CBR-based dynamic decision-making method for emergencies

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Abstract. The randomness of emergencies is very important to emergency management, and case-based reasoning has attracted the attention of emergency decision-makers. In order to improve the one-sidedness of the existing emergency decision-making method based on static case-based reasoning, this paper fully considers the development and evolution stage of the event, and proposes a CBR-based dynamic emergency decision-making method. First, the emergency event is decomposed into multiple time stages; then the comprehensive attributes of each stage are determined according to the event description and treatment measures to calculate the attribute similarity; then the case similarity is calculated through the attribute similarity, and the decision-making plan of current event stage is formed by combining the treatment measures of the case with the highest similarity; at the same time, the current decision-making measures are involved in the case reasoning of the next stage. Finally, a high-rise building fire case in the city shows the feasibility of this method.

1. Introduction
The frequent occurrence of emergencies makes emergency management one of the hotspots of concern. Emergency decision-making, as one of the most important research contents in emergency management, refers to generating emergency plans under unstable conditions. Since emergencies are difficult to predict, Case-Based Reasoning (CBR) [1] which refers to the experiences of similar cases is widely used in emergency response. The general process of CBR problem solving is case retrieval, case reuse, case revise and case retain. Through Case retrieval, the most similar case to the current event can be obtained, and the disposal measures of this case are the source of decision-making reference methods. KANG uses various association rule mining techniques to extract associated knowledge from a given case database, which enhances similarity-based retrieval Strategy [2]. Fan uses mixed similarity to generate historical cases to deal with the problem of different format attribute values of gas explosion events [3]. Qian Jing designed a "local-global" two-stage similarity evaluation mode to improve the accuracy of scheme matching [4]. Song Yinghua builds an effective case database based on the reasoning method of the confidence rule base, and then obtains the recommended plan of urban flood disaster based on evidence reasoning. [5]. Yuan Xiaofang divides the evolution of unconventional emergencies into related key scenarios, which As the input of emergency decision-making, the retrieval results are revised to obtain the decision-making output [6]. Dong Qingxing uses the kernel density aggregation method to reasonably assign attribute weights to make the results of case reasoning more objective [7]. The above research is based on similarity calculation and case generation strategies. The application of CBR in the field of emergency
management has been explored from different perspectives, but there are two limitations: First, the perspective of CBR is static, that is, the development stage of the emergency is not considered, and the emergency plan is assumed to be completed. It only needs to focus on events after the end; second, the impact of emergency measures in case retrieval is rarely considered. In reality, emergencies do not always evolve, and similar cases should be generated based on the development status of current events; in addition, after emergency decision-makers intervene in an emergency, the implementation effect of emergency measures will affect the direction of the event, so emergency measures should also be included in the case search.

In view of this, this article proposes a dynamic CBR idea. Based on the current development stage of the emergency, the most similar historical case is retrieved from the case database, and the disposal measures of this historical case are the best decision-making reference; at the same time, measures taken by the current event are used as one of the attributes of the case and participate in subsequent case retrieval.

2. Problem description

In the CBR-based emergency decision-making problem, for the convenience of description, we suppose that \( X=\{X_1, X_2, \ldots, X_n\} \) is the set of historical emergency cases, \( i \in \{1, 2, \ldots, n\} \); and \( X_0 \) is the target emergency case. A case usually consists of a problem description and a disposal plan. The problem description is represented by the attribute set \( E=\{e_1, e_2, \ldots, e_m\} \), where \( e_j \) is the \( j \)-th attribute, \( j \in \{1, 2, \ldots, m\} \); \( \lambda=\{\lambda_1, \lambda_2, \ldots, \lambda_m\} \) represents the attribute weight of the problem description, and \( \lambda_j \) is the weight of the \( j \)-th attribute, which satisfies \( 0 \leq \lambda_j \leq 1 \) and \( \sum_{j=1}^{m} \lambda_j = 1 \); The treatment plan attributes are expressed in the form of \( A=\{a_1, a_2, \ldots, a_f\} \), where \( a_k \) is the \( k \)-th treatment plan attribute, \( k \in \{1, 2, \ldots, f\} \). When the treatment plan attribute set \( A \) and the problem description attribute set \( E \) participate in the next stage of case retrieval, a new comprehensive attribute set \( EA=\{s_1, s_2, \ldots, s_{m+f}\} = \{e_1, e_2, \ldots, e_m, a_1, a_2, \ldots, a_f\} \) is formed, where \( s_l \) is the \( l \)-th comprehensive attribute, and \( l \in \{1, 2, \ldots, m+f\} \); \( \lambda_s=(\lambda_{s1}, \lambda_{s2}, \ldots, \lambda_{sm+f}) \) represents the weight of the comprehensive attribute, where \( \lambda_{sl} \) is the weight of the \( l \)-th comprehensive attribute, which satisfies \( 0 \leq \lambda_{sl} \leq 1 \) and \( \sum_{l=1}^{m+f} \lambda_{sl} = 1 \).

