hazard management	Inspection situation; Hidden danger correction efficiency; Maximum hidden danger inventory
	Firefighting tactical coordination	Firefighting and rescue training	Training area; Number of training sessions; Training achievement rate; Training equipment and facilities
		Coordinated firefighting and rescue support mechanism	Combat personnel organization mobility; Fire enforcement priority; Emergency plan preparation

Table 3. Index weight interval.

Expert	D_{ab1}	D_{ab2}	…	D_{abm}	…	D_{abn}
P_1	$[w_{ab11}^-, w_{ab11}^+]$	$[w_{ab21}^-, w_{ab21}^+]$	…	$[w_{abm1}^-, w_{abm1}^+]$	…	$[w_{abn1}^-, w_{abn1}^+]$
P_2	$[w_{ab12}^-, w_{ab12}^+]$	$[w_{ab22}^-, w_{ab22}^+]$	…	$[w_{abm2}^-, w_{abm2}^+]$	…	$[w_{abn2}^-, w_{abn2}^+]$
…	…	…	…	…	…	…
P_r	$[w_{ab1r}^-, w_{ab1r}^+]$	$[w_{ab2r}^-, w_{ab2r}^+]$	…	$[w_{abmr}^-, w_{abmr}^+]$	…	$[w_{abnr}^-, w_{abnr}^+]$
…	…	…	…	…	…	…
P	$[w_{ab1p}^-, w_{ab1p}^+]$	$[w_{ab2p}^-, w_{ab2p}^+]$	…	$[w_{abmp}^-, w_{abmp}^+]$	…	$[w_{abnp}^-, w_{abnp}^+]$

According to the experts' experience and authority in coordinated firefighting and rescue, the reliability of each expert is weighted and scored, as shown in Table 4.

The indicator weights are modified according to the expert reliability weights.

$$\overline{w}_{abm} = \frac{\frac{1}{2}\sum_{r=1}^{p} k_r\left(w_{abmr^+}^2 - w_{abmr^-}^2\right)}{\sum_{r=1}^{p} k_r\left(w_{abmr^+} - w_{abmr^-}\right)} \tag{2}$$

Step 4: Weight normalization

Normalize the corrected weights.

$$w_{abm} = \frac{\overline{w}_{abm}}{\sum_{m=1}^{n}\overline{w}_{abm}}\left(\sum_{m=1}^{n}\overline{w}_{abm} = 1\right) \tag{3}$$

Step 5: Evaluation and scoring

Invite five experts to score the indicator C_{11}, and obtain their evaluation sample matrix U_{11} respectively :

$$U_{11} = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} \end{bmatrix} \tag{4}$$

Step 6: Grayscale value whitening

Assume k = 4, that is, there are four evaluation gray categories, namely 'excellent', 'good', 'medium' and 'poor'. The evaluation scores are converted into evaluation coefficients of each gray category through the whitening weight function.

The first category is 'excellent' (k = 1), and the gray number is set to $\oplus 1 \in [9,\infty)$, and its whitening weight function[17] is:

$$f_1\left(x_{ij}\right) = \begin{cases} 1, & x_{ij} \in [9.\infty) \\ \frac{x_{ij}}{9}, & x_{ij} \in [0,9] \\ 0, & x_{ij} \in (-\infty,0] \end{cases} \tag{5}$$

The second category is 'good' (k = 2), and the gray number is set to $\oplus 2 \in (0, 8, 16)$, and its whitening weight function is:

$$f_2\left(x_{ij}\right) = \begin{cases} \frac{x_{ij}}{8}, & x_{ij} \in [0,8] \\ 2-\left(\frac{x_{ij}}{8}\right), & x_{ij} \in [8,16] \\ 0, & x_{ij} \notin (0,16] \end{cases} \tag{6}$$

The third category is 'medium' (k = 3), and the gray number is set to $\oplus 3 \in (0, 6, 12)$. Its whitening weight function is:

$$f_3\left(x_{ij}\right) = \begin{cases} \frac{x_{ij}}{6}, & x_{ij} \in [0,6] \\ 2-\left(\frac{x_{ij}}{6}\right), & x_{ij} \in [6,12] \\ 0, & x_{ij} \notin (0,12] \end{cases} \tag{7}$$

The fourth category 'difference' (k = 4), set the gray number $\oplus 4 \in (0, 1, 5)$, and its whitening weight function is:

$$f_4\left(x_{ij}\right) = \begin{cases} 1, & x_{ij} \in [0,1] \\ \frac{\left(5-x_{ij}\right)}{4}, & x_{ij} \in [1,5] \\ 0, & x_{ij} \notin (0,5] \end{cases} \tag{8}$$

The calculation results of the gray evaluation coefficient of each indicator under the evaluation index C_{11} are shown in Table 5.

