

## Article

# A Decision-Making Model for the Assessment of Emergency Response Capacity in China

Guanyu Chen <sup>1</sup>, Tao Li <sup>2,3</sup>  and Liguao Fei <sup>2,3,\*</sup> <sup>1</sup> School of Public Affairs, Xiamen University, Xiamen 361005, China; gyc718@126.com<sup>2</sup> Smart State Governance Lab, Shandong University, Qingdao 266237, China; 202310712@mail.sdu.edu.cn<sup>3</sup> School of Political Science and Public Administration, Shandong University, Qingdao 266237, China

\* Correspondence: feiliguao@sdu.edu.cn

**Abstract:** Natural disasters and emergencies continue to increase in frequency and severity worldwide, necessitating robust emergency management (EM) systems and evaluation methodologies. This study addresses critical gaps in current emergency response capacity (ERC) evaluation frameworks by developing a comprehensive quantitative decision-making model to assess ERC more effectively. This research constructs a systematic ERC assessment framework based on the four phases of the disaster management cycle (DMC): prevention, preparedness, response, and recovery. The methodology employs multi-criteria decision analysis to evaluate ERC using three distinct information representation environments: intuitionistic fuzzy (IF) sets, linguistic variables (LV), and a novel mixed IF-LV environment. For each environment, we derive appropriate aggregation operators, weight determination methods, and information fusion mechanisms. The proposed model was empirically validated through a case application to emergency plan selection in Shenzhen, China. A statistical analysis of results demonstrates high consistency across all three decision environments (IF, LV, and mixed IF-LV), confirming the model's robustness and reliability. A sensitivity analysis of key parameters further validates the model's stability. Results indicate that the proposed decision-making approach provides significant value for EM by enabling more objective, comprehensive, and flexible ERC assessment. The indicator system and evaluation methodology offer decision-makers (DMs) tools to quantitatively analyze ERC using various information expressions, accommodating both subjective judgments and objective metrics. This framework represents an important advancement in emergency preparedness assessment, supporting more informed decision-making in emergency planning and response capabilities.



Academic Editor: José Niño-Mora

Received: 27 March 2025

Revised: 9 May 2025

Accepted: 19 May 2025

Published: 26 May 2025

**Citation:** Chen, G.; Li, T.; Fei, L. A Decision-Making Model for the Assessment of Emergency Response Capacity in China. *Mathematics* **2025**, *13*, 1772. <https://doi.org/10.3390/math13111772>

**Copyright:** © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

**Keywords:** emergency response capacity; emergency management; integrated assessment; mixed information; MADM

**MSC:** 62C86; 68U35

## 1. Introduction

In recent years, major emergencies have occurred with increasing frequency worldwide, seriously affecting social structures and economic development [1,2]. With rapid economic and social development and profound transformation, various predictable and unforeseeable risk factors have increased significantly [3,4]. Against this background, all countries are striving to enhance their ERC for public emergencies and are working diligently to improve their national EM systems [5,6]. Effective management of ERC presents

a huge challenge for DMs and has become a research topic of great significance worldwide [7,8]. While academia has made numerous efforts to strengthen EM in recent years, and despite some progress, ERC in actual disaster situations remains quite limited [9]. One of the important reasons for this limitation is the failure to effectively assess the ERC of emergency management entities (ESs), resulting in unqualified emergency plans and methods that adversely affect actual rescue operations [10,11].

ERC is a comprehensive ability to deal with emergencies such as natural disasters, public health emergencies, and public security incidents, and it constitutes an important part of disaster EM [12,13]. ERC comprises multiple interacting systems, encompassing capabilities for rapid response after emergencies, commanding and handling emergencies, issuing emergency information, organizing emergency evacuation, saving lives, and protecting property and the environment, among others [14]. The important role of ERC in disaster reduction has been widely recognized, and exceptional ERC can facilitate emergency rescue, prevent economic losses and environmental problems, and control and mitigate the impact of disasters [15].

Improving disaster ERC is of great significance for effectively reducing disaster losses, which prompts relevant EM agencies to discover and correct problems in current emergency preparedness through scientific assessment of ERC. The ERC assessment process consists of three main steps: (1) establishing an index system for evaluating ERC according to practical problems; (2) evaluating each index; (3) developing an aggregation method to systematically integrate individual evaluations to obtain the final result. The results of the ERC assessment can be used as feedback information to improve the status quo of EM and optimize emergency plans [16]. Therefore, the assessment of ERC serves as a foundation for strengthening the EM of emergencies.

While previous research has made significant progress in ERC evaluation, several critical gaps remain in current approaches:

1. **Incomplete indicator systems:** Existing ERC evaluation frameworks often lack comprehensive coverage of all disaster management cycle phases, with most focusing only on the response phase while neglecting prevention, preparedness, and recovery phases [17,18].
2. **Limited information expression methods:** Current evaluation approaches typically employ single information representation forms (e.g., clear numbers, fuzzy sets), which fail to capture the complexity of subjective judgments and the heterogeneity of expert opinions [19,20].
3. **Inadequate uncertainty handling:** Most existing models struggle to effectively address different types of uncertainties simultaneously, including fuzziness, hesitancy, and incompleteness in evaluation information [21,22].
4. **Inflexible evaluation processes:** Current methods often lack the flexibility to adapt to different decision contexts and information availability, constraining their practical applicability in diverse emergency scenarios [23].
5. **Insufficient quantitative analysis:** Many existing approaches are predominantly qualitative, lacking rigorous quantitative analysis capabilities to provide actionable feedback to emergency management departments [24,25].

To address these significant gaps, this paper proposes an integrated decision-making model for the assessment of emergency response capacity. The following motivations and innovations drive this study:

(1) Addressing the problem of imperfections in the current ERC evaluation index system, this paper reconstructs the index system under the guidance of DMC, investigates the ERC from the main aspects of prevention, preparation, response, and recovery, and enhances the practicability, standardization, scientificity, and feasibility of the index system;

(2) Considering the shortcomings of existing methods in reflecting the complexity of objective phenomena and the fuzziness of human cognitive processes, this paper fully considers the convenience and accuracy of providing evaluation information for DMs and develops an information expression method that functions effectively in IF, LV, and mixed IF-LV environments;

(3) Under the decision-making background of IF, LV, and mixed IF-LV, multi-expert, multi-attribute, decision-based ERC evaluation methods are designed to provide EM departments with a flexible way to evaluate the ERC of ESs, offering an effective tool for EM performance evaluation and decision-making under uncertain environments;

(4) To demonstrate and validate the proposed method, it is applied to a decision-making problem involving emergency plan selection in Shenzhen City, China, where the evaluation results verify the validity and consistency of the decision-based ERC evaluation model.

The key contributions of this study are highlighted as follows:

- **Development of a comprehensive ERC indicator system:** We construct a holistic evaluation framework that systematically integrates all four phases of the disaster management cycle (prevention, preparedness, response, and recovery), providing a more complete assessment of emergency response capacity.
- **Creation of a tri-environmental decision model:** We establish a novel decision-making framework that operates seamlessly across three information environments (intuitionistic fuzzy, linguistic variable, and mixed IF-LV), allowing for more flexible and accurate expression of expert evaluations.
- **Design of enhanced aggregation methods:** We propose OWA-based soft likelihood function aggregation operators that effectively handle various types of uncertainty while preserving evaluation information integrity during the fusion process.
- **Introduction of the mixed IF-LV environment:** We develop an innovative approach that allows simultaneous use of different information representation forms, accommodating expert preferences and enhancing evaluation accuracy through intuitionistic uncertain linguistic variables.
- **Validation through real-world application:** We empirically validate the proposed model through application to emergency plan selection in Shenzhen City, demonstrating its practical utility and providing a decision support framework for emergency management practitioners.

The remaining parts of this paper are structured as follows. The literature related to emergency response capacity is outlined in Section 2. The integrated decision-making model for ERC assessment is proposed in Section 3. Section 4 describes the application case of the proposed model in emergency management. The results are analyzed and discussed in Section 5. Finally, Section 6 summarizes the conclusions of this paper and makes recommendations for future work. For clarity and ease of reference, Table 1 provides a comprehensive list of all abbreviations used throughout this paper.

**Table 1.** Summary table of research terms and their abbreviations.

| Term                        | Abbreviation |
|-----------------------------|--------------|
| Emergency management        | EM           |
| Emergency response capacity | ERC          |
| Disaster management cycle   | DMC          |
| Intuitionistic fuzzy        | IF           |
| Linguistic variables        | LV           |
| Decision-makers             | DMs          |

Table 1. *Cont.*

| Term                                                              | Abbreviation |
|-------------------------------------------------------------------|--------------|
| Multi-attribute decision-making                                   | MADM         |
| Emergency subjects                                                | ESs          |
| Ordered weighted averaging                                        | OWA          |
| Technique for order preference by similarity to ideal solution    | TOPSIS       |
| Emergency alternatives                                            | EAs          |
| Evaluation experts                                                | EEs          |
| Evaluation indicators                                             | EIs          |
| Intuitionistic uncertain linguistic variables                     | IULV         |
| Emergency management bureau                                       | EMB          |
| Entropy weight                                                    | EW           |
| Analytic hierarchy process                                        | AHP          |
| Preference ranking organization method for enrichment evaluations | PROMETHEE    |

## 2. Literature Review

This section first introduces ERC and then analyzes the research status of ERC assessment. An overview of the application of MADM methods to the ERC evaluation is provided at the end of this section.

### 2.1. Emergency Response Capacity

An incident or emergency is defined as a situation that may cause harm to a population or damage to property [26]. The types of emergencies mainly include natural disasters, security disasters, public health crises, and social security crises, which have become the primary focus of EM [27,28]. According to the cycle of EM, the handling of emergencies is usually divided into four stages: prevention, preparation, response, and recovery [29]. Emergency response refers to the preparations and measures taken by emergency management entities in response to emergencies, with the purpose of preventing the occurrence of disasters, providing effective response and recovery guidance, and minimizing the losses caused by disasters [30]. Emergency response should not only focus on the response phase during a disaster but also encompass all phases of the entire disaster management cycle. ERC is a key element for assessing the effectiveness of EM, including the ability to prevent and prepare before disasters, the ability to deal with emergencies during disasters, and the ability to recover after disasters.

### 2.2. ERC Evaluation

ERC assessment is an important basis for scientifically guiding emergency capacity-building [31]. Through ERC assessment, it is possible to continuously improve EM, ensure the effectiveness of emergency plans, help emergency responders improve rescue capabilities, and evaluate the progress of emergency preparedness before disasters [32]. The following section introduces the research status of ERC assessment in various countries and summarizes and analyzes their characteristics.

Developed countries such as the United States and Japan have well-established EM systems, focusing on systematic and comprehensive assessments of ERC [33,34]. The United States was the first country in the world to implement the evaluation of government ERC. In recent years, the United States has nearly completed the evaluation of ERC across management functional departments and has constructed an ERC evaluation indicator system that includes 56 elements, 209 attributes, and 1014 indicators [35,36]. Japan, being a country with frequent earthquake disasters, has found it particularly important to establish an effective EM system. To this end, Japan has formulated basic guidelines for crisis management to evaluate ERC and developed an evaluation framework encompassing

more than 10 aspects such as emergency reserve, communication systems, and disaster reduction training, aimed at improving the capacity of disaster prevention and crisis management [37]. China's 14th Five-Year Plan and the Outline of Vision 2035 propose to significantly enhance ERC and put forward requirements for improving the national EM system [38,39]. ERC is an important aspect of EM capacity-building, focusing on making effective responses in the shortest time after an emergency to reduce casualties and property losses. As a result, various quantitative methods [40–42] have been proposed for ERC evaluation.

Based on the above overview, it is clear that many countries have recognized urgent needs for ERC and its assessment. There is a pressing need to build a systematic ERC evaluation index system for emergencies, as well as a set of scientific evaluation approaches.

### 2.3. MADM in ERC Evaluation

The ERC evaluation is essentially a multi-attribute decision-making (MADM) problem with many criteria and sub-criteria [42,43]; consequently, among many ERC evaluation methods, MADM-based evaluation methods are widely employed [44,45]. To evaluate ERC, the hybrid fuzzy method based on fuzzy AHP and a two-tuple fuzzy linguistic method was introduced relatively early [42]. The quantitative ERC evaluation method for miners [41] was applied to engineering practice to verify its effectiveness in selecting safe employers and reducing the occurrence of human-made mine accidents. For the assessment of marine oil spill ERC, Jin et al. [46] established an evaluation index system and used an advanced AHP method and a fuzzy comprehensive evaluation method to determine the ERC level. In addition, interval binary linguistic information was adopted to construct a multi-criteria comprehensive method for ERC assessment [47], which has proved to be a flexible method for effectively addressing ERC perception and evaluation. To solve the problems of incompleteness, inaccuracy, subjectivity, and uncertainty of information in emergency decision-making, a q-rung fuzzy decision-making method [48] was proposed based on weighted distance approximation.

In recent years, emergency support capacity (ESC) assessment methods have been widely studied [49,50]. For example, the fuzzy MADM approach and multi-objective optimization model were combined to establish an efficient two-stage evaluation and selection framework to determine the optimal emergency material location allocation for river chemical spills response plans [51]. The TOPSIS method based on multi-granularity linguistic information was developed to evaluate the performance of emergency logistics [52], and its effectiveness and reliability were verified by its excellent performance in earthquake scenarios. In order to improve the ESC of fire stations, researchers in [53] identified the influencing factors of fire station emergency rescue capacity and established an evaluation system. Mohammad et al. [54] studied the ERC of hospitals in emergencies, applying the TOPSIS method to define the index of hospital emergency and ranking the resilience of hospitals in disasters. Although the existing literature provides useful guidelines for ERC evaluation, the current evaluation indicator systems are neither comprehensive nor systematic, and furthermore, they do not offer experts sufficiently flexible methods of expressing information.

