Road Emergency Events Resources Optimization and Allocation Model

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Abstract: The fast, scientific and accurate deployment of emergency resource is the key restraint of emergency disposal. Based on the degree of demand for medicine, firefighting, police, hazardous chemicals rescue and other special categories of resources in road emergency handling, an emergency resource optimization model was proposed in this paper. Artificial intelligence rule-based-reasoning and fuzzy mathematics were aggregated to build an optimal allocation model. This research is funded by project in the National Science and Technology Program during the Twelfth Five-year Plan Period(Project Number: 2014BAG01B0501). In the process of project implementation, different cases were analyzed based on historical data and the validity of the model was confirmed to support related research and applications.

1. Introduction
Recently, freeway accidents take place in China frequently. It is important for the effect of accident disposal to allocate emergency resources rapidly and effectively during the process. In the past, accident disposal decision-making depended on experts’ experience. Whether the experts failed to hurry to the scene in time or artificial decision was made incorrectly would have a severe impact on the accident disposal. In order to improve the scientificity and timeliness of the major emergencies disposal on freeway, this paper firstly classifies and grades accidents based on the analysis of historical disposal cases. We analyze the demand of emergency resources from four aspects, including police rescue, medical rescue, owners rescue and fire rescue. Considering fault tolerance and robustness need of accident disposal, the method of fuzzy mathematics is introduced to deal with the state of accidents and the degree of demand. A fuzzy evaluation model of the severity of accidents is put forward. Combined with the rule-based reasoning method of artificial intelligence, we build up a rule-based reasoning machine, and establish the Rete network reasoning model, so as to achieve the function of creating fast resource allocation scheme for emergency accidents. The rest of the paper is organized as follows: Section 2 reviews applied theories in our research and related literatures. Section 3 introduces information about events and prepares for modeling. Section 4 proposes a rule-based optimization model combined with fuzzy classification and establishes the Rete network. Section 5 shows a case study applying the proposed model in Anhui province and validates its effectiveness. Finally, Section 6 concludes the paper.

2. Application of Related Theory
2.1 Rule-Based Reasoning
Rule-based reasoning is an effective reasoning method in the field of artificial intelligence, which is
suitable for the development of decision support system of knowledge reasoning. Expert system of rule-based reasoning is a system which imitates human mind to reason based on knowledge or other cognitive forms. In application, according to the experts’ knowledge and experience, a normalized format is used to convert these experiences into rules, and a given algorithm is applied to establish the reasoning network, so as to achieve efficient intelligent reasoning and decision support.

2.2 Fuzzy Mathematics
Fuzzy mathematics is a mathematical theory to deal with the phenomenon of fuzziness. It has been widely used in pattern recognition, artificial intelligence and automatic control. The significance of fuzzy mathematics is to overcome the black-or-white representation of conventional linear or nonlinear mathematic methods. It can be used to describe and solve fuzzy objects which are difficult to be defined, thus to enhance the robustness of the system. In the disposal of emergencies, the phenomenon of deficient and error information is common. Fuzzy mathematics method can improve the adaptability of the system, and can realize adjustment of the system fault-tolerance rate by changing the value of fuzzy parameter.

2.3 Literature Review
Wang Jiwei(2008) studied emergency accident disposal By applying Rete network technology to the rapid disposal of rule-based reasoning of emergency accident, which has significant effect on later research. Zhu Qianyou(2011) of Chang’an University, who gave a summary about the existing problems in the disposal of freeway accidents by analyzing the concept of freeway emergencies. It studied the application of CBR and RBR technology in processing emergencies. Smith S, Kandel A(1994) introduced comprehensively the rule-based reasoning in his work. Jiang Xiaowei(2008) applied rule-based reasoning to public health emergent disposal system. Ekaterina Makarov.(2016) integrated fuzzy mathematics with CBR In his paper, and proposed a decision support system model of case-based reasoning based on fuzzy classification. Wang Peng(2010) studied the establishment of the classification model of emergency material reserves with cluster analysis and fuzzy evaluation in his paper. Fiedich (2000) studied the allocation of emergency resources after earthquake. Zdamar.(2004) Studied the model of emergency material allocation under circumstance of natural disaster. Fan W C.(2007) discussed the relevant issues and recommendations in emergency management in the National Natural Science Foundation.

In this paper, we study the allocation of emergency resources and propose a model for it by synthetically applying the method of fuzzy mathematics and rule-based reasoning, considering the emergency disposal needs of major emergencies on freeway.

