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Research on emergency material demand forecast of earthquake disaster based on case-based reasoning

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ABSTRACT

Emergency material demand forecast of earthquake disaster includes pre-disaster and post-disaster forecast, but study on the pre-disaster forecast is relatively rare at present, this paper focus on the problem of the pre-disaster forecast using CBR (case-based reasoning) method, the purpose is to control the emergency material reserve scale at a reasonably range. First of all, using the analytic hierarchy process (AHP) to calculate the weight of each characteristic attribute for the earthquake disaster emergency demand case. Then according to the different type of characteristic attribute, calculating the similarity degree between characteristic attribute respectively. Next, using the nearest neighbor method to calculate the similarity degree between cases. Finally, using the algorithm based on the analytic method to revise the demand data of similar case set, to get reasonable demand forecast result, the demand forecast result can be used as a decision-making basis that control the emergency material reserve scale.

KEYWORDS

CBR; Earthquake disaster; Emergency material; Demand forecast.

INTRODUCTION

In recent years, the earthquake disaster occurred frequently around the world, which did a serious impact on human social production and living order, and caused huge loss of the people's life and property. Against the background of large earthquake disaster, emergency material reserve is the material basis and basic guarantee for the disposal of the earthquake disaster, while the scientific emergency material demand forecast is an important basis for the construction of an appropriate scale and reasonable structure emergency material reserve system. Consequently, enhancing the research on emergence material demand forecast plays an important role to perfecting emergency material reserve system.

Emergency material demand forecast of earthquake disaster includes two cases: one is the pre-disaster forecast; the other is the post-disaster forecast. The purpose of the pre-disaster forecast is to control the emergency material reserve scale at a reasonably range; the purpose of the post-disaster forecast is to guide the emergency financing and dispatching decision of the emergency material. At present, research on the post-disaster forecast has made some positive progress, as Guo Jinfen[1] used BP neural network forecast the casualties number after earthquake, combined with inventory management knowledge to estimate the demand of emergency materials in disaster area. Fu Zhiyan[2] established the key factor model of CBR, solved the demand forecast problem of initial earthquake disaster emergency material in target case. Zhao Xiaoning[3] applied the CBR method, and used rough set theory and the nearest neighbor algorithm to search the best similar case, established the emergency material demand forecast model in disaster area, etc. But now study on the pre-disaster forecast is relatively rare. Therefore, this paper will focus on the pre-disaster emergency material demand forecast problem.

Forecasting the emergency material demand before the earthquake disaster occurs, the following two important problems need to be solved: One is the earthquake disaster will occur at where, in when, how large; the other is to choose what kind of method to forecast. At present, although we still can't do accurately predict to the specific time of earthquake disaster occur, due to the pre-disaster prediction is for control the emergency material reserve scale at a reasonably range, so we don't need precise to determine the specific time of occurrence, only need to estimate what scale the earthquake disaster will be occur at where in next few years. According to literatures[4-5] show that realize seismic medium-term (1-10 years), long-term (10 years) prediction is entirely possible. In addition, because the consumption data of the past emergency material have non continuity, if using traditional forecasting method, such as "Time Sequence Method", "Regression Analysis", "Trend Extrapolation", it would be difficult to make accurate forecast to the demand of emergency material, the essential reason is the problem of emergency material demand forecast has been changed to semi-structured or unstructured problem, at this time should choose unstructured forecast method, while the CBR is one of the very effective method for solving unstructured forecast problem[6]. Therefore, this paper according to literatures[7,8] which give an estimation result about the earthquake disaster distribution in China in the coming years, using CBR method to forecast the emergency material demand before the earthquake disaster occur, providing basis for decision-making to control reasonable emergency materials reserve scale.

THE BASIC PRINCIPLE OF CBR

CBR is a new reasoning method in the field of artificial intelligence, its core idea is on problem solving, to inference using previous experience and knowledge of solving similar problem, make appropriate adjustments for differences between the old and new problems, thereby get the solution of new problems, and form a new case which can be added to the case base, In order to enrich the "experience" of case base. In the CBR system, the currently facing problem generally called target case, the problem occurred in the past generally called the source case, the basic principles of CBR essentially is a "4R" (Retrieve, Reuse, Revise, Retain) cyclic process, which mainly include four steps: case retrieval, case reuse, case revision and case retain, as shown in Figure 1.

Case Retrieval: according to the description of the target case, use appropriate retrieval method to retrieve similar case (set) in the case base.

Case Reuse: obtain solution from the retrieval of one or a set of case, determine whether it match with the problem about target case, if they match, reusing the solution of the similar case, otherwise, the solution need to be amended.