## 3. An Integrated Decision-Making Model for the Assessment of ERC

In this section, a comprehensive integrated evaluation model of emergency response capacity is constructed based on the perspective of decision-making. First, the ERC evaluation indicator system is proposed based on a literature analysis and expert research. Second, a systematic description of the ERC evaluation problem is presented. Thirdly, an ERC evaluation model under intuitionistic fuzzy and linguistic environments is proposed. In ad-

dition, an ERC evaluation method in the mixed IF-LV decision-making environment is provided. Finally, the prototype of ERC evaluation is summarized and sorted out.

### 3.1. The Evaluation Indicator System for ERC

In this study, an indicator system for assessing emergency response capacity is constructed from the perspective of the disaster management cycle, i.e., prevention, preparedness, response, and recovery. Taking the disaster management cycle as the main reference, this paper systematically develops an evaluation indicator system of emergency response capacity through the literature review and expert research methods. Emergency response capacity is a comprehensive ability to deal with emergencies [42]. According to the disaster management cycle [29], emergency response is divided into four stages, namely, prevention, preparation, response, and recovery, and four corresponding indicators are constructed: disaster prevention and mitigation capacity, emergency material preparedness capacity, emergency process capacity, and disaster recovery capacity.

In the prevention stage, various preventive measures should be taken to eliminate the possibility of disasters or, at minimum, reduce possible damage [55]. Therefore, this stage needs to focus on the ability to prevent and reduce disasters (denoted as  $B_1$ ). The main tasks of the preparation stage include developing different types of emergency plans and improving the ability to mobilize available emergency resources in the event of a disaster [55]. Therefore, this stage should evaluate emergency material preparedness capacity (denoted as  $B_2$ ). During the response phase, contingency plans should be activated to minimize casualties and losses [29], requiring emergency process capacity (denoted as  $B_3$ ) to be adequate. The recovery phase refers to the need to start the recovery plan as soon as possible after the disaster to restore society and life to their original states [29], necessitating the evaluation of disaster recovery capacity (denoted as  $B_4$ ).

In order to evaluate ERC more effectively, each indicator is further subdivided based on literature research. To evaluate disaster prevention and mitigation capacity ( $B_1$ ), indicators such as prevention capacity, means, and effects need to be considered; to evaluate emergency preparedness capacity ( $B_2$ ), it is necessary to pay attention to indicators such as emergency material reserves, emergency plan formulation and drills, and safety education; to evaluate the emergency process capacity ( $B_3$ ), it is necessary to examine indicators such as the speed of emergency rescue, the ability to coordinate command, and the quality of information dissemination; and to evaluate the recovery capacity ( $B_4$ ), indicators such as post-disaster reconstruction, the ability to assess and improve the disaster response process, and social resilience need to be examined. The constructed sub-indicators with their specific descriptions and related references are shown in Table 2.

In addition, in order to make the constructed ERC evaluation indicator system more robust, this study invited more than ten experts in the emergency field to provide guidance to further enrich the system. The specific revisions are as follows. First, publicity and education on disaster prevention and mitigation is very important in the stage of prevention, which can fundamentally cultivate people's emergency awareness, so this sub-indicator is added to  $B_1$ ; secondly, all kinds of emergency materials stored should have sufficient capacity to be mobilized, so the ability to mobilize emergency resources is included in  $B_2$ ; thirdly, for all kinds of emergency plans formulated in the preparation stage, being able to start in time when needed is an important guarantee for them to play a role, so the ability to start emergency plans is included in  $B_2$ . In addition, secondary disasters should be avoided in the disaster area during the rescue process; finally, the ability to start the plan in the recovery phase needs to be investigated, so the sub-indicator is added in  $B_4$ . The indicators obtained through the expert survey are marked in Table 2, and in order to clearly show the structure of the ERC evaluation indicators, Figure 1 provides a structured description.

**Table 2.** The specific meaning of the indicators.

| Indicator & Stage                                                | Sub-Indicator                                                | Meaning                                                                              | References             |
|------------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------------------------------------|------------------------|
| Disaster prevention & mitigation capacity<br>(Prevention stage)  | Monitoring and forecasting capacity                          | Identify possible disasters in advance                                               | [42,56]                |
|                                                                  | Warning and forecasting instrument                           | Various monitoring and forecasting equipment                                         | [36,56]                |
|                                                                  | Warning and forecasting accuracy                             | Provide accurate basis for disaster prediction                                       | [42]                   |
|                                                                  | Publicity and education of disaster prevention and reduction | Provide effective publicity and education for disaster prevention and reduction      | Proposed in this study |
| Emergency material preparedness capacity<br>(Preparedness stage) | Security education training                                  | Adequate safety training for emergency departments                                   | [56]                   |
|                                                                  | Emergency resource mobilization                              | Timely and effective mobilization of emergency materials                             | Proposed in this study |
|                                                                  | Emergency resource reserve                                   | Reserve various emergency supplies (technical, material, and rescue personnel, etc.) | [36,42]                |
|                                                                  | Emergency plan simulation exercise                           | Prepare contingency plans and fully rehearse                                         | [56]                   |
| Emergency process capacity<br>(Response stage)                   | Emergency plan activation                                    | Successful activation of established emergency plans in disasters                    | Proposed in this study |
|                                                                  | Collaboration capacity                                       | Coordination among emergency subjects to deal with disasters                         | [42,57]                |
|                                                                  | Information transmission capacity                            | Timely and accurate transmission of information between subjects                     | [58]                   |
|                                                                  | Rescue speed                                                 | Time from disaster occurrence to effective rescue                                    | [36,42]                |
|                                                                  | Command capacity                                             | Effectively organize multiple departments to respond to disasters                    | [42,56]                |
|                                                                  | Prevent secondary disasters                                  | Rescue operations should not bring any secondary damage                              | Proposed in this study |
| Disaster recovery capacity<br>(Recovery stage)                   | Recovery plan initiation                                     | Successful start of recovery plan after disaster                                     | Proposed in this study |
|                                                                  | Social support system                                        | Take various measures to restore normalcy and social order                           | [42,59]                |
|                                                                  | Evaluation and summary                                       | Conduct disaster and management evaluations                                          | [56,59]                |
|                                                                  | Reconstruction capacity                                      | Rebuild disaster-damaged infrastructure and residential buildings                    | [42]                   |

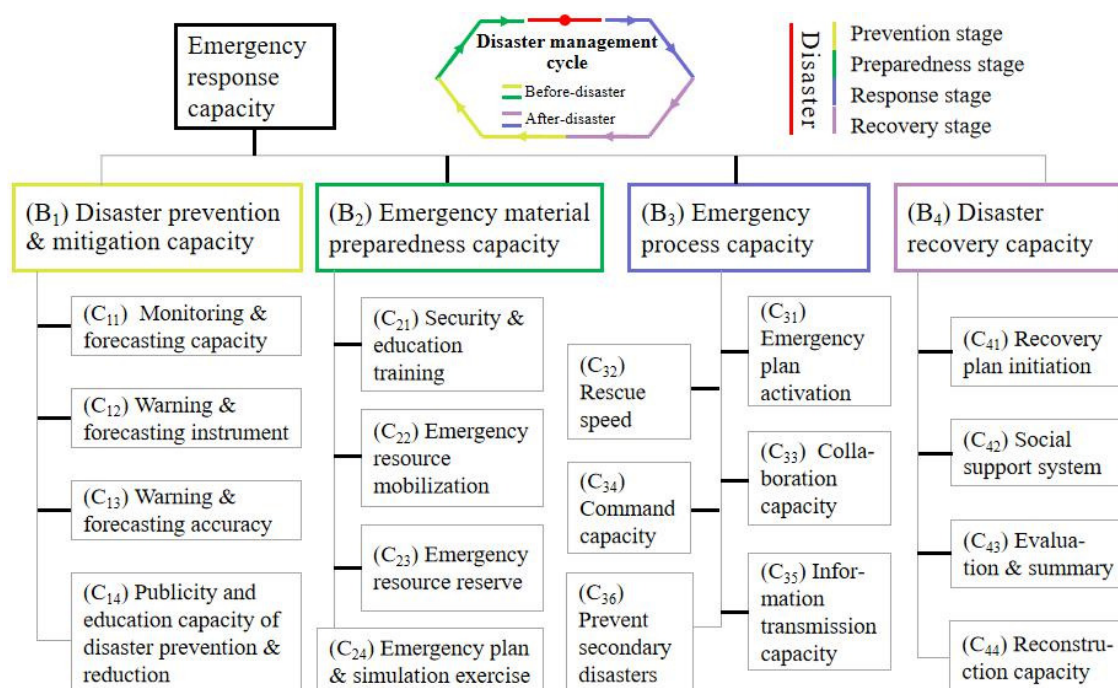


Figure 1. The evaluation indicator system for ERC.

### 3.2. Problem Description of ERC Assessment

An emergency response capacity assessment problem can be described as follows. The set of emergency alternatives to be evaluated is expressed as  $\mathbf{EA} = \{ea_1, ea_2, \dots, ea_m\}$ . Multiple evaluation experts from related fields form a set  $\mathbf{EE} = \{ee_1, ee_2, \dots, ee_q\}$ , and the corresponding weight is  $W_{EE} = \{w_{ee_1}, w_{ee_2}, \dots, w_{ee_q}\}$ , which satisfies  $w_{ee_k} \geq 0$ , and  $\sum w_{ee_k} = 1$ . The set of evaluation indicators is denoted as  $\mathbf{EI} = \{ei_1, ei_2, \dots, ei_n\}$ , and the corresponding weight is  $W_{EI} = \{w_{ei_1}, w_{ei_2}, \dots, w_{ei_n}\}$ , which satisfies  $w_{ei_j} \geq 0$ , and  $\sum w_{ei_j} = 1$ . Decision information in ERC evaluation is expressed in two ways: intuitionistic fuzzy information and linguistic variables. The following describes the evaluation information expression in the two forms, respectively.

#### (i) Intuitionistic fuzzy information.

Intuitively fuzzy information is used to express expert  $ee_k$ 's assessment of the emergency response capacity of emergency alternative  $ea_i$  under evaluation indicators  $ei_j$ , which is expressed as  $IF^k = (if_{ij}^k)_{m \times n}$ , where  $if_{ij}^k = \langle \mu_{if_{ij}^k}, \nu_{if_{ij}^k} \rangle$  is an intuitionistic fuzzy number,  $i = \{1, \dots, m\}$ ,  $j = \{1, \dots, n\}$ ,  $k = \{1, \dots, q\}$ .  $\mu_{if_{ij}^k}$  and  $\nu_{if_{ij}^k}$  respectively, represent the degree of membership of  $ea_i$  under  $ei_j$  as "good" and "bad".

#### (ii) Linguistic variables.

Linguistic variables are employed to represent expert  $ee_k$ 's evaluation of the ERC of  $ea_i$  under  $ei_j$ , which is denoted as  $LV^k = (lv_{ij}^k)_{m \times n}$ . Linguistic variables are defined on a linguistic term set  $S = \{s_0, s_1, \dots, s_\vartheta\}$ , where  $\vartheta$  is an even number, and  $lv_{ij}^k$  can be a single linguistic term  $lv_{ij}^k = s_x$  or a linguistic term interval  $lv_{ij}^k = [(lv_{ij}^k)^-, (lv_{ij}^k)^+] = [s_x, s_y]$ ,  $x < y$ . Both of these two forms can be uniformly expressed as  $LV^k = (lv_{ij}^k)_{m \times n} = [(lv_{ij}^k)^-, (lv_{ij}^k)^+] = [s_x, s_y]$ ,  $x \leq y$ . For instance, with regard to  $S = \{s_0 : \text{bad}, s_1 : \text{medium}, s_2 : \text{good}\}$ ,  $lv_{ij}^k = [s_1, s_2]$  represents the upper-moderate performance of the ERC evaluation of  $ea_i$  under  $ei_j$ .

The ultimate goal of the ERC assessment problem is to evaluate and rank the emergency options based on their performance in emergency response capacity and finally select the most advantageous plan for emergency response.

### 3.3. Summary of Mathematical Notation

To enhance readability and facilitate understanding of the mathematical formulations in subsequent sections, Table 3 presents a summary of the key notation used throughout this paper.

**Table 3.** Summary of key notation used in the ERC assessment model.

| Notation                                                       | Description                                                                                   |
|----------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| $\mathbf{EA} = \{ea_1, ea_2, \dots, ea_m\}$                    | Set of emergency alternatives to be evaluated                                                 |
| $\mathbf{EE} = \{ee_1, ee_2, \dots, ee_q\}$                    | Set of evaluation experts                                                                     |
| $\mathbf{W}_{EE} = \{w_{ee_1}, w_{ee_2}, \dots, w_{ee_q}\}$    | Weight vector of experts                                                                      |
| $\mathbf{EI} = \{ei_1, ei_2, \dots, ei_n\}$                    | Set of evaluation indicators                                                                  |
| $\mathbf{W}_{EI} = \{w_{ei_1}, w_{ei_2}, \dots, w_{ei_n}\}$    | Weight vector of indicators                                                                   |
| $if_{ij}^k = \langle \mu_{if_{ij}^k}, \nu_{if_{ij}^k} \rangle$ | Intuitionistic fuzzy evaluation of alternative $ea_i$ under indicator $ei_j$ by expert $ee_k$ |
| $\mu_{if_{ij}^k}, \nu_{if_{ij}^k}$                             | Membership and non-membership degrees in IF evaluation                                        |
| $lv_{ij}^k = [(lv_{ij}^k)^-, (lv_{ij}^k)^+]$                   | Linguistic variable evaluation of alternative $ea_i$ under indicator $ei_j$ by expert $ee_k$  |
| $S = \{s_0, s_1, \dots, s_\theta\}$                            | Set of linguistic terms with $\theta$ as even number                                          |
| $MIXED^k = (mixed_{ij}^k)_{m \times n}$                        | Mixed evaluation matrix from expert $ee_k$                                                    |
| $iulv_{ij}^k$                                                  | Intuitionistic uncertain linguistic variable representation                                   |
| $\alpha \in [0, 1]$                                            | Attitude parameter of decision-makers in aggregation                                          |
| $\mathcal{D}_{IF}, \mathcal{D}_{LV}, \mathcal{D}_{IULV}$       | Deviation of expert evaluations in different environments                                     |
| $E(ei_j), \bar{E}(ei_j), E^*(ei_j)$                            | Entropy functions for indicator weight determination                                          |

With this notation defined, we can now proceed to present the ERC assessment modeling process.