3. Dynamic decision-making of emergencies based on CBR

From the perspective of the disaster-causing process of the hazard factors of emergencies, its development can be simply divided into three stages: "before, during and after the event" [8]. The problem to be solved in this article is: for emergencies at different stages, Under the effect of implementing different treatment measures, match similar cases for emergencies at various stages based on the comprehensive attributes of the event, and then use the most similar case treatment measures to assist in event decision-making

3.1. Data processing

According to the actual situation, in the case description, the attribute values are considered to be divided into numerical and linguistic types. For example, the values of attributes such as "number of casualties", "burning area" and "fire height" in urban high-rise building fires are generally numerical. The attribute value of "fire protection capability" is generally linguistic, and is represented by language phrases such as "good", "fair" and "very good". Data multi-source requires data processing before calculation. We suppose that \( C_{ij} \), the value of attribute \( j \) of case \( X_i \) is processed by the range transformation method to obtain the specification value \( C'_{ij} \) [9].

When \( C_{ij} \) is an exact number:

\[
C'_{ij} = \begin{cases} 
\frac{c_{ij} - \min c_{ij}}{\max c_{ij} - \min c_{ij}} & \text{if } j \text{ is a benefit-type attribute} \\
\frac{\max c_{ij} - c_{ij}}{\max c_{ij} - \min c_{ij}} & \text{if } j \text{ is a cost-type attribute}
\end{cases}
\]

When \( C_{ij} = [C^l_{ij}, C^r_{ij}] \) is an interval number:
\[
\begin{align*}
\mathbf{c}_y^j &= \left[ c_y^j-, c_y^j+ \right] = \\
&= \begin{cases}
\frac{c_y^j - \min c_y^j}{\max c_y^j - \min c_y^j} & j \text{ is a benefit-type attribute} \\
\frac{c_y^j - \min c_y^j}{\max c_y^j - \min c_y^j} & j \text{ is a cost-type attribute}
\end{cases}
\end{align*}
\]  

(2)

When \( C_{ij} \) is linguistic variable:

First, the linguistic variable is converted into interval numbers, then standardize it according to the standardization method of interval numbers. We suppose that there is a set of the linguistic variable \( l=(I_0,I_1,...,I_m,...,I_n) \), then \( I_m(m=0,1,2,...,n-1,n) \) is expressed by interval number form like this:

\[
\begin{align*}
\mathbf{c}_y^j &= \left[ c_y^j-, c_y^j+ \right] = \\
&= \begin{cases}
\frac{c_y^j - \min c_y^j}{\max c_y^j - \min c_y^j} & j \text{ is a benefit-type attribute} \\
\frac{c_y^j - \min c_y^j}{\max c_y^j - \min c_y^j} & j \text{ is a cost-type attribute}
\end{cases}
\end{align*}
\]  

(3)

3.2. Similarity of attributes

The core idea of case retrieval is the calculation of case similarity, and the calculation of case similarity depends on the attribute similarity. After data processing, there is only two types of data: the exact number and interval number. Thus, the attribute similarity formula is represented as follows:

When \( C_{ij} \) is an exact number:

\[
f_{0ij} = 1 - d_{0ij} = 1 - |c_{ij} - c_{0j}|
\]  

(4)

When \( C_{ij} \) is an interval number:

\[
f_{0ij} = 1 - d_{0ij} = \sqrt{\left( c_{0ij}^- - c_{ij}^- \right)^2 + \left( c_{0ij}^+ - c_{ij}^+ \right)^2}
\]  

(5)

Where \( f_{0ij} \) is the attribute similarity between the target case \( x_0 \) and the historical case \( x_i \) with respect to the attribute \( j \), and \( d_{0ij} \) is the attribute distance.

3.3. Case similarity at each stage and their decision-making method

Emergencies are divided into three management stages: pre-event, during-event, and post-event. For each stage, the most similar cases are recommended to get the current stage of handling reference.

