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Improved Entropy-based Fuzzy Group Decision-making Model and Application in Earthquake Emergency Priority

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Abstract

Integration of Entropy and fuzzy group decision-making method was applied into the earthquake emergency priority problem and difficulty, which provided a practical and scientific assistant decision-making mode. Through the demonstration of index system and its hierarchy of earthquake emergency priority, fuzzy group decision-making was mapped into earthquake emergency, fuzzy decision-making matrix was erected for earthquake emergency priority, and the priority of earthquake emergency was determined with the Improved Entropy weights. Finally, example showed that model could present guidance for the earthquake emergency plans and local decision-making operations.

Keywords*: emergency response; priority; Entropy; fuzzy group decision-making; earthquake*

1. Introduction

Earthquake emergency is a complex, fuzzy and timely systems engineering [1-2], how to measure or optimize the sequence of earthquake emergency tasks was an important part and difficult problem in the orderly response to the complex earthquake-damaged engineering status [3-4], such as the emergency distribution strategy based on Ant Colony Algorithm with RBF Neural Network [5].

Be up against the emergency tasks brought by strong earthquake, retrieving and using some historical or past experiences and methods from the emergency cases, are an important method for assisting the decision-making operations in earthquake emergency, namely plan or Case-Based Reasoning (CBR) [6]. From the common point of view to all type emergency and emergent engineering application, Reference [7] gave the method of emergency aid decision-making based on CBR; Based on earthquake cases and decision-making model, Dong-Ping Li proposed the importance and schedule of emergency response matters [8].

It was the key whether could develop a scientific, rational decision-making and carried it out timely and effectively [9]. In particular, under the condition of lacking historical cases or emergency services, the wisdom of the decision-making groups was important, especially emergency logistics programming in natural disasters [10]. Additionally, Hang Hong established the optimized model on the public emergency disposal based on Information Entropy [11], which provided one certain reference for such earthquake emergency decision-making problem.

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2. Fuzzy Group Decision-making Model under Earthquake Emergency

2.1. Decision-making Hierarchy under Earthquake Emergency

As the foundation of emergency case, and aiming at the problem that much information in the emergency decision-making can't be quantitatively described, Y.L. Zhang presented a fuzzy group decision-making method for the dynamic regulation of emergency decision under complex circumstance of accident disasters [12], but which could not mine the implicit information of decision groups. From the perspective of coefficients' value for engineering projects, Reference [3] established a two-stage fuzzy evaluation level, whose indexes mainly focused on economy, not reflecting timeliness.

On the reference and basis of the historical emergency data, the proposed index system mainly includes 12 index for the earthquake emergency decision-making problem, as shown in Table 1, as well as Identification Code, Index Name and Abbreviation.

Table 1. Decision-making Index System on Earthquake Emergency

No	Identification Code	Index Name	Abbreviation
1	C_1	Economical Value of Earthquake Emergency	EV
2	C_2	Social Value of Earthquake Emergency	SV
3	C_3	Peoples Value of Earthquake Emergency	PV
4	C_4	Life Rescuing Importance	LR
5	C_5	Lifeline Networks Value	LN
6	C_6	Feasibility of Emergency Plans	FE
7	C_7	Satisfiability of Emergency Resources	SE
8	C_8	Survival Guarantee Parameter	SG
9	C_9	Order Measurement of Disaster Control	OM
10	C_{10}	Timely Measurement of Earthquake Emergency	TM
11	C_{11}	Flexiability of Earthquake Emergency	FL
12	C_{12}	Risk Grade of Emergency conditions	RG

On the perspective principle of "People First", decision-making hierarchy was established for the earthquake emergency system, as shown in Figure 1, with the three levels of Object, Rule and Plans.