### 3.4. The Prototype of the ERC Assessment

The proposed decision-making model for the assessment of ERC is more clearly described by a flowchart, as shown in Figure 2. When the ERC evaluation begins, a decision-making expert group is first established to further build an evaluation indicator system and then complete the collection of evaluation information. Regardless of the decision environments (IF/LV/mixed IF-LV), a decision matrix is constructed based on the obtained evaluation information. Of course, if it is a mixed environment, it is necessary to unify the IF and LV into the IULV representation. Then, the OWA-based soft likelihood function is used to calculate the weight of different experts, and then the evaluation information of the experts is combined. Based on the fused decision matrix, the weight of the indicators is calculated, and then the information under different indicators is combined. Additionally, the alternatives are sorted by their scoring function. Finally, the best emergency alternative is recommended according to the ERC evaluation.

### 3.5. ERC Assessment Modeling Process in IF and LV Environments

**STEP 1:** Obtain ERC assessment matrices.

The formed expert group in the emergency field will evaluate the emergency response capacity of each alternative based on their own judgment. The evaluation information is based on intuitionistic fuzzy numbers or linguistic variables, which are represented as decision matrices  $IF^k = (if_{ij}^k)_{m \times n}$  and  $LV^k = (lv_{ij}^k)_{m \times n}$ , respectively.

**STEP 2:** Calculate the weight of different experts.

In view of the different backgrounds and professional abilities of experts, in order to minimize the difference between group evaluation information, i.e., to enhance the consistency of experts' evaluation, this study constructs an optimal method for determining the weight of experts in ERC evaluation based on the minimization of dispersion [60].

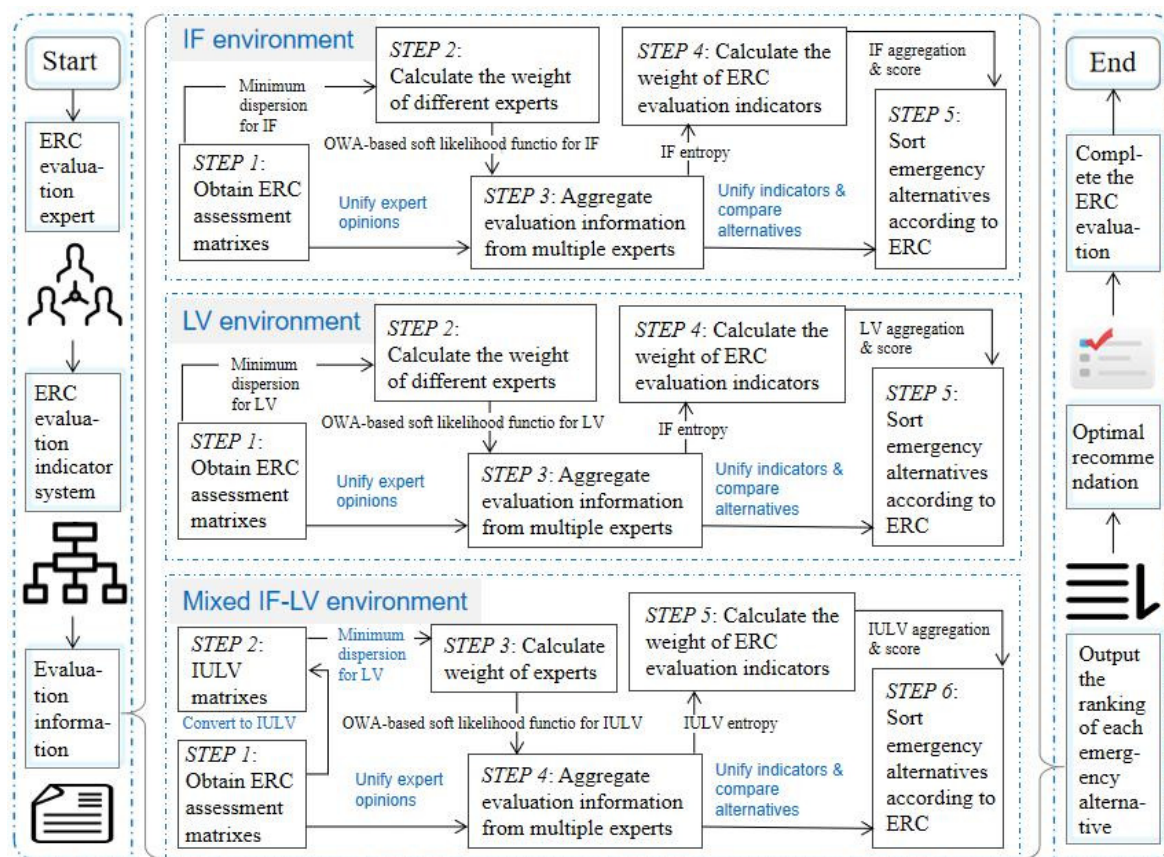


Figure 2. The flowchart of the integrated decision-making model for the assessment of ERC.

(i) In intuitionistic fuzzy environments,

$$\min \mathcal{D}_{IF} = \frac{1}{m \times n} \sum_{k=1}^q w_{ee_k} \sum_{i=1}^m \sum_{j=1}^n (|r_{if_{ij}^k} - \tilde{r}_{ij}|)$$

$$\text{s.t.} \begin{cases} \tilde{r}_{ij} = \sum_{k=1}^q w_{ee_k} r_{if_{ij}^k} \\ w_{ee_k} \in [0, 1] \\ \sum_{k=1}^q w_{ee_k} = 1 \end{cases} \quad (1)$$

where  $\mathcal{D}_{IF}$  indicates the deviation of all experts' evaluation information,  $w_{ee_k}$  indicates the weight of expert  $ee_k$ ,  $\tilde{r}_{ij}$  indicates the group ERC assessment on  $ea_i$  under  $ei_j$ , and  $r_{if_{ij}^k}$  denotes the defuzzified version of  $if_{ij}^k$ , meaning a scoring function, defined as  $r_{if_{ij}^k} = \mu_{if_{ij}^k} - \nu_{if_{ij}^k}(1 - \mu_{if_{ij}^k} - \nu_{if_{ij}^k})$  [61].

(ii) In linguistic information environments,

$$\min \mathcal{D}_{LV} = \frac{1}{m \times n} \sum_{k=1}^q w_{ee_k} \sum_{i=1}^m \sum_{j=1}^n (|g_{lv_{ij}^k} - \tilde{g}_{ij}|)$$

$$\text{s.t.} \begin{cases} \tilde{g}_{ij} = \sum_{k=1}^q w_{ee_k} g_{lv_{ij}^k} \\ w_{ee_k} \in [0, 1] \\ \sum_{k=1}^q w_{ee_k} = 1 \end{cases} \quad (2)$$

where  $\mathcal{D}_{LV}$  indicates the deviation of all experts' evaluation information,  $w_{ee_k}$  indicates the weight of expert  $ee_k$ ,  $\tilde{g}_{ij}$  indicates the group ERC assessment on  $ea_i$  under  $ei_j$ , and  $g_{lv_{ij}^k}$  denotes the scoring function of  $lv_{ij}^k$ , defined as  $g_{lv_{ij}^k} = (y + x)/2\vartheta$ , where  $lv_{ij}^k = [s_x, s_y]$ ,  $x < y$ .

STEP 3: Aggregate evaluation information from multiple experts.

In this step, several aggregation operators based on soft likelihood functions [62–64] are presented to the combination of experts' evaluation information in intuitionistic fuzzy and linguistic environments, respectively.

(i) In intuitionistic fuzzy environments.

The ERC assessment from expert  $ee_k$  for alternative  $ea_i$  against indicator  $ei_j$  is  $if_{ij}^k = \langle \mu_{if_{ij}^k}, \nu_{if_{ij}^k} \rangle$ , and the aggregation operator of the evaluation information of multiple experts is defined by the OWA-based soft likelihood function as

$$\begin{aligned} if_{ij} &= if_{ij}^1 \oplus if_{ij}^2 \oplus \cdots \oplus if_{ij}^q \\ &= \langle \sum_{k=1}^q ((\frac{\mathcal{S}_{ij}^k}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}} - (\frac{\mathcal{S}_{ij}^{k-1}}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}}) \prod_{t=1}^k \mu_{if_{ij}^{\lambda_{ij}^t}}, \sum_{k=1}^q ((\frac{\mathcal{S}_{ij} - \mathcal{S}_{ij}^{k-1}}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}} - (\frac{\mathcal{S}_{ij} - \mathcal{S}_{ij}^k}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}}) \prod_{t=1}^k \nu_{if_{ij}^{\varphi_{ij}^t}} \rangle \\ &= \langle \mu_{if_{ij}}, \nu_{if_{ij}} \rangle \end{aligned} \quad (3)$$

where  $\mathcal{S}_{ij} = \sum_{k=1}^q w_{ee_k}$  and  $\mathcal{S}_{ij}^k = \sum_{t=1}^k w_{ee_{\sigma_{ij}^t}}$ ,  $\sigma$  is an index function, and  $\sigma_{ij}^t$  indicates the index of the  $t$ th largest importance weight of  $W_{EE}$ . Let  $\mathcal{S}_{ij}^0 = 0$ . Then  $\lambda$  and  $\varphi$  are two index functions, and  $\mu_{if_{ij}^{\lambda_{ij}^t}}$  and  $\nu_{if_{ij}^{\varphi_{ij}^t}}$  indicate the indices of the  $t$ th largest elements of  $\{\mu_{if_{ij}^1}, \dots, \mu_{if_{ij}^q}\}$  and  $\{\nu_{if_{ij}^1}, \dots, \nu_{if_{ij}^q}\}$ .  $\alpha \in [0, 1]$  is a parameter representing the attitude characteristic of decision-makers. The smaller  $\alpha$  means that decision-makers are pessimistic, and vice versa [65].

(ii) In linguistic information environments.

Based on the above intuitionistic fuzzy aggregation operator and the literature [64], the aggregation operator in the linguistic environment can be defined as

$$\begin{aligned} lv_{ij} &= lv_{ij}^1 \oplus lv_{ij}^2 \oplus \cdots \oplus lv_{ij}^q \\ &= [\vartheta \sum_{k=1}^q ((\frac{\mathcal{S}_{ij}^k}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}} - (\frac{\mathcal{S}_{ij}^{k-1}}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}}) \prod_{t=1}^k \frac{(lv_{ij}^{\lambda_{ij}^t})^-}{\vartheta}, \vartheta \sum_{k=1}^q ((\frac{\mathcal{S}_{ij} - \mathcal{S}_{ij}^{k-1}}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}} - (\frac{\mathcal{S}_{ij} - \mathcal{S}_{ij}^k}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}}) \prod_{t=1}^k \frac{(lv_{ij}^{\varphi_{ij}^t})^+}{\vartheta}] \\ &= [(lv_{ij})^-, (lv_{ij})^+] \end{aligned} \quad (4)$$

where  $lv_{ij} = [(lv_{ij})^-, (lv_{ij})^+]$  represents the aggregation result of the evaluation information from  $q$  experts.

STEP 4: Calculate the weight of ERC evaluation indicators.

This paper determines the weight of indicators based on the idea of entropy. According to the information entropy theory, entropy is inversely proportional to importance, which leads to the following calculation of weights in two decision-making environments.

(i) In intuitionistic fuzzy environments.

The weight of ERC evaluation indicator  $ei_j$  can be calculated as

$$w_{ei_j} = \frac{1 - E(ei_j)}{n - \sum_{j=1}^n E(ei_j)} \quad (5)$$

in which  $E(\cdot)$  is the entropy function of an intuitionistic fuzzy set, denoted as

$$E(ei_j) = \frac{1}{m} \sum_{i=1}^m \frac{\min(\mu_{if_{ij}}, \nu_{if_{ij}}) + (1 - \mu_{if_{ij}} - \nu_{if_{ij}})}{\max(\mu_{if_{ij}}, \nu_{if_{ij}}) + (1 - \mu_{if_{ij}} - \nu_{if_{ij}})} \quad (6)$$

The weight vector of ERC evaluation indicators can be obtained by normalization, expressed as  $W_{EI} = (w_{ei_1}, w_{ei_2}, \dots, w_{ei_n})^T$ .

(ii) In linguistic information environments.

The weight of  $ei_j$  can be defined as

$$w_{ei_j} = \frac{1 - \tilde{E}(ei_j)}{n - \sum_{j=1}^n \tilde{E}(ei_j)} \quad (7)$$

in which  $\tilde{E}(\cdot)$  is the entropy function of the interval number, denoted as [64]

$$\tilde{E}(ei_j) = \frac{1}{m} \sum_{i=1}^m (1 - \sqrt{2[(lv_{ij})^- - \frac{1}{2}]^2 + [(lv_{ij})^+ - \frac{1}{2}]^2}) \quad (8)$$

The weight vector of ERC evaluation indicators can be obtained by normalization, expressed as  $\tilde{W}_{EI} = (\tilde{w}_{ei_1}, \tilde{w}_{ei_2}, \dots, \tilde{w}_{ei_n})^T$ .