Step 7: Obtain the grey evaluation matrix

Normalize the above evaluation coefficients to get the grey evaluation weight matrix R_{11} of C_{11}. Similarly, we can get $R_{11}, \ldots, R_{an}$:

$$R_{11ik} = \frac{X_{1ik}}{\sum_{k=1}^{4} X_{1ik}} \tag{9}$$

$$R_{11} = \begin{bmatrix} R_{1111} & R_{1112} & R_{1113} & R_{1114} \\ R_{1121} & R_{1122} & R_{1123} & R_{1124} \end{bmatrix} \tag{10}$$

Substitute the weights to conduct a comprehensive evaluation on the grey evaluation matrix and obtain the grey evaluation weight matrix $R_1, \ldots, R_a$:

$$R_1 = W_{11}R_{11} = \begin{bmatrix} w_{111} & w_{112} \end{bmatrix}\begin{bmatrix} R_{1111} & R_{1112} & R_{1113} & R_{1114} \\ R_{1121} & R_{1122} & R_{1123} & R_{1124} \end{bmatrix} \tag{11}$$

Then the grey evaluation matrix of the first-level index is R:

$$R = \begin{bmatrix} R_1 \\ \ldots \\ R_a \end{bmatrix} \tag{12}$$

Bring in the weights to get the final result A:

$$A = WR = \begin{bmatrix} x_1 & \ldots & x_a \end{bmatrix} \tag{13}$$

Step 8: After assigning points, classify abilities according to the scores

The final results are normalized and scored. The scores of excellent, good, medium, and poor levels of collaborative rescue capability are defined as D = (90, 80, 60, 30)[21], and the comprehensive evaluation scores and corresponding levels are obtained:

$$W = BD^T = \begin{bmatrix} \frac{x_1}{\sum_{1}^{a} x_i} & \ldots & \frac{x_a}{\sum_{1}^{a} x_i} \end{bmatrix}\begin{bmatrix} 90 & 80 & 60 & 30 \end{bmatrix}^T \tag{14}$$

Conclusions

(1) Consider shore and ships' coordinated firefighting and rescue efforts for sudden fires in ports and berthed ships.

Because of the high risk of fire on shore and docked ships, we are now considering fire rescue support from shore to ship and ship to shore to reduce fire losses. When a fire occurs, the coordinated firefighting and rescue operations between shore and ship can make full use of the firefighting resources of both places, combining the advantages of large reserves, mobilization, and complete equipment of shore firefighting resources, and the mobility and strong mobility of ships to control the development of the fire promptly.

(2) The firefighting and rescue capability level is evaluated by combining the fuzzy set value method and the grey correlation method.

The fuzzy set value method comprehensively measures the overall importance of each indicator and adds the importance of expert opinions to the weight calculation process. It is suitable for fire rescue scenarios such as ship and shore coordinated firefighting that require experience and judgment. In the evaluation of firefighting combat capability, the information provided is bound to be different, and the gray theory can fully develop the 'minimum information' in this fuzzy situation, balance experience and objective data, and quantify uncertainty indicators.

Table 4. Expert reliability weights.

Expert	P_1	P_2	…	P_r	…	P
Weight	K_1	K_2	…	K	…	k_p

Table 5. Calculation results of gray category evaluation coefficients.

	K = 1	K = 2	K = 3	K = 4
D_{111}	X_{111}	X_{112}	X_{113}	X_{114}
D_{112}	X_{121}	X_{122}	X_{123}	X_{124}

Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Chen Y, Chen Y; data collection: Zhang Y; analysis and interpretation of results: Wang J; draft manuscript preparation: Wang J. All authors reviewed the results and approved the final version of the manuscript.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due their relation to the defense base, but are available from the corresponding author upon reasonable request.

Acknowledgments

This work is supported by DJJG Fire Station and Shore–Ship Collaborative Fire Rescue Strategy and Technology (Grant No. 2021YFC3100202).

Conflict of interest

The authors declare that they have no conflict of interest.