Case Revision: revising the solving solution of similar case (set), making it match with the problem of target case, then get the solution of the target case, and generate new case.

Case Retain: saving new case to the case base according to certain strategy.

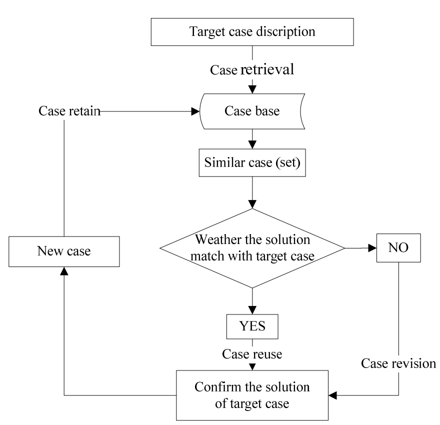

Figure 1 : The basic principle of CBR

THE MODEL DESIGN OF CBR

Case representation

Case representation is the premise and basis of CBR, its essence is make the past problem solving example expressed as the form of case, stored in the case base, that is use some specific code words encode examples into a computer-acceptable data structure. Case usually include description of the problem and description of the solution, can be expressed as an ordered pair : < description of the problem; description of the solution>. A case of earthquake disaster emergency material demand can model expressed as

$$Case(F, D)$$

In the formula, F is the characteristic attribute set of earthquake disaster, it is description of the problem domain; D is the emergency material demand attribute set of earthquake disaster, it is description of the solution domain.

When establishing earthquake emergency material demand case base, supposing there are n cases in case base, the i case is expressed as $C_i, (i = 1,2,\cdots,n)$, the source case set is $C = \{C_1, C_2, \cdots, C_n\}$; The case have m characteristic attributes, which can be expressed as $F = \{f_1, f_2, \cdots f_m\}$; The k variety of emergency material demand in the i case (supposing there are l varieties) can be expressed as $D_i = \{d_{i1}, d_{i2}, \cdots, d_{ik}, \cdots d_{il}\}, (k = 1,2,\cdots l)$; The characteristic attribute of the target case C_0 can be expressed as $F' = \{f_1', f_2', \cdots f_m'\}$, the emergency material demand can be expressed as $D' = \{d_1', d_2', \cdots d_l'\}$.

Case retrieval

Case characteristic attribute selection

The emergency material demand case characteristic attribute of earthquake disaster is constituted by each factor that affect emergency material demand, mainly includes magnitude, population density, economic level in earthquake region, seismic fortification intensity and geographical environment [9], the specific value scope and its type as shown in TABLE 1. It is not difficult to find that different characteristic attribute contains different information quantity and information type. Accordingly, we can merge the characteristic attribute into four types, Respectively numerical type, such as population density"100 person/km^2"; Ordered enumeration type, such as the economic level in earthquake zone is "general", this type has a certain sort rule; Unordered enumeration type, such as the geographical environment is "plateau"; Interval number type, such as the earthquake magnitude of "7.0-7.2", this is because the estimation result of future earthquake may be an interval value.

TABLE :1 : Characteristic attribute value scope and type

No.	Characteristic Attribute	Characteristic Attribute Value Scope	Value Type
1	magnitude	0.5-10	interval number type
2	population density	person/km^2	numerical type
3	economic level in earthquake region	very high, high, general, low, very low	ordered enumeration type
4	seismic fortification intensity	5,6,7,8,9	ordered enumeration type
5	geographical environment	plateau, plain, basin etc.	unordered enumeration type

Characteristic attribute weight calculation

The emergency material demand case of earthquake disaster involve five characteristic attribute, and the relative importance of each characteristic attribute is different, In order to improve the retrieval accuracy of emergency material demand case, we must give appropriate weight to each characteristic attribute according to its importance. There are many ways to determine the weight, such as expert scoring method, multi-objective optimal method, AHP etc. This paper use AHP give appropriate weight for each characteristic attribute, specific steps are as follows[10]:

Construct judgment matrix

Using P represent the target, u_i, u_j $(i, j = 1,2\cdots n)$represent the evaluation factors; u_{ij} represent the relative important numerical value u_i to u_j, generally use 1 to 9 scale method of Satty assign value, as shown in TABLE 2.