STEP 5: Sort emergency alternatives according to ERC.

Combining the aggregation operators in STEP 3 and the ERC indicator weight in STEP 4, the aggregation methods of indicators in two decision environments can be given, respectively, and then the ranking of emergency alternatives can be determined by scoring function.

(i) In intuitionistic fuzzy environments.

The ERC assessment information of alternative  $ea_i$  against indicator  $ei_j$  is obtained as  $if_{ij} = \langle \mu_{if_{ij}}, \nu_{if_{ij}} \rangle$ , and the weight of ERC evaluation indicator  $ei_j$  is  $w_{ei_j}$ , so the aggregated information of alternative  $ea_i$  can be calculated by using Equation (3) as  $if_i = \langle \mu_{if_i}, \nu_{if_i} \rangle$ . Further, the scoring function of  $if_i$  can be obtained as  $r_{if_i} = \mu_{if_i} - \nu_{if_i}(1 - \mu_{if_i} - \nu_{if_i})$ . By comparing the value of  $r$ , the strengths and weaknesses of the emergency alternative in terms of ERC performance can be determined, and the final decision can be made.

(ii) In linguistic information environments.

The linguistic ERC assessment of alternative  $ea_i$  against indicator  $ei_j$  has been obtained as  $lv_{ij} = [(lv_{ij})^-, (lv_{ij})^+]$ , and the weight of ERC evaluation indicator  $ei_j$  is  $w_{ei_j}$ , so the aggregated information of alternative  $ea_i$  can be calculated by using Equation (4) as  $lv_i = [(lv_i)^-, (lv_i)^+] = [s_x, s_y]$ . Further, the scoring function of  $lv_i$  can be obtained as  $\tilde{r}_{lv_i} = (y + x)/2$ . Similarly, the performance of the emergency response capacity of each alternative in the linguistic environment can also be determined by comparing the value of  $\tilde{r}$ . Finally, the optimal alternative can be selected naturally.

### 3.6. ERC Assessment in a Mixed IF-LV Environment

In order to make ERC assessment a more flexible information expression, this paper adopts three decision information input methods. In addition to the intuitionistic fuzzy and linguistic environments introduced above, it also allows the use of IF-LV hybrid methods to input data in the evaluation. In what follows, the mixed form of ERC evaluation method is highlighted. To facilitate ERC evaluation, two information expression methods (i.e., IF and LV) are provided to experts, which can be switched arbitrarily in the decision-making process. The evaluation of the performance of expert  $ee_k$  for alternative  $ea_i$  against  $ei_j$  is expressed as  $MIXED^k = (mixed_{ij}^k)_{m \times n}$ , including IF and LV.

In order to effectively deal with the mixed matrix, this paper introduces the concept of intuitionistic uncertain linguistic variables (IULV) [66]. It consists of two parts, i.e., uncertain linguistic variables and an intuitionistic fuzzy set. The former is employed to express the decision-maker's judgment on the evaluation object, and the latter expresses the confidence

of the judgment. In this study, the mixed decision matrix is transformed into the IULV representation, showing both intuitionistic fuzzy information and linguistic variables.

Let a linguistic term set be  $S = \{s_0, s_1, \dots, s_\theta\}$ ; an uncertain linguistic variable can be represented as  $\tilde{s} = [s_x, s_y]$ , which means that the degree of satisfaction of the evaluated target is  $[s_x, s_y]$ . Let the confidence of the evaluation be expressed as an intuitionistic fuzzy number  $\langle \mu_{\tilde{s}}, \nu_{\tilde{s}} \rangle$ , then the intuitionistic uncertain linguistic variable is defined as  $(\tilde{s}, \langle \mu_{\tilde{s}}, \nu_{\tilde{s}} \rangle)$ . Next, the methods of converting IF and LV to IULV are introduced, respectively.

(i) For intuitionistic fuzzy information.

Suppose the ERC assessment from expert  $ee_k$  for alternative  $ea_i$  against indicator  $ei_j$  is  $if_{ij}^k = \langle \mu_{if_{ij}^k}, \nu_{if_{ij}^k} \rangle$ . In this paper, IF is considered as a special case of IULV, i.e., IF is a special IULV, so an IFN can be written in the form of IULV as

$$if_{ij}^k = \langle \mu_{if_{ij}^k}, \nu_{if_{ij}^k} \rangle \Rightarrow iulv_{ij}^k = ([s_\theta, s_\theta], \langle \mu_{if_{ij}^k}, \nu_{if_{ij}^k} \rangle) \quad (9)$$

The above definition means that if the evaluation information is given in the form of IF, its default linguistic variable is  $[s_\theta, s_\theta]$ , which means that the evaluation result of the target is  $[s_\theta, s_\theta]$ , and the confidence is  $\langle \mu_{if_{ij}^k}, \nu_{if_{ij}^k} \rangle$ . For instance, the linguistic term set is  $S = \{s_0 : \text{bad}, s_1 : \text{medium}, s_2 : \text{good}\}$ , and the ERC evaluation is expressed as  $if_{ij}^k = \langle 0.8, 0.1 \rangle$  in the form of IF, which means that expert  $ee_k$  judges that the emergency alternative  $ea_i$  performs well against the indicator  $ei_j$  with a degree of membership of 0.8 and a degree of non-membership of 0.1. Therefore, it is converted to IULV and expressed as  $([s_2, s_2], \langle 0.8, 0.1 \rangle)$ .

(ii) For linguistic variables.

Let the ERC assessment from expert  $ee_k$  for alternative  $ea_i$  against indicator  $ei_j$  be  $lv_{ij}^k = [(lv_{ij}^k)^-, (lv_{ij}^k)^+]$ . LV is also considered as a special case of IULV, then LV can be written in the form of IULV as

$$lv_{ij}^k = [(lv_{ij}^k)^-, (lv_{ij}^k)^+] \Rightarrow \widetilde{iulv}_{ij}^k = ([s_1, s_2], \langle 1, 0 \rangle) \quad (10)$$

The above definition means that if the evaluation information is given in the form of LV, the default confidence is  $\langle 1, 0 \rangle$ . For instance, the linguistic term set is  $S$ , and the ERC evaluation is expressed as  $[s_1, s_2]$  in the form of LV, which means that expert  $ee_k$  judges that the performance of emergency alternative  $ea_i$  against the indicator  $ei_j$  is upper-middle with absolute confidence, so it is converted to IULV and expressed as  $([s_1, s_2], \langle 1, 0 \rangle)$ .

In the mixed IF-LV environment, the first step is to complete the transformation of the decision matrix and unify the IF and LV information into the form of IULV:  $iulv_{ij}^k = ([s_1, s_2], \langle \mu_{if_{ij}^k}, \nu_{if_{ij}^k} \rangle)$ . The second step is to calculate the weight of experts based on the matrix  $(iulv_{ij}^k)_{m \times n}$  and build the following model:

$$\begin{aligned} \min \quad & \mathcal{D}_{IULV} = \frac{1}{m \times n} \sum_{k=1}^q w_{ee_k} \sum_{i=1}^m \sum_{j=1}^n (|h_{iulv_{ij}^k} - \tilde{h}_{ij}|) \\ \text{s.t.} \quad & \begin{cases} \tilde{h}_{ij} = \sum_{k=1}^q w_{ee_k} h_{iulv_{ij}^k} \\ w_{ee_k} \in [0, 1] \\ \sum_{k=1}^q w_{ee_k} = 1 \end{cases} \end{aligned} \quad (11)$$

where  $\mathcal{D}_{IULV}$  indicates the deviation,  $w_{ee_k}$  indicates the weight of expert  $ee_k$ ,  $\tilde{h}_{ij}$  indicates the group ERC assessment on  $ea_i$  under  $ei_j$ , and  $h_{iulv_{ij}^k}$  denotes the scoring function of  $iulv_{ij}^k$ , defined as  $h_{iulv_{ij}^k} = \frac{1}{2} \times (\mu_{if_{ij}^k} + 1 - \nu_{if_{ij}^k}) \times \frac{(lv_{ij}^k)^- + (lv_{ij}^k)^+}{2\vartheta}$  [66].

The third step is to aggregate the evaluation information of different experts. Based on Equations (3) and (4), the aggregation operator of IULV is obtained as

$$\begin{aligned} iulv_{ij} &= iulv_{ij}^1 \oplus iulv_{ij}^2 \oplus \cdots \oplus iulv_{ij}^q \\ &= ([\vartheta \sum_{k=1}^q ((\frac{\mathcal{S}_{ij}^k}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}} - (\frac{\mathcal{S}_{ij}^{k-1}}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}}) \prod_{t=1}^k \frac{(lv_{ij}^{\lambda_{ij}^t})^-}{\vartheta}, \vartheta \sum_{k=1}^q ((\frac{\mathcal{S}_{ij} - \mathcal{S}_{ij}^{k-1}}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}} - (\frac{\mathcal{S}_{ij} - \mathcal{S}_{ij}^k}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}}) \prod_{t=1}^k \frac{(lv_{ij}^{\phi_{ij}^t})^+}{\vartheta}], \\ &< \sum_{k=1}^q ((\frac{\mathcal{S}_{ij}^k}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}} - (\frac{\mathcal{S}_{ij}^{k-1}}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}}) \prod_{t=1}^k \mu_{if_{ij}^{\rho_{ij}^t}}, \sum_{k=1}^q ((\frac{\mathcal{S}_{ij} - \mathcal{S}_{ij}^{k-1}}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}} - (\frac{\mathcal{S}_{ij} - \mathcal{S}_{ij}^k}{\mathcal{S}_{ij}})^{\frac{1-\alpha}{\alpha}}) \prod_{t=1}^k \nu_{if_{ij}^{\psi_{ij}^t}} > \\ &= ([ (lv_{ij})^-, (lv_{ij})^+ ], < \mu_{if_{ij}}, \nu_{if_{ij}} >) \end{aligned} \quad (12)$$

where  $\mathcal{S}_{ij} = \sum_{k=1}^q w_{ee_k}$  and  $\mathcal{S}_{ij}^k = \sum_{t=1}^k w_{ee_{\sigma_{ij}^t}}$ ,  $\sigma$  is an index function, and  $\sigma_{ij}^t$  indicates the index of the  $t$ th largest importance weight of  $W_{EE}$ . Let  $\mathcal{S}_{ij}^0 = 0$ . Then  $\lambda$ ,  $\varphi$ ,  $\rho$ , and  $\psi$  are four index functions, and  $(lv_{ij}^{\lambda_{ij}^t})^-$ ,  $(lv_{ij}^{\phi_{ij}^t})^+$ ,  $\mu_{if_{ij}^{\rho_{ij}^t}}$ , and  $\nu_{if_{ij}^{\psi_{ij}^t}}$  indicate the indices of the  $t$ th largest elements of  $\{(lv_{ij}^1)^-, \dots, (lv_{ij}^q)^-\}$ ,  $\{(lv_{ij}^1)^+, \dots, (lv_{ij}^q)^+\}$ ,  $\{\mu_{if_{ij}^1}, \dots, \mu_{if_{ij}^q}\}$ , and  $\{\nu_{if_{ij}^1}, \dots, \nu_{if_{ij}^q}\}$ .  $\alpha$  means the attitude of decision-makers.

The fourth step is to determine the weight of the ERC evaluation indicators. Based on the idea of information entropy, the weight of the indicator  $ei_j$  can be obtained as

$$w_{ei_j} = \frac{1 - E^*(ei_j)}{n - \sum_{j=1}^n E^*(ei_j)} \quad (13)$$

where  $E^*(\cdot)$  is the entropy function of the intuitionistic fuzzy set or linguistic variable. When the independent variable is IF,  $E^*(\cdot)$  is the intuitionistic fuzzy entropy, which is calculated using Equation (6); when the independent variable is LV,  $E^*(\cdot)$  is the linguistic variable entropy, which is calculated using Equation (8).

The fifth step is to sort the emergency alternatives according to ERC, which is divided into the following steps: (1) based on the IULV's aggregation operator proposed in Equation (12), the performance of the alternative  $ea_i$  under different indicators is combined into  $iulv_i = iulv_{i1} \oplus iulv_{i2} \oplus \cdots \oplus iulv_{in} = ([ (lv_i)^-, (lv_i)^+ ], < \mu_{if_i}, \nu_{if_i} >)$ ; (2) the scoring function of  $iulv_i$  can be calculated as  $h_{iulv_i} = \frac{1}{2} \times (\mu_{if_i} + 1 - \nu_{if_i}) \times \frac{(lv_i)^- + (lv_i)^+}{2\vartheta}$ ; (3) the ranking of the emergency alternatives is obtained by comparing the scoring functions.

#### 4. Application of the Constructed ERC Evaluation Model in EM

In order to reflect the role of the proposed ERC evaluation model in emergency management (EM), this paper examines an emergency management problem in Shenzhen City, China, as a case to demonstrate the usage and advantages of the constructed model.

In recent years, under the background of global climate change, extreme typhoons and rainstorms, especially short-term heavy rainfall in Shenzhen City, have been increasing in frequency, and the risk of disasters is rising. It is difficult to eliminate the risk of floods by relying on traditional strategies. Under this situation, the Emergency Management Bureau (EMB) of Shenzhen City has actively changed its defense concept, made every effort to prevent and defuse major natural disaster risks, formulated a strategy for building a three-dimensional typhoon and storm prevention system, and explored new paths for flood prevention in megacities.