For the pre-event stage, decision makers usually do not take emergency measures, so the case similarity calculation at this stage only needs to consider the problem description attributes. The calculation formula of case similarity in the pre-event stage:

\[
sim_{0ij} = \sum_{j=1}^{n} \lambda_j f_{ij}
\]  

(6)

Suppose the case with the highest similarity at this stage is \( x_i \), and its emergency response plan is \( A_i \). At this time, \( A_i \) should be used as a reference to make emergency decisions for emergencies in the pre-event phase.

For the mid-event stage, because the decision-maker may have taken some response measures, the similarity calculation at this stage needs to consider the comprehensive attribute \( \mathbf{E} = \{s_1, s_2, ..., s_m, f\} \), which is composed of the attributes from the problem description and the disposal measures. The calculation formula of case similarity in the mid-event stage:

\[
sim_{ij} = \sum_{f=1}^{m+f} \lambda_{if} f_{ij}
\]  

(7)
Suppose the case with the highest similarity at this stage is \( X_i \), and its emergency response plan is \( A_i \). At this time, \( A_i \) should be used as a reference to make emergency decisions for emergencies in the mid-event phase.

For the post-event stage, decision makers pay more attention to the recovery of the situation, so the attributes of the treatment measures should include a description of the implementation effect of the plan, and the calculation method of the case similarity is the same as formula (7). At this time, the most similar case is obtained. Decision makers should make decisions based on the disposal measures of this case.

4. Example

In order to verify the feasibility of the method proposed in this article, an urban high-rise building fire accident [10] is taken as an example. Suppose a high-rise building fire event \( X_0 \) occurs in a city, and the similar cases collected are \{ \( X_1, X_2, \ldots, X_5 \) \}. The problem attributes involved include: number of casualties (\( e_1 / \text{person} \)), burning area (\( e_2 / \text{m}^2 \)), fire height (\( e_3 / \text{m} \)), building height (\( e_4 / \text{m} \)). The disposal plan involves the number of firefighters (\( A_1 / \text{person} \)), Medium and high pressure pump fire truck (\( A_2 / \text{vehicle} \)), emergency rescue vehicle (\( A_3 / \text{vehicle} \)). In addition, the attribute that indicates the implementation effect of the plan is fire-fighting ability (\( A_4 / \text{vehicle} \)), and its language evaluation is very poor (VB), poor (B), General (M), strong (G) and very strong (VG), etc. Table 1 gives case information, where \( t_1, t_2 \) and \( t_3 \) represent pre-event, mid-event and post-event phase, respectively.

### Table 1. Original data of the casebase

|     | \( e_1 \) | \( e_2 \) | \( e_3 \) | \( e_4 \) | \( a_1 \) | \( a_2 \) | \( a_3 \) | \( a_4 \) |
|-----|---------|---------|---------|---------|-------|-------|-------|-------|
| \( X_0 \) | 5 | 160 | 24 | 187 | | | | |
| \( X_1 \) | 48 | 408 | 87 | 187 | | | | |
| \( X_2 \) | 57 | 450 | 104 | 187 | | | | |
| \( X_3 \) | 6 | 100 | 10 | 95.8 | 20 | 2 | 2 | |
| \( X_4 \) | 30 | 375 | 39 | 95.8 | 90 | 18 | 8 | |
| \( X_5 \) | 35 | 400 | 48 | 95.8 | 120 | 23 | 10 | |

When the event is in the pre-event stage, there is only the problem description attribute, and experts are invited to give the attribute weight \( \lambda = \{0.29, 0.37, 0.18, 0.16\} \). First, remove the dimension of the initial value of the attribute according to equations (1) ~ (3), and Equations (4) ~ (5) calculate the attribute similarity between the target case and the historical case; then use equation (6) to calculate the case similarity, and the results are shown in Table 2.

### Table 2. Attribute similarity, case similarity and ranking in the pre-event stage

|     | \( e_1 \) | \( e_2 \) | \( e_3 \) | \( e_4 \) | sim | rank |
|-----|---------|---------|---------|---------|-----|------|
| \( X_1 \) | 0.9737 | 0.4545 | 0.0667 | 0.0598 | 0.4721 | 5 |
| \( X_2 \) | 0.0263 | 0.8182 | 0.9333 | 0.1021 | 0.4947 | 4 |
| \( X_3 \) | 0.6842 | 0.6364 | 0.9333 | 0.6186 | 0.7008 | 1 |
| \( X_4 \) | 0.9737 | 0.7273 | 0.4000 | 0.0000 | 0.6235 | 2 |
At this time, the similarity of X₃ is the highest, and A₃={number of firefighters=90, medium and high-pressure pump fire truck=11, emergency rescue vehicle=4}. Thus, decision of the pre-stage A₀={number of firefighters=70, medium and high pressure pump fire truck =7, rescue vehicle = 1}.