TABLE 2 : 1~9 scale table

Scale	Signification
1	factor u_i compared with factor u_j, have equal importance
3	factor u_i compared with factor u_j, u_i is a little important than u_j
5	factor u_i compared with factor u_j, u_i is obvious important than u_j
7	factor u_i compared with factor u_j, u_i is strongly important than u_j
9	factor u_i compared with factor u_j, u_i is extreme important than u_j
2,4,6,8	The median value of 1-3, 3-5, 5-7, 7-9
Reciprocal	If factor u_i compared with factor u_j is u_{ij} ,then factor u_j compared with factor u_i is $u_{ji} = 1/u_{ij}$

So, the judgment matrix can be determined as follows:

$$P = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ u_{21} & u_{22} & \cdots & u_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ u_{n1} & u_{n2} & \cdots & u_{nn} \end{bmatrix} \quad \textbf{(1)}$$

Calculate weight

According to the judgment matrix, obtained its maximum feature root $\lambda_{\max}$ correspond to the feature vector w. The resolution equation is:

$$Pw = \lambda_{\max} w \quad \textbf{(2)}$$

Make the feature vector w normalized to obtain the weight of each evaluation factor.

Consistency check

In order to determine whether the weight distribution is reasonable, also need to check the consistency of judgment matrix P. The check formula is as follows:

$$CR = CI/RI \quad \textbf{(3)}$$

In the formula: CR is random consistency ratio; CI is consistency index, $CI = (\lambda_{\max} - n)/(n-1)$; RI is the average random consistency index, The specific value RI refer to TABLE 3.

TABLE 3 : The average random consistency index RI

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

If the random consistency ratio $CR < 0.1$ or $\lambda_{\max} = n$, $CI = 0$, considering the judgment matrix P through the consistency check; Otherwise we need to re-construct the judgment matrix.

Case similarity calculation

Case retrieval algorithm directly affects the efficiency and quality of CBR. Retrieval algorithm that commonly used are the nearest neighbor algorithm, reference algorithm and knowledge guide algorithm etc[11]. This paper use the nearest neighbor algorithm for case retrieval. The algorithm use some kind of distance between cases to indicate the similarity between cases. A case contains several characteristic attributes, we must first calculate the similarity degree of each characteristic attribute before calculate the similarity degree between cases. Different characteristic attribute has different similarity degree calculation method, as follows:

Numerical type characteristic attribute similarity degree calculation

Supposing the k attribute type of case C_i and case C_j is numerical type, its attribute value respectively expressed as C_{ik} and C_{jk}, β and α respectively express the maximum and minimum values of the k attribute, so the similarity degree of the k attribute between case C_i and C_j is[12]:

$$sim(C_{ik}, C_{jk}) = 1 - |C_{ik} - C_{jk}| / |\beta - \alpha| \tag{4}$$

Ordered enumeration type characteristic attribute similarity degree calculation

Supposing the k attribute of case C_i and case C_j is ordered enumeration type, its attribute value respectively expressed as C_{ik} and C_{jk}, m represent the grade number of the attribute value, so the similarity degree of the k attribute between case C_i and C_j is [6]:

$$sim(C_{ik}, C_{jk}) = 1 - |C_{ik} - C_{jk}| / m \tag{5}$$

Unordered enumeration type characteristic attribute similarity degree calculation

Supposing the k attribute of case C_i and case C_j is unordered enumeration type, its attribute value respectively expressed as C_{ik} and C_{jk}, so the similarity degree of the k attribute between case C_i and C_j is[13]:

$$sim(C_{ik}, C_{jk}) = \begin{cases} 1 & C_{ik} = C_{jk} \\ 0 & C_{ik} \neq C_{jk} \end{cases} \tag{6}$$

Interval number type characteristic attribute similarity degree calculation

Supposing the k attribute of case C_i is numerical type, its attribute value expressed as C_{ik}, the k attribute of case C_j is interval number type, the value range is $\lfloor C_{jk1}, C_{jk2} \rfloor$, β and α respectively express the maximum and minimum values of the k attribute, so the similarity degree of the k attribute between case C_i and C_j is[12]:

$$sim(C_{ik}, C_{jk}) = \begin{cases} 1 - \dfrac{(C_{jk2} + C_{jk1} - 2C_{ik})}{2(\beta - \alpha)}, & C_{ik} \leq C_{jk1} \\ 1 - \dfrac{(C_{jk2} - C_{ik})^2 + (C_{jk1} - C_{ik})^2}{2(\beta - \alpha)(C_{jk2} - C_{jk1})}, & C_{jk1} < C_{ik} < C_{jk2} \\ 1 + \dfrac{(C_{jk2} + C_{jk1} - 2C_{ik})}{2(\beta - \alpha)}, & C_{ik} \geq C_{jk2} \end{cases} \tag{7}$$

Case similarity degree calculation

After calculating the similarity degree of each characteristic attribute, we can calculate the similarity degree between cases. According to the principle of the nearest neighbor method[14], the similarity degree between the two cases is :

$$sim(C_i, C_j) = \sum_{k=1}^{n} w_k sim(C_{ik}, C_{jk}) \tag{8}$$

In formula (8), n is the number of characteristic attributes, w_k is weight of the k attribute, and $\sum_{k=1}^{n} w_k = 1$.

