Scientific and Social Research, 2023, Volume 5, Issue 12
https://ojs.bbwpublisher.com/index.php/SSR

Study of Low-Altitude Emergency Response Alternative Selection Process

Jie Yu[1]*, Zengqiang Wang[2]

[1]Chongqing Construction Residential Engineering CO., LTD., Chongqing 400000, China

[2]School of Management, Xihua University, Chengdu 610000, Sichuan Province, China

***Corresponding author:** Jie Yu, wzqlinger@163.com

Abstract: To address the complexity of the departmental coordination with others effectively, an approach for selecting emergency alternatives based on multi-granularity linguistic and multidivisional cooperation was presented. Firstly, multi-granularity linguistic phrases were employed to express the preference information, and some transformation functions were used to unify the multi-granular linguistic phrases into a uniform linguistic label set. Secondly, the evaluation indexes of key attributes with respect to each combination of alternations were determined considering multidivisional cooperation. Furthermore, according to the evaluation indexes and the weight vector of key attributes, the comprehensive value of each combination alternative was determined to obtain the best alternative. Finally, a case study of low-attitude airspace emergency rescue after an earthquake is presented to illustrate the validity of the approach.

Keywords: Emergency decision; Low-attitude airspace; Collaborative management; Multi-granularity linguistic information

Online publication: December 27, 2023

1. Introduction

With the rapid development of the economy and the continuous improvement of people's living standards, the number and types of general aviation flights have increased rapidly, leading to the increasing demand for low-altitude airspace and corresponding management measures. In this case, collaborative management guided by the Civil Aviation Administration Department and the local government will become a new mode of low-altitude management. The increasing number of low-altitude flight activities has caused public safety problems and resulted in a significant increase in search and rescue work. In addition, low-altitude rescue is also needed for major accidents such as natural disasters [1]. Therefore, to ensure the coordinated, orderly, and efficient implementation of low-altitude emergency rescue and the selection of a reasonable emergency plan has become a pressing issue.

Typically, when faced with an emergency, emergency rescue teams initially consider various influencing factors based on past experiences and brainstorming [2]. They then organize the gathered information that affects emergency rescue into a tree diagram to identify key indicators influencing decision-making. This paper concentrates on determining the weights of key indicators and constructing a model for emergency decision-making. Decision makers are requested to assign a numerical scale, such as "1-3-5" or "1-4-7," to indicate the importance of a specific index or the performance of a particular scheme across different indexes [3]. While this method is straightforward and widely used, its accuracy is often low. The Analytic Hierarchy Process (AHP) has been employed to analyze various indicators and alternative options, checking the consistency of results through pairwise comparisons [4]. However, the information available during the initial moments of an emergency is extremely limited and subject to strong uncertainty, imposing significant limitations on the application of this method. Fuzzy sets have been integrated with the aforementioned methods to better capture the fuzziness of the decision environment [5]. Nevertheless, the use of fuzzy sets raises issues of de-fuzzification, and different forms of data transformation may lead to the loss of decision information.

Emergency decision-making for low-altitude coordination often involves multiple decision-making departments determining the appropriate emergency plan following an emergency event [6]. In order to make full use of the limited information, participating departments are required to consider the key factors affecting the decision-making comprehensively when making the emergency plan, including the coordination between departments [7]. There have been a few studies done on departmental collaboration. A multi-stage and multi-objective emergency decision-making model has been established to take into account the opinions of multiple departments [8].

In this study, we used a numerical scale to represent the preference information of key indicators and emergency plans. the application of this model may introduce significant deviations. In view of this, based on the language information decision theory, we comprehensively considered the heterogeneity of different departments. We built a multi-department collaborative operation model and used the multi-attribute decision method based on multi-granularity language information to determine the comprehensive evaluation index of the combination scheme. Then, we selected the best alternative.

2. Proposed approach

The management of low-altitude emergency response usually involves multiple departments, such as military and civil aviation air traffic control departments, local emergency response departments, and public security departments. Some decision-making departments are independent of each other, and some decisions are made jointly by several departments. In addition, it is difficult for the decision-making department to fully understand everything about the emergency in the initial stages. Consequently, they tend to prefer using language information to express their preference for information on cooperative departments, key indicators, and emergency plans. Additionally, the choice of language scales during the decision-making process varies among decision-making departments due to the influence of their resources and the nature of their work. Building upon this context, this paper proposes a collaborative emergency decision-making method for low-altitude cooperative management based on multi-granularity language phrases.

