Research on Emergency Decision Making Based on Bayesian Method

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Abstract—In today's society, the sudden nature of emergencies, many inducements, and large impact determine the difficulty of emergency management and decision-making. How to minimize losses and ensure the safety of people’s lives and property after an emergency occurs is the top priority of the country’s emergency management work today. Bayesian decision-making method is a common method for program selection: use Bayesian formula to modify the prior probability, and then use the modified probability to calculate the expected value of each program's utility. The plan with the higher expected value of utility is the best. Based on previous research results, this paper introduces the application background of original emergencies and the Bayesian decision-making method with fuzzy intervals, and uses specific cases to verify the effectiveness and rationality of the decision-making method.

1. INTRODUCTION

With the rapid economic and social development, emergencies in various fields have occurred frequently in various countries around the world, which not only caused unpredictable economic losses, but also claimed hundreds of millions of lives, and caused increasing global impact and harm. When an emergency occurs, decision makers must make efficient and reasonable emergency decisions to minimize the harm of the emergency. Therefore, emergency decision-making is the core of emergency management.

Emergency decision-making is a dynamic process of selecting a satisfactory plan when an emergency occurs, organizing the implementation and correcting errors in the decision-making process in time. In many cases, emergency decision-making needs to choose an optimal one from multiple alternatives for execution. Bayesian decision-making can just solve the problem of optimal solution selection, and it has been widely used in many fields.

At present, Bayesian decision-making methods have been widely used in the emergency decision-making process of emergencies. The traditional research method is mainly to directly apply the decision-making mathematical model of the Bayesian method, with the risk gain and loss value or the expected maximum value as the best. This paper introduces specific cases of primitive emergencies to illustrate the improved Bayesian decision-making method with fuzzy interval numbers, in order to achieve the purpose of improving the effectiveness and rationality of decision-making.
2. MATERIALS & METHODS

At present, Bayesian decision-making is applied in many fields such as society, economy, health, and management. Scholars at home and abroad have also made detailed explanations of Bayesian decision-making. The following is an example of emergency decision-making for urban water logging disasters. The application process of the Bayesian decision method is explained to better explain the characteristics of the Bayesian decision method.

According to the Meteorological Observatory’s forecast, an exceptionally heavy rainfall will occur in Tongzhou District, Nantong City, Jiangsu Province at 3:30 am on August 21, 2020. The flood control headquarters of Tongzhou District ordered the flood control rescue team to receive the order to be responsible for emergency rescue of flood-prone spots in the Tongzhou Bay area.

Assuming that the level of water logging is divided into \( \alpha_i (i=1, 2, 3) \), \( \alpha_i \in \emptyset \), \( \emptyset \) is the level of water logging, where \( \emptyset = \{ \text{Level I, Level II, Level III} \} \). Assuming the level of water logging is \( \alpha_i \) and the probability of expert judgment as \( \tau_j \) is \( P(\tau_j | \alpha_i) \), and the posterior probability of occurrence of water logging is obtained from formula 1, that is, the probability \( P(\alpha_i | \tau_j) \) that the expert judges that the water logging level is \( \tau_j \) and the actual water logging level is \( \alpha_i \).

\[
P(\alpha_i | \tau_j) = \frac{P(\tau_j | \alpha_i) P(\alpha_i)}{\sum_{\alpha_i} P(\tau_j | \alpha_i) P(\alpha_i)}
\]  

When the water logging level is \( \alpha_i \) and the expert judges it as \( \tau_j \), the utility level of the rescue group when the decision-making group adopts the plan \( \theta_i \) is expressed by the function \( U(\alpha_i, \tau_j, \theta_i) \), and the objective function of the rescue group is:

\[
\text{Max} = \sum_{\tau_j=1}^{n} P(\tau_j | \alpha_i) \mu(\alpha_i, \tau_j, \theta_i)
\]

Introduce the definition of fuzzy interval:

Assuming that \( a \neq b \) and \( a > b \) may appear as shown in Figure 1, 2, and 3, the value distribution on the right side of the following formula 3 is the probability that the interval number \( a \) is greater than \( b \), represented by \( P_a>b \).

\[
P_{a>b} = P_{a>b} = \begin{cases} \frac{a-b}{a^*-(a-b)} & a^* - b^* \leq a-b \\ \frac{a-b}{a^*-a} & a^* - b^* > a-b \\ 0 & a^* - b^* = a-b \\ \end{cases}
\]

Similarly, the probability of \( b>a \) is:

\[
P_{b>a} = \begin{cases} \frac{b-a}{b^*-(b-a)} & b^* - a^* \leq b-a \\ \frac{b-a}{b-a} & b^* - a^* > b-a \\ 0 & b^* - a^* = b-a \\ \end{cases}
\]
If the probability of \( a > b \) is \( P_{a>b} = 1 \), then the scheme \( S_a \) is completely better than \( S_b \), which is recorded as \( S_a \succ S_b \); if \( P_{a>b} = 0.5 \), then the scheme \( S_a \) and \( S_b \) are equivalent, marked as \( S_a \equiv S_b \); if \( 0 < P_{a>b} < 0.5 \), then the scheme \( S_b \) is better than \( S_a \), which is recorded as \( S_b \succ P_{a>b} S_a \).

3. RESULTS & DISCUSSION

Suppose that the decision-making group judges the three levels of probabilities of rainstorm and water logging as: \( P(\alpha_1) = 0.2 \), \( P(\alpha_2) = 0.5 \), \( P(\alpha_3) = 0.3 \). Then when the actual water logging level is \( \alpha_i \), the expert judges it as the conditional probability \( P(\tau_j | \alpha_i) \), the value is shown in the following Table 1:

| CONDITIONAL PROBABILITY | \( \alpha_1 \) | \( \alpha_2 \) | \( \alpha_3 \) |
|-------------------------|----------------|----------------|----------------|
| \( T_1 \)               | 0.25           | 0.5            | 0.25           |
| \( T_2 \)               | 0.5            | 0.25           | 0.5            |
| \( T_3 \)               | 0.25           | 0.25           | 0.25           |

Use formula 1 to calculate the posterior probability of occurrence of three levels of water logging, as shown in Table 2:

| POSTERIOR PROBABILITY | \( \alpha_1 \) | \( \alpha_2 \) | \( \alpha_3 \) |
|------------------------|----------------|----------------|----------------|
| \( T_1 \)              | 0.13           | 0.67           | 0.20           |
| \( T_2 \)              | 0.27           | 0.40           | 0.33           |
| \( T_3 \)              | 0.20           | 0.50           | 0.30           |

According to the weather forecast and the depth of accumulated water collected from flood-prone points, experts believe that the level of water logging is level II. From Table 2, the posterior probability of the three levels is 0.27, 0.40, and 0.33.

The traditional Bayesian decision-making method mainly uses formula 2 to calculate the expected utility value of the implementation of the three options. After calculation, the expected utility values are 0.2056, 0.5186, 0.2758 respectively. Following the principle of maximum expected utility, the decision-making group chooses option two to implement.

The improved Bayesian decision-making method introduces the fuzzy binary interval of the direct utility and the indirect utility of the emergency plan. Through the numerical calculation of the possibility degree matrix after weighting, the final result is obtained and the Bayesian decision-making method is optimized and upgraded.