Case reuse and revision

After the case retrieval, if retrieved same case as the target case in case base, then the solution of the same case can be reused to solve the problem of target case, otherwise, similar cases need to be revised to obtain solution of new case. In fact, the situation that two case exactly the same is rarely, generally we need introduce the threshold τ (this value can be given by experts). Supposing the case similarity degree is $k_{\max}$, which most similar with target case in the case base, if $k_{\max} \geq \tau$, we can consider the solution of the most similar case is the solution of the target case; If $k_{\max} \leq \tau$, the retrieved case needs to revise.

If the retrieved case needs to revise, then synthesizing three selected cases which most similar with target case[15], make the similarity degree of the three most similar cases expressed as $K = \{k_1, k_2, k_3\}$, then the impact degree of each similar case to target case is:

$$p_s = \frac{k_s}{\sum_{s=1}^{3} k_s} \tag{9}$$

Using matrix expressed as:

$$P = [p_1, p_2, p_3] \tag{10}$$

In formula (9), the impact degree p_s can be considered as each case impact weight on target case solution, $\sum_{s=1}^{3} p_s = 1$.

Supposing the emergency material demand matrix of the three similar cases is:

$$D = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1l} \\ d_{21} & d_{22} & \cdots & d_{2l} \\ d_{31} & d_{32} & \cdots & d_{3l} \end{bmatrix} \tag{11}$$

In formula (11), d_{il} indicate the i similar case demand for the l variety emergency material. Then, the calculation formula of target case for all kinds of emergency materials demand is:

$$D' = \begin{bmatrix} d'_1 & d'_2 & \cdots & d'_l \end{bmatrix} = ceil(P \times D) \tag{12}$$

Case retain

When $k_{\max} \geq \tau$, the case does not need to be saved; when $k_{\max} \leq \tau$, the newly generated case need to be saved. It should be noted that new case should be first saved in the reserve case base, then add to the case base after expert assessment and practice test, in order to ensure the accuracy of case study.

EXAMPLE ANALYSIS

According to the literatures[7,8] analysis on China earthquake situation, the region in China where may occur $M_S \geq$ 7.0 magnitude earthquake in the coming years mainly distributed in Xichang earthquake region, Xianshuihe earthquake region, Zhaotong earthquake region, the southern of Erdos basin and other regions. In view of the fact that in recent years earthquake disaster occurred frequently, large scale, heavy losses in Sichuan and Yunnan region. Therefore, this paper adopted the view in literatures[7,8], taking Xichang region which will occur M_S 7.3-7.6 magnitude earthquake as the target case, using CBR method to forecast the emergency material demand for disposal of the earthquake region.

TABLE 4 : Earthquake disaster case base and target case

Case	Magnitude	Population density (person/km^2)	Economic level of earthquake region	Seismic fortification intensity	Geomorphic environment
C_1	7.9	6	very low	7	plateau
C_2	7.1	106	very low	7	plateau
C_3	7.3	727	low	7	plain
C_4	7.4	73	very low	9	plateau
C_5	7.8	497	low	5	plain
C_6	7.0	57	low	8	plateau
C_7	8.0	237	general	7	basin
C_8	7.1	7	general	7	plateau
C_9	7.0	50	general	7	basin
C_{10}	6.5	265	general	7	plateau
C_0	7.3-7.6	271	general	9	plateau

Note: earthquake disaster cases showing in TABLE are: C_1. Luhuo,Sichuan (1973.2.6); C_2.Daguan,Yunnan (1974.5.11); C_3.Haicheng, Liaoning (1975.2.4); C_4.Longling,Yunnan (1976.5.29); C_5.Tangshan,Hebei (1976.7.28); C_6.Lijiang,Yunnan (1996.2.3); C_7.Wenchuan,Sichuan (2008.5.12); C_8.Yushu,Qinghai (2010.4.14); C_9.Lushan,Sichuan (2013.4.20); C_{10}.Ludian,Yunnan (2014.8.3); C_0.target case.

First of all, selected ten groups of earthquake disaster historical data that is close to the target case, to construct the earthquake disaster case base, as shown in TABLE 4.