Dates

Received 20 May 2025; Revised 10 November 2025; Accepted 1 December 2025; Published online 26 December 2025

References

1. Jiang X, Ren W, Xu H, Zheng S, Wu S. 2025. Mechanism-based fire hazard chain risk assessment for roll-on/roll-off passenger vessels transporting electric vehicles: a fault tree–fuzzy Bayesian network approach. *Journal of Marine Science and Engineering* 13(2):227
2. Cui X, Zhang M, Pan W. 2022. Dynamic probability analysis on accident chain of atmospheric tank farm based on Bayesian network. *Process Safety and Environmental Protection* 158:146–58
3. Ouache R, Nahiduzzaman KM, Hewage K, Sadiq R. 2021. Performance investigation of fire protection and intervention strategies: artificial neural network-based assessment framework. *Journal of Building Engineering* 42:102439
4. Zhang G. 2007. 论消防部队应急抢险救援骨干作用的发挥 [On Exerting the Influence of Officers in Fire Fescue Forces]. *武警学院学报 [Journal of China People's Police University]* 2:12–15 (in Chinese)
5. Shang K. 2006. 消防部队战斗力动态评估系统设计构想 [The designing concept of dynamic evaluating system on fire forces fighting capacity]. *消防科学与技术 [Fire Science and Technology]* 2:253–55 (in Chinese)
6. Xia D, Shang K, Cheng X, Xu Y, Xin J. 2008. 灭火救援战斗力综合评估指标体系研究 [Study on the general evaluation index system of the fire fighting and rescue capability of the fire troop]. *消防科学与技术 [Fire Science and Technology]* 4:273–76 (in Chinese)
7. Sun S, Huang G, Jin L, Li Y, Zhao X. 2016. Fuzzy comprehensive evaluation of emergency capability of port coal storage base with G1 method. *Proceeding of 3rd International Symposium on Mine Safety Science and Engineering (ISMS)*. Montreal, Canada: McGill University. pp. 231–35
8. Guo Z, Qi M. 2010. Comprehensive assessment method of urban emergency response capability based on FAHP. *Proceedings of International Conference on Management Science and Engineering, Wuhan, China*. pp. 273–76
9. Shang P, Sun Y, Zhou Z, Huang N, Zhou J. 2021. Assessment of large vessel support capability based on comprehensive weighting model. *2021 IEEE International Conference on Mechatronics and Automation (ICMA). Takamatsu, Japan, 8–11 August, 2021*. USA: IEEE. pp. 356–62 doi:10.1109/ICMA52036.2021.9512812
10. Zadeh LA. 1965. Fuzzy sets. *Information and Control* 8(3):338–53
11. Wu C, Liu C, Kang L. 2022. Method for quantitative expression of psychological safety and security distance (PSSD) using fuzzy theory. *Emergency Management Science and Technology* 2(1):1–8
12. Hu D, Jiang T, Yu X. 2020. Construction of non-convex fuzzy sets and its application. *Neurocomputing* 393:175–86
13. Garg H, Chen SM. 2020. Multiattribute group decision making based on neutrality aggregation operators of q-rung orthopair fuzzy sets. *Information Sciences* 517:427–47
14. Atanassov KT. 1986. Intuitionistic fuzzy sets. *Fuzzy Sets and Systems* 20(1):87–96
15. Krawczak M, Szkatuła G. 2020. On matching of intuitionistic fuzzy sets. *Information Sciences* 517:254–74
16. Ngan RT, Son LH, Ali M, Tamir DE, Rishe ND, et al. 2020. Representing complex intuitionistic fuzzy set by quaternion numbers and applications to decision making. *Applied Soft Computing* 87:105961
17. Xia D. 2018. 灭火救援效能分析与评估 *[Fire extinguishing and rescue effectiveness analysis and evaluation]* (in Chinese). Beijing: Chemical Industry Press
18. Li P, Ji Y, Wu Z, Qu SJ. 2020. A new multi-attribute emergency decision-making algorithm based on intuitionistic fuzzy cross-entropy and comprehensive grey correlation analysis. *Entropy* 22(7):768
19. Feng Q, Sun T. 2020. Comprehensive evaluation of benefits from environmental investment: take China as an example. *Environmental Science and Pollution Research International* 27(13):15292–304
20. Tian G, Hao N, Zhou M, Pedrycz W, Zhang C, et al. 2021. Fuzzy grey choquet integral for evaluation of multicriteria decision making problems with interactive and qualitative indices. *IEEE Transactions on Systems, Man, and Cybernetics: Systems* 51(3):1855–68
21. Xu G, Yang YP, Lu SY, Li L, Song X. 2011. Comprehensive evaluation of coal-fired power plants based on grey relational analysis and analytic hierarchy process. *Energy Policy* 39(5):2343–51