Shenzhen City received a typhoon forecast, and in order to effectively deal with possible flood disasters, three emergency plans were formulated, denoted as  $\mathbf{EA} = \{ea_1, ea_2, ea_3\}$ . In order to select the optimal emergency plan, each alternative was evaluated from the perspective of emergency response capacity, and the decision-making process was carried out according to the ERC evaluation model proposed in this paper.

The selection of experts and the data collection procedure were carefully designed to ensure comprehensive evaluation. Three domain experts were selected representing different perspectives of emergency management: a senior official with over 10 years of leadership experience in local emergency management ( $ee_1$ ), a technical specialist with expertise in meteorological monitoring and early warning systems ( $ee_2$ ), and a professor from a top-tier Chinese university with a research background in disaster management ( $ee_3$ ).

The data collection process followed a systematic approach that included initial briefings to familiarize experts with emergency plans and evaluation indicators, independent assessment sessions where each expert evaluated alternatives using their preferred information expression form, clarification interviews to ensure consistent understanding of criteria, and a final validation workshop for discussing significant discrepancies. Throughout this process, expert judgments remained independent to preserve diverse perspectives while ensuring they were well-informed and properly captured in the evaluation model. The weight determination method in Equations (1) and (2) further accounted for differences in expert reliability, which effectively addressed concerns about the limited number of experts.

According to the process shown in Figure 2, three domain experts were selected firstly by the EMB, denoted as  $\mathbf{EE} = \{ee_1, ee_2, ee_3\}$ , to evaluate the ERC of the alternatives. Then the ERC evaluation indicator system constructed in Section 3.1 was adopted, and 18 evaluation indicators were obtained, which are denoted  $\mathbf{EI} = \{ei_1, ei_2, \dots, ei_{18}\}$ . What follows is divided into three decision environments to demonstrate the proposed ERC evaluation model, i.e., to collect the evaluation information of experts under three information expressions.

The ERC evaluation information in the *IF* environment is shown in Table 4. First, the dispersion minimization method in Equation (1) was used to calculate the weight of each expert, which was obtained as  $W_{EE}^{if} = \{w_{ee_1} = 0.34, w_{ee_2} = 0.19, w_{ee_3} = 0.47\}$ . Then, the OWA-based soft likelihood function was employed to combine the decision matrices of experts. The results are shown in Table 5, and the indicator weights shown in Table 6 were further obtained. By fusing the indicator information, the comprehensive evaluation of the emergency alternatives was obtained, which is expressed as  $if_1 = \langle 0.37, 0.22 \rangle$ ,  $if_2 = \langle 0.57, 0.10 \rangle$ ,  $if_3 = \langle 0.28, 0.23 \rangle$ . Further, we calculated the scoring functions of each alternative and their rankings, as shown in Table 7.

Table 4. ERC evaluation information under IF, LV, and IULV environments.

| DMs                   | Emergency Alternative | IF                         |                            |                            |         |                            | LV                                                   |                                                      |                                                      |         |                                                      | IULV                                                                              |                                                                                   |                                                                                   |         |                                                                                   |
|-----------------------|-----------------------|----------------------------|----------------------------|----------------------------|---------|----------------------------|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|---------|------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|---------|-----------------------------------------------------------------------------------|
|                       |                       | $ei_1$                     | $ei_2$                     | $ei_3$                     | $\dots$ | $ei_{18}$                  | $ei_1$                                               | $ei_2$                                               | $ei_3$                                               | $\dots$ | $ei_{18}$                                            | $ei_1$                                                                            | $ei_2$                                                                            | $ei_3$                                                                            | $\dots$ | $ei_{18}$                                                                         |
| <b>ee<sub>1</sub></b> | $ea_1$                | $\langle 0.5, 0.4 \rangle$ | $\langle 0.5, 0.3 \rangle$ | $\langle 0.6, 0.3 \rangle$ | $\dots$ | $\langle 0.6, 0.4 \rangle$ | $\begin{bmatrix} s_3, s_4 \\ s_5, s_6 \end{bmatrix}$ | $\begin{bmatrix} s_4, s_4 \\ s_4, s_6 \end{bmatrix}$ | $\begin{bmatrix} s_3, s_5 \\ s_5, s_5 \end{bmatrix}$ | $\dots$ | $\begin{bmatrix} s_2, s_3 \\ s_5, s_6 \end{bmatrix}$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.5, 0.4 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.5, 0.3 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.6, 0.3 \rangle \right)$ | $\dots$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.6, 0.4 \rangle \right)$ |
|                       | $ea_2$                | $\langle 0.7, 0.2 \rangle$ | $\langle 0.9, 0.1 \rangle$ | $\langle 0.7, 0.1 \rangle$ | $\dots$ | $\langle 0.6, 0.1 \rangle$ | $\begin{bmatrix} s_5, s_6 \\ s_1, s_2 \end{bmatrix}$ | $\begin{bmatrix} s_4, s_6 \\ s_2, s_3 \end{bmatrix}$ | $\begin{bmatrix} s_5, s_5 \\ s_0, s_3 \end{bmatrix}$ | $\dots$ | $\begin{bmatrix} s_5, s_6 \\ s_1, s_3 \end{bmatrix}$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.7, 0.2 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.9, 0.1 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.7, 0.1 \rangle \right)$ | $\dots$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.6, 0.1 \rangle \right)$ |
|                       | $ea_3$                | $\langle 0.3, 0.6 \rangle$ | $\langle 0.2, 0.5 \rangle$ | $\langle 0.7, 0.3 \rangle$ | $\dots$ | $\langle 0.3, 0.4 \rangle$ | $\begin{bmatrix} s_1, s_2 \\ s_0, s_1 \end{bmatrix}$ | $\begin{bmatrix} s_2, s_3 \\ s_3, s_3 \end{bmatrix}$ | $\begin{bmatrix} s_0, s_3 \\ s_2, s_2 \end{bmatrix}$ | $\dots$ | $\begin{bmatrix} s_1, s_3 \\ s_2, s_3 \end{bmatrix}$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.3, 0.6 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.2, 0.5 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.7, 0.3 \rangle \right)$ | $\dots$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.3, 0.4 \rangle \right)$ |
| <b>ee<sub>2</sub></b> | $ea_1$                | $\langle 0.7, 0.3 \rangle$ | $\langle 0.8, 0.1 \rangle$ | $\langle 0.5, 0.3 \rangle$ | $\dots$ | $\langle 0.5, 0.5 \rangle$ | $\begin{bmatrix} s_2, s_4 \\ s_4, s_5 \end{bmatrix}$ | $\begin{bmatrix} s_3, s_3 \\ s_3, s_6 \end{bmatrix}$ | $\begin{bmatrix} s_3, s_4 \\ s_4, s_6 \end{bmatrix}$ | $\dots$ | $\begin{bmatrix} s_4, s_4 \\ s_5, s_6 \end{bmatrix}$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.7, 0.3 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.8, 0.1 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.5, 0.3 \rangle \right)$ | $\dots$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.5, 0.5 \rangle \right)$ |
|                       | $ea_2$                | $\langle 0.8, 0.1 \rangle$ | $\langle 0.7, 0.3 \rangle$ | $\langle 0.6, 0.3 \rangle$ | $\dots$ | $\langle 0.7, 0.2 \rangle$ | $\begin{bmatrix} s_4, s_5 \\ s_0, s_1 \end{bmatrix}$ | $\begin{bmatrix} s_3, s_6 \\ s_3, s_3 \end{bmatrix}$ | $\begin{bmatrix} s_4, s_6 \\ s_2, s_2 \end{bmatrix}$ | $\dots$ | $\begin{bmatrix} s_5, s_6 \\ s_2, s_3 \end{bmatrix}$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.8, 0.1 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.7, 0.3 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.6, 0.3 \rangle \right)$ | $\dots$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.7, 0.2 \rangle \right)$ |
|                       | $ea_3$                | $\langle 0.4, 0.3 \rangle$ | $\langle 0.5, 0.5 \rangle$ | $\langle 0.6, 0.4 \rangle$ | $\dots$ | $\langle 0.3, 0.4 \rangle$ | $\begin{bmatrix} s_0, s_1 \\ s_3, s_3 \end{bmatrix}$ | $\begin{bmatrix} s_3, s_3 \\ s_2, s_2 \end{bmatrix}$ | $\begin{bmatrix} s_2, s_2 \\ s_2, s_2 \end{bmatrix}$ | $\dots$ | $\begin{bmatrix} s_2, s_3 \\ s_2, s_3 \end{bmatrix}$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.4, 0.3 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.5, 0.5 \rangle \right)$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.6, 0.4 \rangle \right)$ | $\dots$ | $\left( \begin{bmatrix} s_6, s_6 \end{bmatrix}, \langle 0.3, 0.4 \rangle \right)$ |
| <b>ee<sub>3</sub></b> | $ea_1$                | $\langle 0.6, 0.2 \rangle$ | $\langle 0.5, 0.4 \rangle$ | $\langle 0.6, 0.3 \rangle$ | $\dots$ | $\langle 0.4, 0.6 \rangle$ | $\begin{bmatrix} s_3, s_3 \\ s_4, s_5 \end{bmatrix}$ | $\begin{bmatrix} s_2, s_4 \\ s_3, s_5 \end{bmatrix}$ | $\begin{bmatrix} s_3, s_4 \\ s_4, s_4 \end{bmatrix}$ | $\dots$ | $\begin{bmatrix} s_3, s_4 \\ s_4, s_5 \end{bmatrix}$ | $\left( \begin{bmatrix} s_3, s_3 \end{bmatrix}, \langle 1, 0 \rangle \right)$     | $\left( \begin{bmatrix} s_2, s_4 \end{bmatrix}, \langle 1, 0 \rangle \right)$     | $\left( \begin{bmatrix} s_3, s_4 \end{bmatrix}, \langle 1, 0 \rangle \right)$     | $\dots$ | $\left( \begin{bmatrix} s_3, s_4 \end{bmatrix}, \langle 1, 0 \rangle \right)$     |
|                       | $ea_2$                | $\langle 0.3, 0.2 \rangle$ | $\langle 0.7, 0.2 \rangle$ | $\langle 0.8, 0.1 \rangle$ | $\dots$ | $\langle 0.8, 0.2 \rangle$ | $\begin{bmatrix} s_4, s_5 \\ s_3, s_3 \end{bmatrix}$ | $\begin{bmatrix} s_3, s_5 \\ s_2, s_3 \end{bmatrix}$ | $\begin{bmatrix} s_4, s_4 \\ s_1, s_2 \end{bmatrix}$ | $\dots$ | $\begin{bmatrix} s_4, s_5 \\ s_0, s_1 \end{bmatrix}$ | $\left( \begin{bmatrix} s_4, s_5 \end{bmatrix}, \langle 1, 0 \rangle \right)$     | $\left( \begin{bmatrix} s_3, s_5 \end{bmatrix}, \langle 1, 0 \rangle \right)$     | $\left( \begin{bmatrix} s_4, s_4 \end{bmatrix}, \langle 1, 0 \rangle \right)$     | $\dots$ | $\left( \begin{bmatrix} s_4, s_5 \end{bmatrix}, \langle 1, 0 \rangle \right)$     |
|                       | $ea_3$                | $\langle 0.6, 0.3 \rangle$ | $\langle 0.5, 0.5 \rangle$ | $\langle 0.5, 0.4 \rangle$ | $\dots$ | $\langle 0.3, 0.5 \rangle$ | $\begin{bmatrix} s_3, s_3 \\ s_3, s_3 \end{bmatrix}$ | $\begin{bmatrix} s_2, s_3 \\ s_2, s_3 \end{bmatrix}$ | $\begin{bmatrix} s_1, s_2 \\ s_1, s_2 \end{bmatrix}$ | $\dots$ | $\begin{bmatrix} s_0, s_1 \\ s_0, s_1 \end{bmatrix}$ | $\left( \begin{bmatrix} s_4, s_4 \end{bmatrix}, \langle 1, 0 \rangle \right)$     | $\left( \begin{bmatrix} s_2, s_3 \end{bmatrix}, \langle 1, 0 \rangle \right)$     | $\left( \begin{bmatrix} s_1, s_2 \end{bmatrix}, \langle 1, 0 \rangle \right)$     | $\dots$ | $\left( \begin{bmatrix} s_0, s_1 \end{bmatrix}, \langle 1, 0 \rangle \right)$     |

Table 5. The aggregated ERC evaluation information.