Secondly, calculate the similarity degree of cases, procedure are as follows:

(1) Determine the weight of each characteristic attribute. First construct judgment matrix by magnitude, population density, economic level of earthquake region, seismic fortification intensity and geomorphic environment as follows:

$$P=\begin{bmatrix} 1 & 3 & 4 & 5 & 7 \\ 1/3 & 1 & 2 & 3 & 5 \\ 1/4 & 1/2 & 1 & 5/2 & 4 \\ 1/5 & 1/3 & 2/5 & 1 & 3 \\ 1/7 & 1/5 & 1/4 & 1/3 & 1 \end{bmatrix}$$

Then according to the judgment matrix P, obtain maximum feature root $\lambda_{\max} = 5.1665$, and the feature vector $w = (0.4821, 0.2273, 0.1542, 0.0914, 0.0450)$ after its normalized, the feature vector w is the final weight of each characteristic attribute.

Finally, calculate $CR = 0.0372$ according to the formula (3), Obviously, $CR < 0.1$, So judgment matrix P through the consistency check.

(2) Calculate the similarity degree of each characteristic attribute. Calculate the similarity degree of each characteristic attribute respectively by the formula (4) ~ (7). It should be noted that we can refer to the maximum value and minimum value of attribute which is in case base and target case, when determining the maximum value and minimum value of attribute, or determining after combined with the specific circumstance of each attribute[12]. Such as the maximum value of population density can select 727 person/km^2, the minimum value can select 3 person/km2; The value of the magnitude generally between 0.5~10, but consider only $M_S \geq 4.5$ magnitude earthquake will cause damage to buildings, So the maximum value can select 10 magnitude, the minimum value can select 4.5 magnitude. Following take target case C_0 and C_1 for example, to illustrate the calculation method of characteristic attributes similarity degree.

$$sim(C_{11}, C_{01}) = 1 + \frac{(7.3 + 7.6 - 2 \times 7.9)}{2 \times (10 - 4.5)} = 0.9182$$

$$sim(C_{12}, C_{02}) = 1 - \frac{|271-6|}{|727-3|} = 0.6340$$

$$sim(C_{13}, C_{03}) = 1 - \frac{|3-1|}{5} = 0.6000$$

$$sim(C_{14}, C_{04}) = 1 - \frac{|9-7|}{5} = 0.6000$$

$$sim(C_{15}, C_{05}) = 1$$

(3) Calculate similarity degree of cases. After obtained the similarity degree of characteristic attribute between C_0 and each source case, we can calculate the similarity degree between C_0 and each source case by formula (8). The similarity degree between C_0 and C_1 is:

$$sim(C_1, C_0) = \sum_{k=1}^{5} w_k sim(C_{0k}, C_{1k}) = 0.7791$$

Similarly, we can obtain the characteristic attribute similarity degree between C_0 and each source case, and the case similarity degree between C_0 and each source case. The calculation results are shown in TABLE 5.

TABLE 5 : Characteristic attributes similarity degree between target case and source case and case similarity degree

Case	Magnitude	Population density	Economic level of earthquake region	Seismic fortification intensity	Geomorphic environment	Case similarity degree
C_1	0.9182	0.6340	0.6000	0.6000	1	0.7791
C_2	0.9364	0.7721	0.6000	0.6000	1	0.8193
C_3	0.9727	0.3702	0.8000	0.6000	0	0.7313
C_4	0.9848	0.7265	0.6000	0.6000	1	0.8323
C_5	0.9364	0.6878	0.8000	0.2000	0	0.7860
C_6	0.9182	0.7044	0.8000	0.8000	1	0.8443
C_7	0.9000	0.9530	1	0.6000	0	0.8589
C_8	0.9364	0.6354	1	0.6000	1	0.8499
C_9	0.9182	0.6948	1	0.6000	0	0.8096
C_{10}	0.8273	0.9917	0.8000	0.6000	1	0.8475

Finally, calculating target case demand for all kinds of emergency materials. TABLE 5 shows, three cases that most similar to the target case are C_7, C_8 and C_{10}. Supposing threshold $\tau = 0.9$, then $k_{\max} < \tau$, we can obtain target case demand for all kinds of emergency materials by formula (9)~(12).

CONCLUSION

The pre-disaster emergency material demand forecast is an important premise and basis for the optimization of emergency material reserve system. Against to the emergency material demand forecast problem that before earthquake disaster occur. Firstly, according to the occurrence tendency of earthquake disaster in China in the next few years, selected Xichang earthquake region in Sichuan and Yunnan area where earthquake occurred high frequency, large scale, heavy losses as the target case, then used CBR method to forecast the emergency material demand for disposal of the earthquake disaster region, example analysis shows, We can make full use of emergency materials consumption data of "Wenchuan earthquake", "Yushu earthquake" and "Ludian earthquake", as the basis for decision making, which can control the scale of China current emergency material reserve.

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