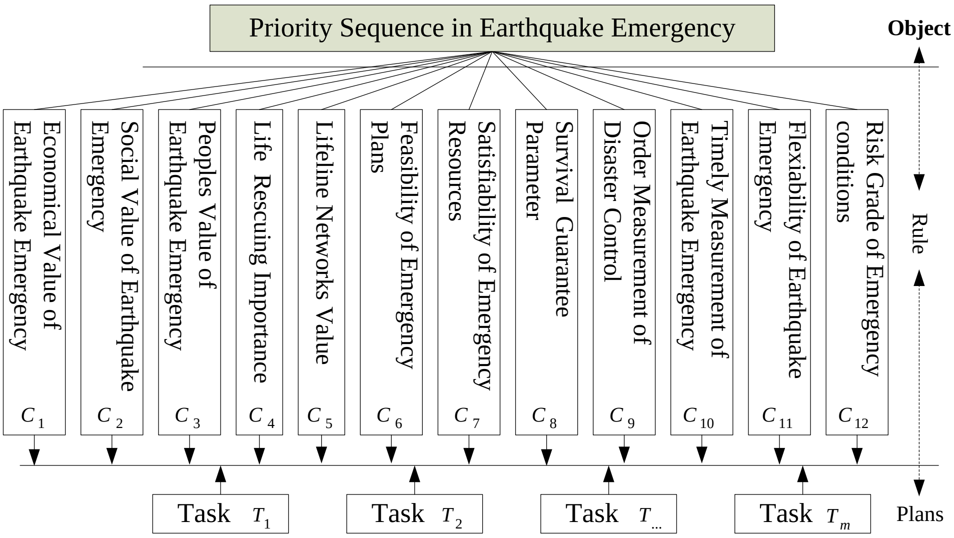

Figure 1. Decision-making Hierarchy of Earthquake Emergency Priority

Following the basic goal of earthquake emergency priority, the emergency tasks included T_1, T_2, …, T_m, T_i indicated the general description about the emergency task, and T denoted the emergency tasks set; C_j expressed the general index in the rule level, whose set was $C = \{C_1, C_2, ...C_n\}$, and the weight was expressed as α_j, satisfying $0 \le \alpha_j \le 1$, $\sum \alpha_j = 1$.

2.2. Fuzzy Group Decision-making Mapping in the Earthquake Emergency

Objective unintelligibility, uncertainty in the earthquake emergency, and the ambiguity of human thinking induced the typical multiple fuzzy criteria decision-making characteristics [13].

$U = \{U_r \mid r = 1,2,..., s\}$ was set as the decision-making group, and the weight of decision-making individual ρ_r of decision-making individual U_r, $U_r \in U$, where $\rho_1 = \rho_2 = ... = \rho_s = 1/s$. $V = \{V_1, V_2, ..., V_p\}$ was the reviews set of decision-making groups, which could be expressed as {excellent, relative excellent, equal, relative poor, poor }, and could also be fuzzy quantified as {1.0,0.85,0.5,0.35,0.1}, namely the evaluation grade.

The assessment of decision-making individual U_r about emergency task T_i, could look as the subjected degree of task T_i on each evaluation grade of index C_j, namely the fuzzy mapping, as follows in Formula (1).

$$\begin{cases} f_{r,j} : T \to V \\ T_i \mapsto f_{r,j}(T_i) = \dfrac{y_{i,1}^{r,j}}{V_1} + ... + \dfrac{y_{i,d}^{r,j}}{V_d} + ... + \dfrac{y_{i,p}^{r,j}}{V_p} \end{cases} \quad (1)$$

Here, $f_{r,j}$ denotes that the decision-making individual U_r gives the expert judgement under the index C_j, including the m tasks and 5 evaluation grade.

Let the fuzzy validity threshold of expert judgments as ε. If $y_{i,d}^{r,j} \geq \varepsilon$ existed, namely the sentence of task T_i was in effect on the reviews set V_d ($1 \leq d \leq p$), $\beta = 1$ was set; else $\beta = 0$ was set.

Based on the fuzzy decision-making of the individual U_r, the quantitative decision-making information was set as $x_{i,d}^{j}$, as the following expression in Formula (2).

$$x_{i,d}^{j} = \sum_{r=1}^{s} (\rho_i \cdot y_{i,d}^{r,j} \cdot \beta) \tag{2}$$

Accordingly, the fuzzy mapping of group decision-making was erected under the earthquake emergency state, as shown in Formula (3).

$$\begin{cases} g_j : T \rightarrow V \\ T_i \mapsto f_j(T_i) = \dfrac{x_{i,1}^{j}}{V_1} + \ldots + \dfrac{x_{i,d}^{j}}{V_d} + \ldots + \dfrac{x_{i,p}^{j}}{V_p} \end{cases} \tag{3}$$

2.3. Fuzzy Decision-making Matrix of the Earthquake Emergency Priority

As the relative effectiveness of task T_i was denoted as $z_{i,j}$ on the emergency index C_j, and $M(\cdot,\oplus)$ was regarded as the fuzzy reckoning operator about the earthquake emergency priority, shown in Formula (4).