Assuming that the direct and indirect effects of the corresponding schemes implemented at different levels of water logging are shown in Table 3:

| DIRECT UTILITY | \( M_1 \)     | \( M_2 \)     | \( M_3 \)     |
|---------------|---------------|---------------|---------------|
| \( \alpha_1 \)| [0.0, 0.8]    | [0.1, 0.3]    | [0.1, 0.3]    |
| \( \alpha_2 \)| [0.3, 0.9]    | [0.2, 0.6]    | [0.0, 0.4]    |
| \( \alpha_3 \)| —             | [0.2, 0.4]    | [0.4, 0.8]    |
In this paper, suppose the weight of direct utility is $\alpha$ and $\alpha=0.6$, the weight of indirect utility is $\beta$ and $\beta=0.4$, and the weighted utility is:

$$U_{\text{weighted}} = \alpha u_1 + \beta u_2$$

the weighted utility of water logging is calculated as shown in Table 4:

| WEIGHTED UTILITY | $M_1$         | $M_2$         | $M_3$         |
|------------------|---------------|---------------|---------------|
| $\alpha_1$       | [0.08,0.72]   | [0.10,0.26]   | [0.22,0.38]   |
| $\alpha_2$       | [0.18,0.54]   | [0.20,0.56]   | [0.16,0.56]   |
| $\alpha_3$       | [0.08,0.24]   | [0.12,0.24]   | [0.44,0.84]   |

According to the formula 2, the expected utility of the water logging emergency plan $\alpha_1$, $\alpha_2$, $\alpha_3$ are $[0.120,0.490]$, $[0.147,0.373]$, $[0.269,0.604]$, respectively.

According to formula 3 and formula 4, obtain the pairwise comparison possibility matrix of each plan under the original emergency:

$$P_m = \begin{pmatrix}
- & 0.6173 & 0.8925 \\
0.3827 & - & 0 \\
0.1075 & 1 & -
\end{pmatrix}$$

It can be seen that the order of the flood contingency plan is:

$$m_3 \succ m_1 \succ m_2.$$  

The traditional utility expectation and the improved utility expectation in the Bayesian decision model are used to select the optimal scheme for the original emergencies. The sequence of emergency options before and after improvement is shown in the following table 5:

| ORDER | TRADITIONAL DECISION MODEL | IMPROVED DECISION MODEL |
|-------|----------------------------|-------------------------|
| 1     | $M_2$                      | $M_3$                   |
| 2     | $M_3$                      | $M_1$                   |
| 3     | $M_1$                      | $M_2$                   |

It can be seen from the table that the decision-making scheme model before and after the improvement has a great influence on the scheme ranking. Therefore, in the process of emergencies, when data related to measurement indicators is not easy to obtain, the interval number decision model can be used to help decision-makers make decisions.

But the actual decision-making process has many factors and changes, and the decision-making environment is also complex. Therefore, the decision-making model constructed in this article exists in the actual application process. There are many shortcomings and areas that need to be improved. In future research, there is still a lot of work worthy of further study:

Firstly, this article does not incorporate multi-stage, multi-dynamic and group decision-making into the decision-making model constructed in this article. In future studies, other features can be
incorporated into the model to further improve the reliability and scientificity of the decision-making results. And effectiveness, making the emergency decision-making model more suitable for actual conditions.

Secondly, the Bayesian decision-making method in this paper has the principle of choosing the maximum expected value of utility as long as it does not consider the factors of risk gains and losses. In future studies, the expected value of utility and the risk gains and losses can be combined to analyze and study from multiple angles. And enrich and improve the theoretical methods of emergency decision-making, and improve the scientific nature of decision-making.

Thirdly, this article only deals with how to select a satisfactory plan from multiple alternative contingency plans. It does not study the specific generation process of the alternative contingency plan. Incorporating the plan selection process into the research work can make emergency decision-making more complete.

4. CONCLUSIONS

Based on the analysis and research of emergency emergency decision-making and traditional Bayesian decision-making methods, this paper constructs an emergency emergency decision-making model based on the Bayesian decision-making method of fuzzy binary interval, and uses the model for emergency treatment. In the decision-making process of water logging disasters, the final alternatives are ranked, which verifies the rationality and effectiveness of the decision-making model. Provides a better solution for future emergency decision-making.

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