| Environment          | Emergency Alternative | Indicators                                                                                    |                                                                                               |                                                                                               |                                                                                               |                                                                                               |
|----------------------|-----------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
|                      |                       | $ei_1$                                                                                        | $ei_2$                                                                                        | $ei_3$                                                                                        | $ei_4$                                                                                        | $ei_{18}$                                                                                     |
| <i>IF</i>            | $ea_1$                | $\langle 0.42, 0.17 \rangle$                                                                  | $\langle 0.44, 0.16 \rangle$                                                                  | $\langle 0.36, 0.13 \rangle$                                                                  | $\langle 0.29, 0.26 \rangle$                                                                  | $\langle 0.32, 0.32 \rangle$                                                                  |
|                      | $ea_2$                | $\langle 0.46, 0.08 \rangle$                                                                  | $\langle 0.63, 0.12 \rangle$                                                                  | $\langle 0.54, 0.11 \rangle$                                                                  | $\langle 0.54, 0.11 \rangle$                                                                  | $\langle 0.54, 0.08 \rangle$                                                                  |
|                      | $ea_3$                | $\langle 0.28, 0.26 \rangle$                                                                  | $\langle 0.24, 0.28 \rangle$                                                                  | $\langle 0.42, 0.19 \rangle$                                                                  | $\langle 0.26, 0.24 \rangle$                                                                  | $\langle 0.13, 0.25 \rangle$                                                                  |
| <i>LV</i>            | $ea_1$                | $\begin{bmatrix} s_{1.34}, s_{2.26} \end{bmatrix}$                                            | $\begin{bmatrix} s_{1.79}, s_{2.26} \end{bmatrix}$                                            | $\begin{bmatrix} s_{1.49}, s_{3.16} \end{bmatrix}$                                            | $\begin{bmatrix} s_{1.79}, s_{2.26} \end{bmatrix}$                                            | $\begin{bmatrix} s_{1.79}, s_{2.00} \end{bmatrix}$                                            |
|                      | $ea_2$                | $\begin{bmatrix} s_{3.16}, s_{4.79} \end{bmatrix}$                                            | $\begin{bmatrix} s_{1.99}, s_{5.41} \end{bmatrix}$                                            | $\begin{bmatrix} s_{1.49}, s_{4.30} \end{bmatrix}$                                            | $\begin{bmatrix} s_{3.16}, s_{4.82} \end{bmatrix}$                                            | $\begin{bmatrix} s_{3.58}, s_{5.41} \end{bmatrix}$                                            |
|                      | $ea_3$                | $\begin{bmatrix} s_{0.93}, s_{1.08} \end{bmatrix}$                                            | $\begin{bmatrix} s_{1.18}, s_{1.49} \end{bmatrix}$                                            | $\begin{bmatrix} s_{0.62}, s_{1.18} \end{bmatrix}$                                            | $\begin{bmatrix} s_{1.08}, s_{1.34} \end{bmatrix}$                                            | $\begin{bmatrix} s_{0.62}, s_{1.19} \end{bmatrix}$                                            |
| <i>Mixed IF – LV</i> | $ea_1$                | $\left( \begin{bmatrix} s_{4.56}, s_{4.56} \end{bmatrix}, \langle 0.61, 0.14 \rangle \right)$ | $\left( \begin{bmatrix} s_{4.08}, s_{5.04} \end{bmatrix}, \langle 0.66, 0.09 \rangle \right)$ | $\left( \begin{bmatrix} s_{4.56}, s_{5.04} \end{bmatrix}, \langle 0.57, 0.10 \rangle \right)$ | $\left( \begin{bmatrix} s_{4.56}, s_{4.56} \end{bmatrix}, \langle 0.54, 0.10 \rangle \right)$ | $\left( \begin{bmatrix} s_{4.56}, s_{5.04} \end{bmatrix}, \langle 0.57, 0.19 \rangle \right)$ |
|                      | $ea_2$                | $\left( \begin{bmatrix} s_{5.04}, s_{5.52} \end{bmatrix}, \langle 0.74, 0.06 \rangle \right)$ | $\left( \begin{bmatrix} s_{4.56}, s_{5.52} \end{bmatrix}, \langle 0.79, 0.09 \rangle \right)$ | $\left( \begin{bmatrix} s_{5.04}, s_{5.04} \end{bmatrix}, \langle 0.65, 0.09 \rangle \right)$ | $\left( \begin{bmatrix} s_{5.52}, s_6 \end{bmatrix}, \langle 0.74, 0.03 \rangle \right)$      | $\left( \begin{bmatrix} s_{5.04}, s_{5.52} \end{bmatrix}, \langle 0.65, 0.06 \rangle \right)$ |
|                      | $ea_3$                | $\left( \begin{bmatrix} s_{4.56}, s_{4.56} \end{bmatrix}, \langle 0.43, 0.21 \rangle \right)$ | $\left( \begin{bmatrix} s_{4.08}, s_{4.56} \end{bmatrix}, \langle 0.45, 0.20 \rangle \right)$ | $\left( \begin{bmatrix} s_{3.6}, s_{4.08} \end{bmatrix}, \langle 0.65, 0.14 \rangle \right)$  | $\left( \begin{bmatrix} s_{4.08}, s_{4.08} \end{bmatrix}, \langle 0.52, 0.14 \rangle \right)$ | $\left( \begin{bmatrix} s_{3.12}, s_{3.6} \end{bmatrix}, \langle 0.40, 0.15 \rangle \right)$  |

For the *LV* environment, the evaluation process is the same as that of the *IF* environment except that the relevant calculation is switched to the method corresponding to the *LV*. Using Equation (2) to calculate the weight of experts is as follows:  $W_{EE}^{lv} = \{w_{ee_1} = 0.29, w_{ee_2} = 0.12, w_{ee_3} = 0.59\}$ . The expert fusion results are shown in Table 5, the indicator weights are shown in Table 6, the indicator fusion results are  $lv_1 = [s_{1.69}, s_{2.53}]$ ,  $lv_2 = [s_{3.36}, s_5]$ ,  $lv_3 = [s_{1.48}, s_5]$ , and the final ranking is shown in Table 7.

In addition, in order to demonstrate the ERC evaluation process in the mixed *IF* – *LV* environment, this study selected the *IF* evaluation information of experts  $ee_1$  and  $ee_2$  and the *LV* evaluation information of expert  $ee_3$  to form the mixed evaluation information and used the method proposed in Section 3.6 to convert the mixed information into *IULV* representations, as shown in Table 4. Based on Equation (11), the expert weight was obtained as  $W_{EE}^{iulv} = \{w_{ee_1} = 0.29, w_{ee_2} = 0.23, w_{ee_3} = 0.48\}$ , and the aggregated matrix was further obtained as shown in Table 5. The indicator weights are shown in Table 6, and the indicator fusion results are  $iulv_1 = ([s_{4.53}, s_5], < 0.57, 0.15 >)$ ,  $iulv_2 = ([s_{5.28}, s_{5.71}], < 0.71, 0.07 >)$ ,  $iulv_3 = ([s_4, s_{4.39}], < 0.50, 0.16 >)$ . The final ranking is shown in Table 7.

**Table 6.** The weight of indicators in three decision environments.

|                      | $w_{ei_1}$ | $w_{ei_2}$ | $w_{ei_3}$ | $w_{ei_4}$ | $w_{ei_5}$ | $w_{ei_6}$ | $w_{ei_7}$ | ... | $w_{ei_{18}}$ |
|----------------------|------------|------------|------------|------------|------------|------------|------------|-----|---------------|
| <i>IF</i>            | 0.0524     | 0.0683     | 0.0729     | 0.0389     | 0.0430     | 0.0835     | 0.0793     | ... | 0.0451        |
| <i>LV</i>            | 0.0586     | 0.0583     | 0.0593     | 0.0527     | 0.0483     | 0.0492     | 0.0600     | ... | 0.0641        |
| <i>Mixed IF – LV</i> | 0.0544     | 0.0552     | 0.0537     | 0.0563     | 0.0596     | 0.0548     | 0.0636     | ... | 0.0471        |

**Table 7.** ERC evaluation table for emergency management.

| Decision Environment | Emergency Alternative |        |        | Ranking                      |
|----------------------|-----------------------|--------|--------|------------------------------|
|                      | $ei_1$                | $ei_2$ | $ei_3$ |                              |
| <i>IF</i>            | 0.2858                | 0.5467 | 0.1699 | $ea_2 \succ ea_1 \succ ea_3$ |
| <i>LV</i>            | 0.3523                | 0.6969 | 0.2067 | $ea_2 \succ ea_1 \succ ea_3$ |
| <i>Mixed IF – LV</i> | 0.5609                | 0.7517 | 0.4649 | $ea_2 \succ ea_1 \succ ea_3$ |

## 5. Results and Analysis

The conclusion can be drawn from Table 7. The same conclusion is obtained in the three decision-making environments, that is, the order of emergency alternatives from the perspective of ERC is  $ea_2 \succ ea_1 \succ ea_3$ . It can also be seen from the obtained results that in the three decision-making environments, the three emergency alternatives are also relatively distinct in terms of score values, which is important for decisive ranking. In order to verify the accuracy of the results obtained by the ERC evaluation model, this study continued to track the emergency management problems in the case analysis and found that the second emergency alternative was finally used in the rainstorm disaster in Shenzhen City, which can explain the accuracy of the results obtained in this study.

In order to realize the aggregation of evaluation information, this study proposes the OWA-based soft likelihood function aggregation methods (Equations (3), (4) and (12)). In the two-step information fusion (expert matrix fusion and indicator fusion), a parameter  $\alpha$  is involved, which represents the attitude of DMs. The larger the value of  $\alpha$ , the more optimistic the attitude of DMs, and vice versa. It refers to the fact that the value of  $\alpha$  is set to 0.5 in the case study of this paper, indicating an emotionally neutral attitude of DMs. In order to study the influence of  $\alpha$  on the evaluation results, a sensitivity analysis of  $\alpha$  is carried out below, and the results are shown in Figures 3–5.

The effect of parameter  $\alpha$  on the final score of emergency alternatives during the expert evaluation information fusion process is shown in Figure 3, and the  $\alpha$  value in the indicator fusion stage is set to 0.5. As can be seen from the figure, as  $\alpha$  increases, the DMs become

more optimistic, and the overall score of emergency alternatives is on the rise, but under different  $\alpha$  values, the order of  $ei_2 > ei_1 > ei_3$  is still maintained. In Figure 4, the parameter of the first-stage fusion is kept at 0.5, and the  $\alpha$  in the second-stage fusion is changed. It is observed that the larger the  $\alpha$ , the higher the score, and there is still a trend of  $ei_2 > ei_1 > ei_3$ . In Figure 5, the values of  $\alpha$  for two fusion stages are changed simultaneously, where the first stage is denoted as  $a_I$  and the second stage is denoted as  $a_{II}$ , and the results shown in the figure are consistent with the above analysis. It can be concluded from the three sets of sensitivity analysis that the value of  $\alpha$  is proportional to the final scoring function and hardly affects the ranking results, but in the application of rank evaluation, the attitude characteristics of DMs will have an impact on the evaluation results; this research will be carried out in depth in the future.

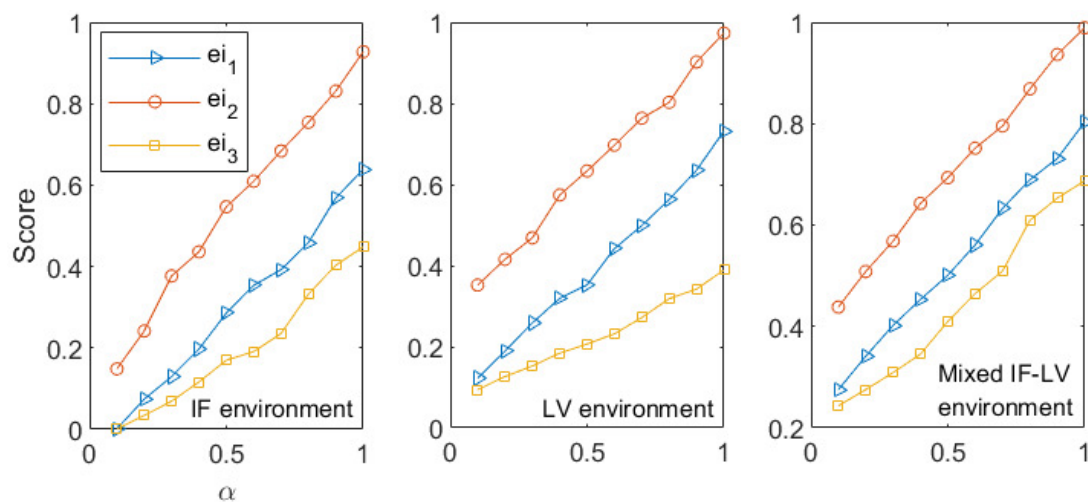


Figure 3. Sensitivity analysis of parameter  $\alpha$  in expert evaluation matrix fusion.

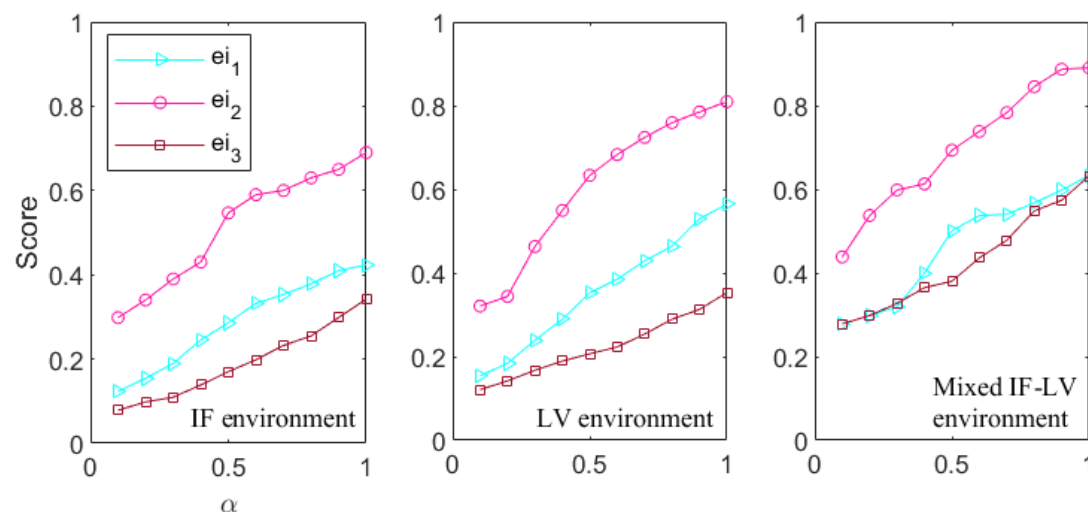


Figure 4. Sensitivity analysis of parameter  $\alpha$  in indicator fusion.