$$z_{i,j} = \sum_{d=1}^{p} x_{i,d}^{j} \cdot V_d \tag{4}$$

Thus, the fuzzy group decision-making matrix Z was erected for the earthquake emergency, as shown in Formula (5).

$$Z = \left[\begin{array}{c|cccc} & C_1 & C_2 & \cdots & C_n \\ \hline T_1 & z_{1,1} & z_{1,2} & \cdots & z_{1,n} \\ T_2 & z_{2,1} & z_{2,2} & \cdots & z_{2,n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ T_m & z_{m,1} & z_{m,2} & \cdots & z_{m,n} \end{array}\right] \tag{5}$$

3. Improved Entropy-based Decision-making Model on Earthquake Emergency Priority

3.1. Calculate the Weight of Priority Index under Earthquake Emergency

In order to reduce the subjective warp of decision-making individual in earthquake emergency as much as possible, Information Entropy [14] was applied into measuring the disorder degree of the decision-making system, which aimed to depress the complexity and uncertainty, providing the relatively impersonal index weight for earthquake emergency decision-making system.

For the primary analysis and design about intellectualized emergency decision-making support system [15], according to the fuzzy group decision-making matrix Z about the earthquake emergency priority, $h_{i,j}$ was supposed as the proportion of task T_i on the index C_j, as the following Expression in Equation (6).

$$h_{i,j} = z_{i,j} / \sum_{i=1}^{m} z_{i,j} \tag{6}$$

According to Information Entropy method [16], the *Shannon* entropy of the priority index C_j about the earthquake emergency decision-making could be got as e_j in Formula (7).

$$e_j = H(C_j) = -\frac{1}{ln(m)} \sum_{i=1}^{m} h_{i,j} ln(h_{i,j}) \tag{7}$$

Here, e_j denoted the entropy value of the index C_j about earthquake emergency decision-making, whose value reflected the inherent disorder degree among the characteristics. When $h_{i,j} = 0$, $h_{i,j} = 0.00001$ replaced.

Thus, the weight of index C_j was calculated for the earthquake emergency decision-making system, namely Formula (8).

$$u_j = (1 - e_j) / (n - \sum_{j=1}^{n} e_j), \quad \sum_{j=1}^{n} u_j = 1 \tag{8}$$

Where, u_j said the weight of priority index C_j about earthquake emergency decision-making, and $\tilde{U}$ expressed the collection or set, $\tilde{U} = \{u_j \mid j = 1,2,...,n\}$.

3.2. Calculate the Weight of Priority Index under Improved Entropy Method

Objectively, e_j reflected the index's entropy effectiveness about earthquake emergency priority matter, but this value lacked the horizontal comparison among indexes, hardly reflecting the differences within the index system or structure. Standardization is an important way to improve the entropy, which aims at the objective and scientific purposes of the entropy value [17].

Supposed that $\bar{z}_j$ said the equal value of system task sample T under the index C_j, and δ_j expressed the standard deviation, then:

$$\bar{z}_j = \frac{1}{m} \sum_{i=1}^{m} z_{i,j} \tag{9}$$

$$\delta_j^2 = \frac{1}{m-1} \sum_{i=1}^{m} (z_{i,j} - \bar{z}_j)^2 \tag{10}$$

In order to reduce the differences among earthquake emergency priority matters' indexes, the entropy weight method was improved with the standardized methods, as shown in Formula (11) and (12).

$$a_{i,j} = z_{i,j} - \bar{z}_j / \delta_j \tag{11}$$

$$h_{i,j} = a_{i,j} / \sum_{i=1}^{m} a_{i,j} \tag{12}$$

Accordingly, in accordance with Formula (7) and (8), the entropy value and index weight of earthquake emergency priority matter was calculated through the improved entropy method [18].

3.3. Calculation on Priority of Earthquake Emergency

With the advantage of entropy method for fuzzy decision-making information [19], as a sample foundation about the fuzzy decision-making matrix and index weight measurement of decision-making groups, $S(T_i)$ was set as the priority matter of earthquake emergency task T_i, namely the group decision-making model as follows in Formula (13).

$$S(T_i) = \sum_{j=1}^{n} e_j \cdot h_{i,j} \tag{13}$$

For analyzing the application of entropy effectively and improving entropy in fuzzy group decision-making about the earthquake emergency priority, $\bar{S}(T_i)$ and $\tilde{S}(T_i)$ was set separately as the method of Entropy and improved Entropy respectively.