Step 1: The evaluation information matrix was given by the decision-making department using the preferred language granularity. Language information of different granularity is converted to obtain the same granularity matrix of relative importance, denoted as $SB = (sb_{h1h2})_{k\times k}$. Then the relative importance of the decision-making department can be obtained by Equation (1).

$$\omega_h = \frac{\sum_{h_1=1}^{k} sb_{h_1 h}}{\sum_{h_1=1}^{k}\sum_{h_2=1}^{k} sb_{h_1 h_2}}, h, h_1, h_2 = 1,2,\ldots,k \tag{1}$$

Step 2: Departments involved in decision-making use language information to evaluate the influence degree of other departments, then the preference information is transformed to obtain the same granularity matrix of the influence degree, denoted as $SG = (sg_{h1h2})_{k \times k}$. The influence coefficient of the decision-making department on the other decision-making department can be obtained by Equation (2).

$$\theta = \frac{\alpha}{\beta - 1}, \alpha \in [-\lambda, \lambda] \tag{2}$$

Step 3: The decision-making department uses the preferred language granularity to give the evaluation information matrix of the importance of each key indicator, then the preference information is transformed to obtain the same granularity matrix of importance, denoted as $SC = (sC_{hi})_{k \times n}$. The weight of each key indicator can be obtained by Equation (3).

$$\rho_i = \frac{\sum_{h=1}^{k} \omega_h sc_{hi}}{\sum_{h=1}^{k} \sum_{i=1}^{n} \omega_h sc_{hi}}, h, h_1, h_2 = 1,2, \ldots, k, i = 1,2, \ldots, n \tag{3}$$

Step 4: Each decision-making department judges the performance of its own department's alternatives on different indicators, and then the preference information is converted to obtain the same granularity matrix within the department, denoted as $SX = (sx_{j_h i})_{\sum_{j_h=1}^{m_h} j_h \times n}$.

Step 5: The alternative solutions given by each department is combined to form a comprehensive solution set, denoted as $Z = \{z_p | p = 1,2,\ldots,q\}$. The evaluation index of the combination scheme in different indicators can be obtained by Equation (4).

$$v_i(z_p) = v_i\left(a_{j_{h_1}}^{d_1} a_{j_{h_2}}^{d_2} \ldots a_{j_{h_k}}^{d_k}\right) = \omega_1 \theta_{h_1 h_1} sx_{j_{h_1} i} + \omega_2 \theta_{h_2 h_2} sx_{j_{h_2} i} + \ldots + \omega_k \theta_{h_k h_k} sx_{j_{h_k} i} + a_{h_1 h_2} sy_{j_{h_1} j_{h_2}}^{i} + \ldots + a_{h_{k-1} h_k} sy_{j_{h_{k-1}} j_{h_k}}^{i} \tag{4}$$

Step 6: The evaluation index of various portfolio alternatives in different indicators and the weight information of various key indicators are aggregated to obtain the comprehensive evaluation index of various portfolio alternatives, the various portfolio alternatives can be sorted. The comprehensive evaluation index can be obtained by Equation (5).

$$cv(z_p) = \rho_1 nv_1(z_p) + \rho_2 nv_2(z_p) + \ldots + \rho_n nv_n(z_p) \tag{5}$$

3. Application examples

To validate the effectiveness and feasibility of the proposed method, the emergency rescue operation following a 6.8 magnitude earthquake in an area prone to natural disasters serves as an illustrative example. The earthquake's epicenter is within approximately 20 kilometers of 35,000 people residing in an area with poor geological conditions. Meteorological information indicates continuous rainy weather for three days following the earthquake, resulting in low visibility and near-paralysis of local traffic. In response to these conditions and to minimize the loss of public life and property, the local government promptly initiates Level 1 emergency procedures. An emergency work leading group is established to select appropriate emergency plans and swiftly organize rescue efforts.

Step 1: The emergency front liners contact the military aviation, civil aviation, and relevant local departments to form a low-altitude emergency rescue team. Among them, the language scale set selected by military aviation and civil aviation is S^4 and the language scale set selected by local relevant departments is S^5. The preference information matrix of the same granularity is obtained, as shown in **Table 1**. Due to limited space, different granularity preference information matrices are not listed, the same goes for the following.

Table 1. The evaluation matrix of the importance of departments

	d_1	d_2	d_3
d_1	-	$S^4_{1/3}$	$S^4_{4/3}$
d_2	S^4_3	-	$S^4_{4/3}$
d_3	$S^4_{3/4}$	$S^4_{3/2}$	-

The relative importance of the decision-making department is obtained by Equation (1) as $\omega_1 = 0.455$, $\omega_2 = 0.222$, $\omega_3 = 0.323$.

Step 2: The influence coefficient of the decision-making department on the other decision-making department is obtained by Equation (2), as shown in **Table 2**.

Table 2. The evaluation matrix of the cooperative coefficient between different departments

	d_1	d_2	d_3
d_1	1.000	0.444	0.444
d_2	0.111	1.000	0.111
d_3	0.250	0.500	1.000

Step 3: According to the actual situation of the earthquake and limited data, the low-altitude emergency rescue team selects the key influencing factors, namely, reducing casualties, matching materials, aerial photography, and rescue costs. The weight of each key indicator is obtained by Equation (3) as $\rho = (0.554, 0.172, 0.215, 0.059)$.