In order to further highlight the advantages of the method presented in this paper, a comparative analysis is carried out from two perspectives, qualitative and quantitative. In terms of qualitative analysis, a variety of ERC evaluation methods based on MADM are selected for comparison, mainly from seven aspects, namely, information expression, aggregation method, indicator system, expert participation, uncertainty, fuzziness, and alternative decision-making environment. Table 8 shows the results of the qualitative comparison. From a horizontal perspective, only the method proposed in this paper

satisfies all the criteria. From a vertical perspective, our method includes several decision-making environments such as intuitionistic fuzzy set, linguistic variables, and mixed mode, which means it handles the uncertainty and fuzziness in ERC evaluation more effectively. In addition, it is worth noting that our method constructs a comprehensive indicator system and explores the key points of ERC evaluation from a new perspective. Finally, the cases in this paper are taken from real-world problems, and relevant experts were invited to participate, which ultimately verifies the consistency of the evaluation results based on our method with the real situation. Through this comparison, it can be concluded that the method proposed in this paper is relatively superior overall.

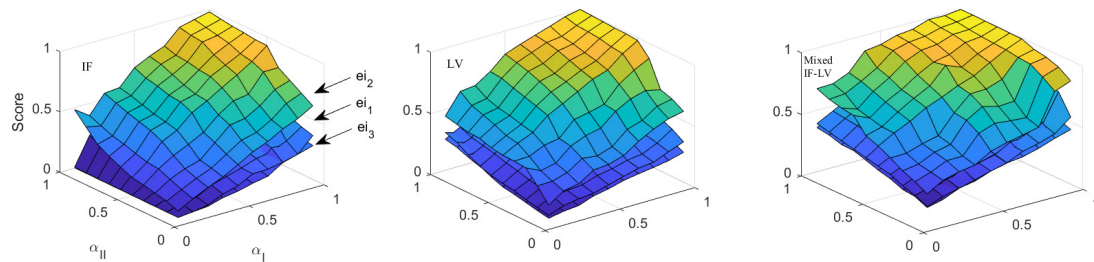


Figure 5. Sensitivity analysis of parameter  $\alpha$  in two fusion steps.

Table 8. Qualitative comparison of ERC assessment approaches.

| Method     | <sup>†</sup> Information Expression | Aggregation Method                                       | Indicator System? | Are There Experts Involved? | Dealing with Uncertainty? | Consider Fuzziness? | Are There Alternative Decision Environments? |
|------------|-------------------------------------|----------------------------------------------------------|-------------------|-----------------------------|---------------------------|---------------------|----------------------------------------------|
| [56]       | I2LI                                | Interval 2-tuple interval weighted aggregation operators | ×                 | ×                           | ✓                         | ✓                   | ×                                            |
| [42]       | 2FLA                                | 2-tuple linguistic weighted average operator             | ✓                 | ✓                           | ✓                         | ✓                   | ×                                            |
| [53]       | CN                                  | AHP                                                      | ✓                 | ×                           | ×                         | ✓                   | ×                                            |
| [58]       | CN                                  | PROMETHEE method                                         | ✓                 | ×                           | ×                         | ×                   | ×                                            |
| [57]       | CN                                  | TOPSIS method                                            | ×                 | ×                           | ×                         | ×                   | ×                                            |
| [67]       | HFLS                                | TOPSIS-EW                                                | ×                 | ×                           | ✓                         | ✓                   | ×                                            |
| [68]       | CD                                  | Cloud generalized information aggregation operators      | ✓                 | ×                           | ✓                         | ✓                   | ×                                            |
| Our method | IFS&LV                              | OWA-based soft likelihood functions                      | ✓                 | ✓                           | ✓                         | ✓                   | ✓                                            |

<sup>†</sup> I2LI: interval 2-tuple linguistic information, 2FLA: 2-tuple fuzzy linguistic approach, HFLS: hesitant fuzzy linguistic set, CN: clear number, CD: cloud drop, IFS: intuitionistic fuzzy set, LV: linguistic variables.

In the quantitative comparison, the important difference between the comparison methods and our method lies in different information expression. In order to enable different methods to use the data in this paper, an adaptation description of information type is carried out first. From our data to the two-tuple fuzzy linguistic approach, the data in Table 4 are clarified based on the scoring function of the linguistic variable and then converted into the two-tuple fuzzy linguistic approach using the conversion method in the literature [42]. Two-tuple fuzzy linguistic information is a special case of interval two-tuple linguistic information, and the above method can be used. The data in Table 4 can be directly converted into hesitant fuzzy linguistic sets, for example,  $[s_3, s_5] \Rightarrow \{s_3, s_4, s_5\}$ . For clear numbers, the scoring function can be used directly for conversion. The results of the quantitative comparison are shown in Table 9. The key technologies used by each comparison method and the evaluation results are presented. It can be seen that the ranking of the three alternative emergency plans is consistent across all methods, which demonstrates the effectiveness of the method proposed in this paper.

**Table 9.** Quantitative comparison of ERC assessment approaches.

| Literature | Key Technologies                                                                                                                  | Decision Result              |
|------------|-----------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| [56]       | A multi-criteria comprehensive evaluation approach is proposed for assessing ERC with interval 2-tuple linguistic information     | $ea_2 \succ ea_1 \succ ea_3$ |
| [42]       | ERC is evaluated by fuzzy AHP and 2-tuple fuzzy linguistic approach                                                               | $ea_2 \succ ea_1 \succ ea_3$ |
| [53]       | The fuzzy comprehensive evaluation method is chosen to evaluate emergency rescue capability                                       | $ea_2 \succ ea_1 \succ ea_3$ |
| [58]       | A multi-criteria decision-making approach is proposed to evaluate ERC by taking into account the interactions synergy             | $ea_2 \succ ea_1 \succ ea_3$ |
| [57]       | A questionnaire-TOPSIS innovative algorithm is proposed to evaluate college students' ERC                                         | $ea_2 \succ ea_1 \succ ea_3$ |
| [67]       | A fuzzy TOPSIS-EW method with multi-granularity linguistic information is proposed for evaluating emergency logistics performance | $ea_2 \succ ea_1 \succ ea_3$ |
| Our method | An integrated decision-making model for the assessment of ERC is proposed                                                         | $ea_2 \succ ea_1 \succ ea_3$ |

## 6. Conclusions

The purpose of this paper is to study the evaluation method of emergency response capacity, and to this end, an integrated decision-making model is proposed. The specific contributions are as follows:

(1) From the perspective of the disaster management cycle, an indicator system for evaluating emergency response capacity is constructed. Compared with previous studies, the indicator system is more complete and comprehensive.

(2) Considering three decision-making environments, namely, *IF*, *LV*, and mixed *IF* – *LV*, a comprehensive decision-making model for ERC evaluation is constructed. This model allows decision-makers to choose appropriate information expression methods according to personal preferences and usage habits, making the evaluation process more efficient and flexible.

(3) In the decision model, the expression and calculation of the mixed evaluation information is completed, including the unified conversion of *IF* and *LV* information into the *IULV* form, and the aggregation operators of the OWA-based soft likelihood function are proposed.

(4) An emergency plan selection case is extracted from the emergency management project of Shenzhen City, China, and the constructed ERC evaluation model is verified. Through the analysis of the evaluation results and related comparisons, it is demonstrated that the methods in this paper can comprehensively and accurately evaluate the emergency management problems from the perspective of ERC.

The evaluation indicator system constructed in this study provides an effective basis for the evaluation of emergency response capacity. The three decision-making environments considered in this paper are in line with human thinking habits and provide a flexible way for decision-makers to make assessments. The ERC evaluation process proposed in this study provides a scientific decision-making reference for multi-expert and multi-attribute emergency plan selection.

The limitations of this study and plans for future improvements are described below:

(1) Information loss in representation conversion: In the process of converting *IF* and *LV* evaluation information into *IULV* representation, there is an inevitable loss of information fidelity. The current conversion mechanisms prioritize computational efficiency but may sacrifice some nuance in expert evaluations. Future research should focus on developing more sophisticated transformation algorithms that can better preserve the original assessment intentions while maintaining computational feasibility.

(2) Indicator system refinement needs: While our ERC evaluation indicator system is constructed based on extensive literature review and expert consultation, it still requires further validation across diverse emergency scenarios. The weighting and importance of different indicators may vary significantly depending on the type of emergency

(natural disaster vs. public health crisis vs. technological accident), geographic context, and social–economic conditions. Future work should involve more domain experts from various emergency management fields to further subdivide, validate, and contextualize the indicator system.

(3) Limited empirical validation: Although we validated our model with a case study from Shenzhen City, the generalizability of our findings to other urban contexts, particularly to rural areas or regions with different emergency management infrastructures, remains to be established. The decision-making model would benefit from broader empirical testing across diverse emergency scenarios and geographical contexts to refine its parameters and enhance its robustness.

(4) Computational complexity considerations: The integrated decision-making approach, particularly in the mixed IF-LV environment, introduces significant computational complexity that may limit real-time application during actual emergencies. Future research should explore algorithmic optimizations and simplified versions of the model that could be deployed in time-sensitive emergency situations without substantial loss of evaluation accuracy.

**Author Contributions:** Methodology, software, visualization, writing—original draft, G.C.; writing—original draft, T.L.; conceptualization, supervision, funding acquisition, writing—review and editing, L.F. All authors have read and agreed to the published version of the manuscript.

**Funding:** The work is partially supported by the National Natural Science Foundation of China (Grant No. 72404172), the Humanities and Social Science Fund of the Ministry of Education of China (Grant No. 24YJC630042), the Natural Science Foundation of Shandong Province of China (Grant No. ZR2023QG099), and the National Key Research and Development Program of China (Grant No. 2024YFE0106600).

**Data Availability Statement:** The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

**Acknowledgments:** The authors would like to express gratitude to the journal *Mathematics* for its support and consideration.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Ayyildiz, E.; Taskin, A. A novel spherical fuzzy AHP-VIKOR methodology to determine serving petrol station selection during COVID-19 lockdown: A pilot study for Istanbul. *Socio-Econ. Plan. Sci.* **2022**, *83*, 101345. [[CrossRef](#)] [[PubMed](#)]
2. Fei, L.; Li, T.; Ding, W. Dempster–Shafer theory-based information fusion for natural disaster emergency management: A systematic literature review. *Inf. Fusion* **2024**, *112*, 102585. [[CrossRef](#)]
3. Sun, Y.; Mi, J.; Chen, J.; Liu, W. A new fuzzy multi-attribute group decision-making method with generalized maximal consistent block and its application in emergency management. *Knowl.-Based Syst.* **2021**, *215*, 106594. [[CrossRef](#)]
4. Li, T.; Sun, J.; Fei, L. Dempster–Shafer theory in emergency management: A review. *Nat. Hazards* **2025**, *121*, 6413–6440. [[CrossRef](#)]
5. Selerio, E., Jr.; Caladcad, J.A.; Catamco, M.R.; Capinpin, E.M.; Ocampo, L. Emergency preparedness during the COVID-19 pandemic: Modelling the roles of social media with fuzzy DEMATEL and analytic network process. *Socio-Econ. Plan. Sci.* **2021**, *82*, 101217. [[CrossRef](#)]
6. Fei, L.; Li, T. Investigating determinants of public participation in community emergency preparedness in China using DEMATEL methodology. *Int. J. Disaster Risk Reduct.* **2024**, *112*, 104803. [[CrossRef](#)]
7. Fei, L.; Feng, Y.; Wang, H. Modeling heterogeneous multi-attribute emergency decision-making with Dempster–Shafer theory. *Comput. Ind. Eng.* **2021**, *161*, 107633. [[CrossRef](#)]
8. Li, T.; Sun, J.; Fei, L. Application of Multiple-Criteria Decision-Making Technology in Emergency Decision-Making: Uncertainty, Heterogeneity, Dynamicity, and Interaction. *Mathematics* **2025**, *13*, 731. [[CrossRef](#)]
9. Ding, Q.; Goh, M.; Wang, Y.M. Interval-valued hesitant fuzzy TODIM method for dynamic emergency responses. *Soft Comput.* **2021**, *25*, 8263–8279. [[CrossRef](#)]