4. Example and Application Analysis

Supposed that a strong earthquake occurred in certain regional urban, and the emergency organization need carry on some related rescue mission, including T_1, T_2, T_3, T_4 and T_5, and there was no correlation among these tasks.

Through the group decision-making simulation platform, the fuzzy decision-making matrix of group decision-making sample under earthquake emergency was given, as shown in Table 2.

Table 2. Fuzzy Group Decision-making Matrix of Sample under Earthquake Emergency

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
T_1	1.99	3.00	3.83	3.36	1.39	1.40	1.14	0.30	0.51	0.64	2.40	1.18
T_2	3.84	1.02	2.18	1.01	0.78	3.32	3.02	0.21	2.27	3.17	1.05	2.06
T_3	1.36	2.02	0.55	3.25	1.00	2.34	3.01	2.12	1.87	1.24	2.61	0.49
T_4	2.34	2.79	0.59	0.97	2.46	2.19	1.52	3.11	0.04	2.11	2.75	3.21
T_5	0.89	3.56	1.03	3.71	1.89	3.66	2.27	3.73	1.34	0.66	2.99	1.85

Under the prototype Entropy method, the entropy and weight of index was calculated about earthquake emergency group decision-making example, as shown in Table 3. And, Table 4 showed the entropy and weight of index with Improved Entropy method. Comparison between Table 3 and Table 4, showed that the Improved Entropy method reduced the entropy value of the priority decision-making index, which resolved the defect of entropy weight deviation.

Table 3. Entropy and Weight of Index on Earthquake Emergency

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
Entropy	0.9291	0.9561	0.8325	0.9154	0.9494	0.9681	0.9603	0.7838	0.8123	0.8854	0.9694	0.9111
Weight	0.0629	0.0390	0.1486	0.0751	0.0449	0.0283	0.0352	0.1918	0.1666	0.1017	0.0271	0.0788

Table 4. Improved Entropy and Weight of Index on Earthquake Emergency

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
Entropy	0.7480	0.8311	0.5694	0.6979	0.7389	0.8043	0.7802	0.6939	0.7885	0.6107	0.8561	0.7956
Weight	0.0817	0.0547	0.1396	0.0979	0.0846	0.0634	0.0712	0.0992	0.0685	0.1262	0.0466	0.0663

Set $\bar{S}(T_i)$ and $\tilde{S}(T_i)$ respectively denoted the group earthquake emergency decision-making priority with the prototype and improved entropy model, and according to the earthquake emergency priority model, then the priority of the group earthquake emergency decision-making sample, as shown in Table 5.

Table 5. Priority of Group Decision-making Sample

	T_1	T_2	T_3	T_4	T_5
$\bar{S}(T_i)$	0.1712	0.2229	0.1863	0.1905	0.2291
$\tilde{S}(T_i)$	0.1833	0.2406	0.1559	0.2019	0.2182

Under the prototype Entropy method, the task sequence was T_5, T_2, T_4, T_3, T_1; Otherwise, the Improved Entropy method regarded the sequence as T_2, T_5, T_4, T_1, T_3. Improved Entropy model presented that T_2, T_5 and T_4 were the first need to perform.

5. Conclusion

Fuzzy group decision-making is an important means in planning earthquake emergency rescue, which mainly depended on the wisdom of experts, the subjective consciousness and group decision-making ability. Therefore, how to reduce the instability caused by the subjective conclusion of decision-making group, was the important task in the earthquake emergency management, which could ensure the scientific and reasonable grade of the decision-making conclusion given by group wisdom.

With the subjective judgments of decision-making group and the dispersion degree of index system, the index weight of earthquake emergency priority was obtained by the improved entropy model, which objectively reduced the deviation of the fuzzy conclusions given by decision-making group. Model greatly advanced the earthquake emergency decision-making more scientific and effective, which could provide information and theoretical guidance for the order decision-making in earthquake emergency.

Examples showed that the integration of Improved Entropy and Fuzzy Group Decision-making effectively mined the implicit information of group decision-making samples about earthquake emergency, which greatly improved the quality and credibility of group decisions. However, how to make or grasp core elements in the earthquake emergency relied on further exploration, and expected to establish a more perfect decision-making system for earthquake emergency response.

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