When the event is in the mid-event stage, the problem description attribute and A₀ form a comprehensive attribute set, and experts are again invited to give the comprehensive attribute weight λ={0.19,0.2,0.11,0.1,0.14,0.18,0.08}. According to equation (1)~ (6) Calculate the similarity between the target case and the historical case, and the results are shown in Table 3.

| e₁ | e₂ | e₃ | e₄ | a₁ | a₂ | a₃ | sim | rank |
|----|----|----|----|----|----|----|-----|------|
| X₁ | 0.7429 | 0.7740 | 0.0000 | 0.0598 | 0.8214 | 0.5600 | 0.4615 | 0.5546 | 2 |
| X₂ | 0.2571 | 0.2260 | 0.7292 | 0.1021 | 0.0000 | 0.0000 | 0.0000 | 0.1845 | 5 |
| X₃ | 0.7429 | 0.5068 | 0.4375 | 0.6186 | 0.4643 | 0.2800 | 0.1538 | 0.4802 | 4 |
| X₄ | 0.8714 | 0.8356 | 0.1458 | 0.0000 | 0.7321 | 0.5200 | 0.6154 | 0.5941 | 1 |
| X₅ | 0.9571 | 0.4178 | 0.3125 | 0.0619 | 0.6429 | 0.3600 | 0.3846 | 0.4915 | 3 |

At this time, the similarity of X₄ is the highest, and A₄={number of firefighters=100, medium and high-pressure pump fire truck=19, emergency rescue vehicle=6}, Thus, decision of the mid-stage A₀=number of firefighters=90, medium and high pressure pump fire fighting Vehicle=20, rescue vehicle=8), and the evaluation value a₄=G on the implementation effect of the current event is obtained.

When the event is in the post-event stage, using the problem description attribute and the mid-event stage attribute, including the implementation effect a₄, to form a comprehensive attribute set, and experts are again invited to give the comprehensive attribute weight λ=(0.14,0.14,0.11,0.1,0.12,0.128, 0.12, 0.15). Calculate the similarity between the target case and the historical case according to equations (1) ~ (6), and the results are shown in Table 4.

| e₁ | e₂ | e₃ | e₄ | a₁ | a₂ | a₃ | a₄ | sim | rank |
|----|----|----|----|----|----|----|----|-----|------|
| X₁ | 0.7412 | 0.7585 | 0.0000 | 0.0598 | 0.7857 | 0.8333 | 0.8000 | 0.2828 | 0.5486 | 2 |
| X₂ | 0.2588 | 0.2415 | 0.7857 | 0.1021 | 0.0000 | 0.0000 | 0.0000 | 0.2828 | 0.2091 | 5 |
| X₃ | 0.8353 | 0.7585 | 0.5714 | 0.6186 | 0.5714 | 0.4444 | 0.3000 | 0.2828 | 0.5482 | 3 |
| X₄ | 0.9059 | 0.5169 | 0.3571 | 0.0000 | 0.7143 | 0.7222 | 0.8000 | 0.2828 | 0.5493 | 1 |
| X₅ | 0.8706 | 0.4686 | 0.3036 | 0.0619 | 0.6786 | 0.6667 | 0.6000 | 0.0000 | 0.4605 | 4 |

At this time, the similarity of X₄ is still the highest, indicating that the current event is effectively controlled.

5. Conclusion
Aiming at the emergency decision-making of difficult prediction, multi-attribute evaluation, and dynamic development, this paper proposes an emergency decision-making method based on dynamic CBR. This method divides the development process of the event into three stages, and uses CBR technology to recommend solutions for different stages. The method has the following characteristics: (1) Emphasizes the development process of emergencies in CBR, so that decision makers can choose the best solution at different stages, avoiding the absoluteness of static decision-making, and enriching the study of case reasoning; (2) Treat the emergency system as a mode of human-computer interaction, consider the impact of the emergency plan on subsequent events after current solutions have been taken, and provide an opportunity for managers to adjust the their plans.

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