3. Modeling Preparation

3.1 Process Framework
In this paper, rule-based reasoning and fuzzy mathematics are applied to model the emergency resource allocation, which can be decomposed into formalization, index extraction, rule instantiation, rule adjustment and configuration. The technological process was shown in Figure 1.
3.2 Event Classification
We study the emergency response resource allocation model for emergency disposal of expressway emergencies in this paper. The corresponding emergent events can be classified into social security, natural disaster, facilities damage and traffic accident. Each kind of events can be divided into different subcategories. The scope and classification of the events studied are shown in Table 1.

| First Category       | Secondary Category        |
|----------------------|---------------------------|
| Social Security      | Terrorist attacks         |
|                      | Group events              |
|                      | Hazardous chemical leakage|
| Natural disasters    | Blizzard, heavy rain      |
|                      | earthquake                |
|                      | Fog                       |
| Facilities damage    | The bridge collapsed       |
|                      | Road damage               |
| Traffic accident     | Major accident            |
|                      | Serious accident           |

3.3 Event Information
Combined with experts’ field command experience, this paper extracts the index set and model, and formats the description of accident based on the analysis of historical events. The specific indicators are shown in Figure 2.

3.4 Emergency Resources
According to historical data, emergency resources are divided into four categories. The classification of emergency resources involved in this subject is shown in Figure 3.
4. Algorithm And Modeling

The overall algorithm modeling is composed of four parts: rule base construction, event fuzzy evaluation, rete reasoning network construction and conflict rule construction. When building a rule base, the rules are abstracted according to the flow path as shown in Figure 4.

4.1 Event Level Fuzzy Evaluation

**Step1:** Determine the evaluation index and range. According to the event description indexes in Figure 2, the evaluation index set is:

\[ X = \{x_1, x_2, x_3, \ldots, x_n, s\} \]  
\[ x_i \in \{(a, b)\} \]  
\[ X_i \in \{(c_1, c_2, \ldots, c_n)\} \]  

In the formula 1, \( X \) is the set of event description indexes and \( X_i \) represents the i-th evaluation index. Each event has n indexes to describe, and s represents the event number. The range of \( X_i \) can be divided into discrete type and continuous type, as shown in formula 2.

**Step2:** Build review set. According to the severity, an incident can be divided into three grades, from level one to level three with severity increasing. In formula 3, \( V \) is the set of reviews, and, respectively, corresponding to level one, two, three severity.

\[ V = \{v_1, v_2, v_3\} \]  

**Step3:** Build membership function. The membership function is constructed according to the membership degree between indicators and grades. In this model, the trigonometric function is chosen as the membership function of each index.
In formula 4, we can adjust the range of a, b, c, d to find the suitable membership function for each indicator according to the actual situation.

**Step 4:** According to expert experience, average method is used to obtain the weight of each index (formula omitted). In formula 5, W represents the weight set, $w_i$ represent the impact of the i-th index on the event severity.

$$W = \{w_1, w_2, \ldots, w_n\}$$

**Step 5:** Calculate the event severity level.

$$V_j = \sum_{i=1}^{n} u_i(x_i) \times w_j$$

$$k = \begin{cases} k_1, & V = V_1 \\ k_2, & V = V_2 \\ k_3, & V = V_3 \end{cases}$$

In formula 6, $V_j$ represents the degree of membership of the j-th event to each event level, and the membership degree of the first, second and third events can be calculated by the weighted summation method. The maximum value is taken as the event classification result. In formula 7, $k$ is the resource allocation coefficient, and the different configuration coefficients are selected according to the degree of membership.

### 4.2 Rule Base Build

**Step 1:** Variable elements. According to the event description index set, each index item is abstracted into a variable in rule reasoning, X represents the event description index with n items in total, and Y represents the emergency resource allocation index with s items in total.

$$X = \{x_1, x_2, x_3, \ldots, x_n\}$$

$$Y = \{y_1, y_2, y_3, \ldots, y_s\}$$

**Step 2:** Condition. First, the state description indexes of each kind of emergency events are discretized, and the conditional statements are obtained by combining different indexes with m groups in total.

$$C_j: \text{ If } x_1 = a, \ x_2 = b, \ldots, x_j = k$$

$$C = \{C_1, C_2, \ldots, C_m\}$$

**Step 3:** Result. In this model, the reasoning result is the emergency resource allocation scheme, including types and quantities of configuration resources. There are s classes of resources in total, so the configuration scheme contains s execution variables in total.

$$E_j: \text{ Then } y_1 = a, \ y_2 = b, \ldots, y_s = k$$

**Step 4:** Rule. According to expert experience and emergency disposal knowledge, the relationships between event state and resource allocation are listed one by one and transformed into inference rules by abstraction language. R represents the rule set with q group rules in total.

$$R_j: \text{ If } x_1 = a, \ x_2 = b, \ldots, x_j = k,$$

$$\text{ Then } y_1 = d, \ y_2 = e, \ldots, y_s = f$$
\[ R = \{ R_1, R_2, \ldots, R_m \} \]

4.3 Rete network construction

(1) Rete Network Introduction

Rete network was first proposed by Dr. Charles.F. Freyy (1980). The advantage is to avoid duplication of matches, reduce operation times and improve the computational efficiency of rule-based reasoning and pattern matching. Rete network is a directed non-loop graph with a unique root node. All nodes except for the root node and the endpoint represent the pattern. The LHS (conditional statement) part of the rule is formed by the path from the root node to all leaf nodes. And the endpoint represents the RHS (Execution Result statement). In this paper, under the basic principles of the Rete network, the rule-based reasoning network model is established based on the actual condition of the project.