10. Ding, Q.; Wang, Y.M.; Goh, M. An extended TODIM approach for group emergency decision making based on bidirectional projection with hesitant triangular fuzzy sets. *Comput. Ind. Eng.* **2021**, *151*, 106959. [\[CrossRef\]](#)
11. Fei, L.; Li, T.; Liu, X.; Ding, W. A novel multi-source information fusion method for emergency spatial resilience assessment based on Dempster-Shafer theory. *Inf. Sci.* **2025**, *686*, 121373. [\[CrossRef\]](#)
12. Chen, Y.; Liu, H.; Ma, L. Can the experience in COVID-19 prevention and control improve the emergency response capacity of local civil servants in China? In *Public Management Review*; Taylor & Francis: Abingdon, UK, 2024; pp. 1–19.
13. Jiang, P.; Rowsell, J.; Schmidt, S. Crisis-ready telecom: Global approaches to emergency management in telecommunications. *Telecommun. Policy* **2025**, *49*, 102914. [\[CrossRef\]](#)
14. Xiao, Z.; Xie, M.; Wang, X.; Wang, H.; Fang, S.; Arnáez, R. Risk assessment of emergency operations of floating storage and regasification unit. *J. Mar. Eng. Technol.* **2024**, *23*, 357–372. [\[CrossRef\]](#)
15. Islam, M.Z.; Wang, C. Cost of high-level flooding as a consequence of climate change driver?: A case study of China's flood-prone regions. *Ecol. Indic.* **2024**, *160*, 111944. [\[CrossRef\]](#)
16. Schwindt, E.M.; Stockenhuber, R.; Schwindt, J.C. Ventilation practices and preparedness of healthcare providers in term newborn resuscitation: A comprehensive survey study in Austrian hospitals. *Resusc. Plus* **2024**, *20*, 100817. [\[CrossRef\]](#)
17. Ansari, A.J.; Vaidya, P.; Malik, B.A.; Ali, P.N. Preparing for the unthinkable: A systematic look at disaster preparedness in libraries. *Int. J. Disaster Risk Reduct.* **2024**, *108*, 104551. [\[CrossRef\]](#)
18. Greenberg, M.I.; Jurgens, S.M.; Gracely, E.J. Emergency department preparedness for the evaluation and treatment of victims of biological or chemical terrorist attack. *J. Emerg. Med.* **2002**, *22*, 273–278. [\[CrossRef\]](#)
19. Hajek, P.; Sahut, J.M.; Olej, V. Credit rating prediction using a fuzzy MCDM approach with criteria interactions and TOPSIS sorting. In *Annals of Operations Research*; Springer: Berlin/Heidelberg, Germany, 2024; pp. 1–29.
20. Barnett, D.J.; Everly, G.S., Jr.; Parker, C.L.; Links, J.M. Applying educational gaming to public health workforce emergency preparedness. *Am. J. Prev. Med.* **2005**, *28*, 390–395. [\[CrossRef\]](#)
21. Saqib, M.; Ashraf, S.; Farid, H.M.A.; Simic, V.; Kousar, M.; Tirkolaee, E.B. Benchmarking of industrial wastewater treatment processes using a complex probabilistic hesitant fuzzy soft Schweizer-Sklar prioritized-based framework. *Appl. Soft Comput.* **2024**, *162*, 111780. [\[CrossRef\]](#)
22. Henstra, D. Evaluating local government emergency management programs: What framework should public managers adopt? *Public Adm. Rev.* **2010**, *70*, 236–246. [\[CrossRef\]](#)
23. Jackson, B.A.; Sullivan Faith, K.; Willis, H.H. Are we prepared? Using reliability analysis to evaluate emergency response systems. *J. Contingencies Crisis Manag.* **2011**, *19*, 147–157. [\[CrossRef\]](#)
24. Gacitua, R.; Klafft, M.; Harari, I.; Duarte, S.B.; Dudzinska-Jarmolinska, A. Structured insights: Enhancing disaster preparedness through survivor testimonies and interoperable data systems. *Int. J. Disaster Risk Reduct.* **2025**, *116*, 105115. [\[CrossRef\]](#)
25. Duan, W.; He, B. Emergency response system for pollution accidents in chemical industrial parks, China. *Int. J. Environ. Res. Public Health* **2015**, *12*, 7868–7885. [\[CrossRef\]](#) [\[PubMed\]](#)
26. Tannenbaum-Baruchi, C.; Ashkenazi, I.; Rapaport, C. Risk inclusion of vulnerable people during a climate-related disaster: A case study of people with hearing loss facing wildfires. *Int. J. Disaster Risk Reduct.* **2024**, *103*, 104335. [\[CrossRef\]](#)
27. Stallings, R.A.; Quarantelli, E.L. Emergent citizen groups and emergency management. *Public Adm. Rev.* **1985**, *45*, 93–100. [\[CrossRef\]](#)
28. Chen, H.; Guo, Y.; Lin, X.; Qi, X. Dynamic changes and improvement paths of China's emergency logistics response capabilities under public emergencies—Research based on the entropy weight TOPSIS method. *Front. Public Health* **2024**, *12*, 1397747. [\[CrossRef\]](#)
29. Khan, H.; Vasilescu, L.G.; Khan, A. Disaster management cycle—a theoretical approach. *J. Manag. Mark.* **2008**, *6*, 43–50.
30. Perry, R.W.; Lindell, M.K. Preparedness for emergency response: Guidelines for the emergency planning process. *Disasters* **2003**, *27*, 336–350. [\[CrossRef\]](#)
31. Baker, R.; DeFrancesco, J.; PMP, R.D. Decoding Training Needs: Developing a Needs Assessment Tool to Inform Workforce Capacity Building in Retail Food Safety. *J. Environ. Health* **2024**, *6*, 34–38.
32. Kyrkou, C.; Kolios, P.; Theocharides, T.; Polycarpou, M. Machine Learning for Emergency Management: A Survey and Future Outlook. *Proc. IEEE* **2023**, *111*, 19–41. [\[CrossRef\]](#)
33. Bekirsky, N.; Hoicka, C.E.; Brisbois, M.C.; Camargo, L.R. Many actors amongst multiple renewables: A systematic review of actor involvement in complementarity of renewable energy sources. *Renew. Sustain. Energy Rev.* **2022**, *161*, 112368. [\[CrossRef\]](#)
34. Tao, J.; Liu, Z.; Wang, X.; Cao, Y.; Zhang, M.; Loughney, S.; Wang, J.; Yang, Z. Hazard identification and risk analysis of maritime autonomous surface ships: A systematic review and future directions. *Ocean Eng.* **2024**, *307*, 118174. [\[CrossRef\]](#)
35. Raikes, J.; Smith, T.F.; Jacobson, C.; Baldwin, C. Pre-disaster planning and preparedness for floods and droughts: A systematic review. *Int. J. Disaster Risk Reduct.* **2019**, *38*, 101207. [\[CrossRef\]](#)
36. Ma, G.; Tan, S.; Shang, S. The evaluation of building fire emergency response capability based on the CMM. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1962. [\[CrossRef\]](#)

37. Esteban, M.; Bricker, J.; Arce, R.S.C.; Takagi, H.; Yun, N.; Chaiyapa, W.; Sjoegren, A.; Shibayama, T. Tsunami awareness: A comparative assessment between Japan and the USA. *Nat. Hazards* **2018**, *93*, 1507–1528. [\[CrossRef\]](#)
38. Feng, J.R.; Gai, W.m.; Yan, Y.b. Emergency evacuation risk assessment and mitigation strategy for a toxic gas leak in an underground space: The case of a subway station in Guangzhou, China. *Saf. Sci.* **2021**, *134*, 105039. [\[CrossRef\]](#)
39. Li, T.; Fei, L. Exploring obstacles to the use of unmanned aerial vehicles in emergency rescue: A BWM-DEMATEL approach. *Technol. Soc.* **2025**, *81*, 102863. [\[CrossRef\]](#)
40. Hämäläinen, R.P.; Lindstedt, M.R.; Sinkko, K. Multiattribute risk analysis in nuclear emergency management. *Risk Anal.* **2000**, *20*, 455–468. [\[CrossRef\]](#)
41. Zhang, J.s.; He, P.p.; Gao, S.s.; Jia, T. Quantitative method on miners emergency response capacity. *Syst. Eng. Procedia* **2012**, *5*, 260–265. [\[CrossRef\]](#)
42. Ju, Y.; Wang, A.; Liu, X. Evaluating emergency response capacity by fuzzy AHP and 2-tuple fuzzy linguistic approach. *Expert Syst. Appl.* **2012**, *39*, 6972–6981. [\[CrossRef\]](#)
43. Sharma, H.K.; Roy, J.; Kar, S.; Prentkovskis, O. Multi criteria evaluation framework for prioritizing indian railway stations using modified rough ahp-mabac method. *Transp. Telecommun.* **2018**, *19*, 113–127. [\[CrossRef\]](#)
44. Sharma, H.K.; Kumari, K. Tourist Arrivals Demand Forecasting Using Rough Set-Based Time Series Models. *Decis. Mak. Adv.* **2025**, *3*, 216–227. [\[CrossRef\]](#)
45. Lin, S.H.; Zhao, X.; Wu, J.; Liang, F.; Li, J.H.; Lai, R.J.; Hsieh, J.C.; Tzeng, G.H. An evaluation framework for developing green infrastructure by using a new hybrid multiple attribute decision-making model for promoting environmental sustainability. *Socio-Econ. Plan. Sci.* **2021**, *75*, 100909. [\[CrossRef\]](#)
46. Jin, W.; An, W.; Zhao, Y.; Qiu, Z.; Li, J.; Song, S. Research on evaluation of emergency response capacity of oil spill emergency vessels. *Aquat. Procedia* **2015**, *3*, 66–73.
47. Bilgili, A.; Arda, T.; Kilic, B. Explainability in wind farm planning: A machine learning framework for automatic site selection of wind farms. *Energy Convers. Manag.* **2024**, *309*, 118441. [\[CrossRef\]](#)
48. Ali, J.; Bashir, Z.; Rashid, T.; Mashwani, W.K. A q-rung orthopair hesitant fuzzy stochastic method based on regret theory with unknown weight information. *J. Ambient Intell. Humaniz. Comput.* **2023**, *14*, 11935–11952. [\[CrossRef\]](#)
49. Chang, K.H.; Wu, Y.Z.; Su, W.R.; Lin, L.Y. A simulation evacuation framework for effective disaster preparedness strategies and response decision making. *Eur. J. Oper. Res.* **2024**, *313*, 733–746. [\[CrossRef\]](#)
50. Liu, X.; Wang, C.; Yin, Z.; An, X.; Meng, H. Risk-informed multi-objective decision-making of emergency schemes optimization. *Reliab. Eng. Syst. Saf.* **2024**, *245*, 109979. [\[CrossRef\]](#)
51. Liu, J.; Dexun, J.; Guo, L.; Jun, N.; Wukui, C.; Wang, P. Emergency material location-allocation planning using a risk-based integration methodology for river chemical spills. *Environ. Sci. Pollut. Res. Int.* **2020**, *27*, 17949–17962. [\[CrossRef\]](#)
52. Qi, K.; Chai, H.; Duan, Q.; Du, Y.; Wang, Q.; Sun, J.; Liew, K.M. A collaborative emergency decision making approach based on BWM and TODIM under interval 2-tuple linguistic environment. *Int. J. Mach. Learn. Cybern.* **2022**, *13*, 383–405. [\[CrossRef\]](#)
53. Chen, L.; Li, Z.; Deng, X. Emergency alternative evaluation under group decision makers: A new method based on entropy weight and DEMATEL. *Int. J. Syst. Sci.* **2020**, *51*, 570–583. [\[CrossRef\]](#)
54. Mojtahedi, M.; Sunindijo, R.Y.; Lestari, F.; Suparni, S.; Wijaya, O. Developing Hospital Emergency and Disaster Management Index Using TOPSIS Method. *Sustainability* **2021**, *13*, 5213. [\[CrossRef\]](#)
55. Cao, J.; Zhu, L.; Han, H.; Zhu, X. *Modern Emergency Management*; Springer: Berlin/Heidelberg, Germany, 2018.
56. Qi, K.; Wang, Q.; Duan, Q.; Gong, L.; Sun, J.; Liew, K.M.; Jiang, L. A multi criteria comprehensive evaluation approach for emergency response capacity with interval 2-tuple linguistic information. *Appl. Soft Comput.* **2018**, *72*, 419–441. [\[CrossRef\]](#)
57. Liu, Y.; Zhou, W.; Song, Y. Evaluation of College Students' Emergency Response Capability Based on Questionnaire-TOPSIS Innovative Algorithm. *Complexity* **2021**, *2021*, 6295003. [\[CrossRef\]](#)
58. Nassereddine, M.; Azar, A.; Rajabzadeh, A.; Afsar, A. Decision making application in collaborative emergency response: A new PROMETHEE preference function. *Int. J. Disaster Risk Reduct.* **2019**, *38*, 101221. [\[CrossRef\]](#)
59. Andreassen, N.; Borch, O.J.; Sydnes, A.K. Information sharing and emergency response coordination. *Saf. Sci.* **2020**, *130*, 104895. [\[CrossRef\]](#)
60. Liu, P.; Wang, X.; Teng, F.; Li, Y.; Wang, F. Distance education quality evaluation based on multigranularity probabilistic linguistic term sets and disappointment theory. *Inf. Sci.* **2022**, *605*, 159–181. [\[CrossRef\]](#)
61. De, S.K.; Biswas, R.; Roy, A.R. An application of intuitionistic fuzzy sets in medical diagnosis. *Fuzzy Sets Syst.* **2001**, *117*, 209–213. [\[CrossRef\]](#)
62. Yager, R.R.; Elmore, P.; Petry, F. Soft likelihood functions in combining evidence. *Inf. Fusion* **2017**, *36*, 185–190. [\[CrossRef\]](#)
63. Fei, L.; Feng, Y.; Liu, L.; Mao, W. On intuitionistic fuzzy decision-making using soft likelihood functions. *Int. J. Intell. Syst.* **2019**, *34*, 2225–2242. [\[CrossRef\]](#)
64. Fei, L. On interval-valued fuzzy decision-making using soft likelihood functions. *Int. J. Intell. Syst.* **2019**, *34*, 1631–1652. [\[CrossRef\]](#)
65. Yager, R.R. Quantifier guided aggregation using OWA operators. *Int. J. Intell. Syst.* **1996**, *11*, 49–73. [\[CrossRef\]](#)

66. Liu, P.; Jin, F. Methods for aggregating intuitionistic uncertain linguistic variables and their application to group decision making. *Inf. Sci.* **2012**, *205*, 58–71. [CrossRef](#)
67. Liu, Y.; Li, L.; Tu, Y.; Mei, Y. Fuzzy TOPSIS-EW Method with Multi-Granularity Linguistic Assessment Information for Emergency Logistics Performance Evaluation. *Symmetry* **2020**, *12*, 1331. [CrossRef](#)
68. Guan, X.; Qian, L.; Li, M.; Chen, H.; Zhou, L. Earthquake relief emergency logistics capacity evaluation model integrating cloud generalized information aggregation operators. *J. Intell. Fuzzy Syst.* **2017**, *32*, 2281–2294. [CrossRef](#)

**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.