Step 4: After the formation of the low-altitude emergency rescue team, each decision-making department put forward the corresponding alternative plan according to the task to be completed. The alternatives of $\alpha_1^{d_1}$ and $\alpha_2^{d_1}$ are put forward by the military aviation, the alternatives of $\alpha_1^{d_2}$ and $\alpha_2^{d_2}$ are put forward by the civil aviation, and the alternatives of $\alpha_1^{d_3}$ and $\alpha_2^{d_3}$ was put forward other relevant departments. The preference information of the same granularity matrix within the department are shown in **Table 3**.

Table 3. The matrix of the department self-evaluation

	t_1	t_2	t_3	t_4
$\alpha_1^{d_1}$	$S^4_{4/3}$	$S^4_{1/3}$	$S^4_{1/3}$	$S^4_{4/3}$
$\alpha_2^{d_1}$	$S^4_{1/3}$	$S^4_{1/3}$	$S^4_{1/3}$	$S^4_{1/3}$
$\alpha_1^{d_2}$	$S^4_{4/3}$	$S^4_{1/3}$	S^4_0	$S^4_{1/3}$
$\alpha_2^{d_2}$	$S^4_{1/3}$	$S^4_{1/3}$	S^4_0	$S^4_{4/3}$
$\alpha_1^{d_3}$	$S^4_{3/2}$	$S^4_{3/4}$	$S^4_{3/10}$	$S^4_{3/4}$
$\alpha_2^{d_3}$	S^4_3	$S^4_{3/2}$	$S^4_{3/2}$	$S^4_{3/2}$

Step 5: The evaluation index of the combination scheme in different indicators can be obtained as shown in **Table 4**.

Table 4. The matrix of the department self-evaluation

	t_1	t_2	t_3	t_4
$\alpha_1^{d_1}\alpha_1^{d_2}\alpha_1^{d_3}$	$S_{0.087}^4$	$S_{0.055}^4$	$S_{0.081}^4$	$S_{0.131}^4$
$\alpha_1^{d_1}\alpha_1^{d_2}\alpha_2^{d_3}$	$S_{0.125}^4$	$S_{0.092}^4$	$S_{0.200}^4$	$S_{0.070}^4$
$\alpha_1^{d_1}\alpha_2^{d_2}\alpha_1^{d_3}$	$S_{0.095}^4$	$S_{0.084}^4$	$S_{0.125}^4$	$S_{0.088}^4$
$\alpha_1^{d_1}\alpha_2^{d_2}\alpha_2^{d_3}$	$S_{0.199}^4$	$S_{0.193}^4$	$S_{0.255}^4$	$S_{0.060}^4$
$\alpha_2^{d_1}\alpha_1^{d_2}\alpha_1^{d_3}$	$S_{0.076}^4$	$S_{0.755}^4$	$S_{0.040}^4$	$S_{0.281}^4$
$\alpha_2^{d_1}\alpha_1^{d_2}\alpha_2^{d_3}$	$S_{0.126}^4$	$S_{0.130}^4$	$S_{0.085}^4$	$S_{0.129}^4$
$\alpha_2^{d_1}\alpha_2^{d_2}\alpha_1^{d_3}$	$S_{0.096}^4$	$S_{0.122}^4$	$S_{0.057}^4$	$S_{0.151}^4$
$\alpha_2^{d_1}\alpha_2^{d_2}\alpha_2^{d_3}$	$S_{0.195}^4$	$S_{0.248}^4$	$S_{0.157}^4$	$S_{0.091}^4$

Step 6: The comprehensive evaluation index can be obtained by (5) as $cv(z_1) = 0.083$, $cv(z_2) = 0.132$, $cv(z_3) = 0.099$, $cv(z_4) = 0.202$, $cv(z_5) = 0.197$, $cv(z_6) = 0.188$, $cv(z_7) = 0.095$, $cv(z_8) = 0.190$. Therefore, the sorting result of the portfolio alternatives is $z_4 \succ z_5 \succ z_8 \succ z_2 \succ z_6 \succ z_7 \succ z_1$.

4. Conclusion

The collaborative emergency decision-making method proposed in this study takes into account the mutual influence among participating departments, providing a more accurate reflection of the decision-making environment. This ensures the model's applicability to low-altitude emergency decision-making problems and yields better results. The decision method, based on multi-granularity semantic information, avoids information loss during the transformation of different forms of preference information, fully addressing uncertainty in the emergency decision-making process and maximizing the use of limited decision information. Further research is needed to enhance the applicability of decision-making methods in responding to dynamic emergencies.

Disclosure statement

The authors declare no conflict of interest.

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