(2) Network Establishment

**Step1**: Root node.
In this paper, a unique root node is constructed. It is used as the unique entry matching with the fact of accident status, which is denoted by N1.

**Step2**: α node.
Each conditional statement of rule consists of various patterns. The patterns included in all rules are summarized. A corresponding relationship between each pattern and node is constructed. The existing α node in network should not be repeated again.

**Step3**: β node.
Some rules consist of several patterns. Each pattern in a rule is connected from left to right respectively. Each node connecting two adjacent patterns generates a β node. The input of the β node is operated by the pattern represented by two α nodes of upper level.

**Step4**: End point.
Each rule statement corresponds to an execution result statement, and the endpoint represents the execution result. In this paper, the endpoints represent the configuration results of various types of emergency resources.

**Step5**: Production memory initialization (Fact match)
When the reasoning network is built, the historical cases as the initial data are one-by-one added to the Rete network. Thus, the production memory is formed. When a new event occurs, it can speed up
the network operation rate. While the same event re-enter the network, it can be matched with the corresponding implementation program directly, thereby promoting the calculation speed of reasoning. In this paper, the final generated rule-based reasoning network is shown in Figure 5.

5. Case Study
When an event is detected, the system works by the process of event fuzzy evaluation, rule reasoning and generation configuration scheme as is shown in Figure 6.

Figure 6. Example Analysis Flowchart

5.1 Case Preparation
Case Event Information is declared as follows. The accident occurred at 19:10 July 28, 2014, a heavily rainy day, in a place (“XX” location) where four cars collided with the accident, and died on the spot 1. Four persons were severely injured and two persons were bleeding heavily. Besides, the accident caused 5 tons or less vehicle deformation and cracking with no open flame at site. Road barrier level is about 7 tons and site area is about 200-500m2 with gasoline leakage less than 1t, etc.

5.2 Severity Rating
According to the fuzzy evaluation model proposed in Section 4, we can calculate the severity grade of the available events. The results are shown in Table 2 to 4.

**Step1:** Single Indicator Membership

| $u'_1(x_1)$ | $u'_2(x_2)$ | $u'_3(x_3)$ | $u'_4(x_4)$ | $u'_5(x_5)$ | $u'_6(x_6)$ | $u'_7(x_7)$ | ... | $u'_{10}(x_{16})$ |
|------------|-------------|-------------|-------------|-------------|-------------|-------------|-----|----------------|
| 0.37       | 0.69        | 0.15        | 0.37        | 0.28        | 0.11        | 0.05        | ... | 0.21           |

| $u''_1(x_1)$ | $u''_2(x_2)$ | $u''_3(x_3)$ | $u''_4(x_4)$ | $u''_5(x_5)$ | $u''_6(x_6)$ | $u''_7(x_7)$ | ... | $u''_{10}(x_{16})$ |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-----|----------------|
| 0.74        | 0.84        | 0.79        | 0.91        | 0.92        | 0.87        | 0.78        | ... | 0.72           |

| $u'''_1(x_1)$ | $u'''_2(x_2)$ | $u'''_3(x_3)$ | $u'''_4(x_4)$ | $u'''_5(x_5)$ | $u'''_6(x_6)$ | $u'''_7(x_7)$ | ... | $u'''_{10}(x_{16})$ |
|--------------|--------------|--------------|--------------|--------------|--------------|--------------|-----|----------------|
| 0.32         | 0.22         | 0.01         | 0.02         | 0.31         | 0.35         | 0.25         | ... | 0.09           |

**Step2:** Weights

| $w_1$ | $w_2$ | $w_3$ | $w_4$ | $w_5$ | $w_6$ | $w_7$ | ... | $w_{16}$ |
|-------|-------|-------|-------|-------|-------|-------|-----|----------|
| 0.09  | 0.08  | 0.01  | 0.03  | 0.09  | 0.05  | 0.02  | ... | 0.09     |

**Step3:** Evaluation results

| $V_1$ | $V_2$ | $V_3$ | $K = K_2$ |
|-------|-------|-------|------------|
| 0.293 | 0.698 | 0.196 | 1.5        |
5.3 Reasoning Result
Based on the event basic information and severity data, the rete network constructed in Section 4 was applied to reasoning, and the emergency resource allocation scheme is shown in Table 5 to 8.

(1) Police Resources

Table 5. Police Resources

| Police office | Auxiliary police | Cones | Police car |
|---------------|------------------|-------|------------|
| 5             | 8                | 60    | 4          |
| Site disposal personnel | Cordon | Warning sign | Flashlight |
| 4             | 10               | 6     | 10         |

(2) Medical Resources

Table 6. Medical Resources

| First aid kit | Ambulance | Surgeon |
|---------------|-----------|---------|
| 20            | 3         | 3       |
| Nurse         | Blood     | Physician |
| 6             | 10000     | 3       |

(3) Fire Resources

Table 7. Fire Resources

| Catheter | Demolition personnel | Hazardous chemicals special rescuer | The pump |
|----------|-----------------------|-------------------------------------|----------|
| 3        | 4                     | 2                                  | 2        |
| Sand     | Fire extinguishers    | Hazardous chemicals rescue vehicles | Fire engines |
| 3        | 1                     | 2                                  | 0        |
| Firemen  | Hydraulic shears      | Recovery tank                      | -        |
| 2        | 2                     | 2                                  | -        |

(4) Owner Rescue Resources

Table 8. Owner Rescue Resources.

| Clear obstacles vehicle | Crane | Trailer | Anti-skid agent |
|-------------------------|-------|---------|-----------------|
| 3                       | 2     | 3       | 2               |
| Snow melting agent      | 2     | 30      | 0               |
| 0                       |       |         |                 |

5.4 Analysis and validation
In order to verify the effectiveness of the model, we selected ten historical cases for comparative analysis in this paper. The results obtained by the inference engine constructed in this paper are compared with those obtained by manual processing. The results show that the average time for the computer system to generate a single configuration is less than 5 seconds, and the time for manual processing is about 3 minutes. The error between the system and the manual scheme is less than 10% for each case. Error formula is shown in Figure 8.

\[ E = 1 - \sum_{i=1}^{10} w_i \frac{|y_i - y'_i|}{y'_i} \]  

In formula 8, \( y_i \) represents the i-th system calculation value, \( y'_i \) represents the i-th artificial reasoning value, \( w_i \) stands for the weight of the i-th index. The model has 32 output indicators, and \( E \) denotes the error of each case.

6. Conclusion
In this paper, the rapid disposition of contingency emergency resources of expressway is taken as the object of study. The fuzzy classification method is used to construct the classification model of the emergency severity. Based on the rule-based network model of Rete, combined with expert knowledge and historical case experience, a rapid allocation reasoning model of emergency resources is
constructed. Relying on the implementation of National "Twelfth Five-Year" Plan for Science & Technology Support (Project Number: 2014BAG01B0501), a case study is accomplished, according to the concrete case and the model proposed in this paper. A rapid disposal emergency response system for expressway emergency is developed, which has been deployed and demonstrated in Anhui Province.

References
[1] Forgy, C. L. (1982). “Rete: a fast algorithm for the many pattern/many object pattern match problem *.”, 19(1), 17-37.
[2] Makarova, E., Avdeenko, T., & Bakaev, M. (2016). “A Case-Based Reasoning Approach with Fuzzy Linguistic Rules.” International Forum on Strategic Technology.
[3] Fiedrich, F., Gehbauer, F., & Rickers, U. (2000). “Optimized resource allocation for emergency response after earthquake disasters.” Safety Science, 35(1–3), 41-57.
[4] Xiaowei, Jiang. (2008). “Application on Ontology-based RBR in Public Emergency Response System.” Master dissertation, University of DongHua, Shanghai, China.
[5] Oezdamar, L., Ekinci, E., & Kuecuekyazici, B. (2004). “Emergency logistics planning in natural disasters.” Annals of Operations Research, 129(1), 217-245.
[6] Smith, S., & Kandel, A. (1994). “Verification and Validation of Rule-Based Expert Systems.” CRC Press, Inc.
[7] Fan, W. (2007). “Advisement and suggestion to scientific problems of emergency management for public incidents.” Bulletin of National Natural Science Foundation of China, 21(2), 71-76.
[8] Peng, Wang. (2010). “Research on Emergency Materials Reserve Classification Based on Clustering Analysis and Fuzzy Evaluation.” Master dissertation, University of Science and Technology of China, Hefei, China.
[9] Qianyou, Zhu. (2011). “The Study of Emergency PrePlan Management System Based on the CBR and RBR Technology.” Master dissertation, University of Chang’an, Xi’an, China.