Research on the decision-making of flood prevention emergency plans during reservoir construction based on generalized intuitionistic fuzzy soft sets and TOPSIS

Han Wu, Junwu Wang, Jingtao Feng, Denghui Liu and Sen Liu

ABSTRACT

Reservoir engineering is of great significance for the reduction of regional flood disasters and ensuring the sustainable development of agriculture. This paper proposed a decision-making model based on generalized intuitionistic fuzzy soft sets and TOPSIS. First, an evaluation index system was comprehensively identified and constructed. Then, generalized intuitionistic fuzzy soft sets were used to describe the index attribute values of emergency plans to fully reflect the certainty, uncertainty, and hesitancy of indexes, and their weights were calculated by Fuzzy Ordered Weighted Averaging (FOWA) to adequately consider the ambiguity of experts’ judgment. Finally, the TOPSIS method was extended via the generalized intuitionistic fuzzy soft sets to the sequencing of emergency plans. In addition, the Wangjiazhou Reservoir Project in China was selected as a case study. The case study demonstrated that full use of emergency materials and personnel was the most important factor, and the plan of the overflow rock-fill dam was the optimal flood prevention emergency plan. Compared with the classical TOPSIS, the new model proposed in this paper was found to have improved feasibility and effectiveness, and its evaluation results were more objective and reasonable. Therefore, the proposed method could provide both theoretical and practical reference.

Key words | decision-making, flood prevention emergency plan, Fuzzy Ordered Weighted Averaging, generalized intuitionistic fuzzy soft sets, reservoir construction, TOPSIS

HIGHLIGHTS

- The certainty, uncertainty, and hesitancy of the decision-making indicators of flood prevention emergency plans during reservoir engineering are described by the membership, non-membership, and hesitancy degrees in the intuitive fuzzy sets. The membership degree of each index is accurately calculated by the parameterization tool of the soft sets.
- In this paper, Fuzzy Ordered Weighted Averaging (FOWA) is used to calculate the index weights, thereby avoiding the subjectivity of the Analytic Hierarchy Process (AHP) and the large number of computational defects and fully considering the ambiguity of experts’ judgment in the calculation of weights.
- The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) is expanded under generalized intuitionistic fuzzy soft sets, thus effectively coordinating the intricate relationship between multiple targets in the decision-making and overcoming the difficulty of scientifically, effectively presenting the decision-making and evaluation levels.
- This paper, for the first time, reveals that the implementation cost of the emergency plan is the most important factor, which influences the decision-making of flood prevention emergency plans during reservoir construction.

The weights of these indexes conformed to relevant regulations and policies, and the implementation costs, implementation time, and the number of people mobilized were found to gradually decrease as the risk attitude of the decision-makers was changed from conservative to risky.

INTRODUCTION

Reservoir engineering is an important component of water conservancy construction, and plays a vital role in regional flood interception, water storage, and the regulation of water flow. To prevent and mitigate flood disasters during flood seasons, reservoir engineering project managers frequently make decisions pertaining to flood prevention emergency plans before the arrival of the flood season, and select appropriate emergency plans under limited resource constraints. In the decision-making of flood prevention emergency plans during reservoir construction, the decision-makers have incomplete information and therefore cannot accurately estimate the impact range, casualties, and property loss that will be caused by an incident (Xie et al. 2014). However, the existing practices of flood prevention emergency plan decision-making for water conservancy projects often emphasize the subjective experience of project decision-makers, resulting in a lack of scientific and effective decision-making method support.

At present, relevant scholars have made some achievements in research on the flood disaster management of water conservancy projects, but the existing research has primarily been focused on the emergency treatment of completed projects. For example, Xiang et al. (2013) studied the emergency treatment of reservoirs in high-altitude areas after they encountered excess flooding. They assessed and made decisions regarding two emergency treatment plans, namely the renovation of the practical weir and the construction of a new emergency spillway, from the aspects of safety, the economy, the environment, and social impact. Wu et al. (2015) used the Analytic Hierarchy Process (AHP) to study the impacts of the reservoir storage modulus and other factors on regional flood risk. However, when used for the study of regional flood risk, the AHP has the defects of strong subjectivity and the requirement of a large amount of calculation for consistency tests, and it cannot reflect the ambiguity of experts’ judgment in the calculation of weights. In contrast, Fuzzy Ordered Weighted Averaging (FOWA) has a high practical value (Golfam et al. 2019), and can not only make full use of existing decision information, but also avoids the adverse influences of decision-makers due to subjective factors on the decision results. Chen et al. (2018) proposed a risk-based model for the real-time flood control operation of a cascade reservoir system in extreme floods and other emergency situations. Currently, flood disaster management in the construction stage of water projects is often a part of the construction schedule management of water projects (Xu & Zhang 2012). To the best of the authors’ knowledge, individualized research on the decision-making of flood prevention emergency plans during reservoir construction has not yet been reported.

Recently, relevant scholars have made some achievements in decision-making research. Chen et al. (2019) developed a decision-making model based on prospect theory and genetic algorithms, which effectively solved the problem of emergency resource allocation among multiple emergency locations under resource constraints. However, this method could not effectively deal with the uncertainty in emergency decision-making, which reduced the applicable value of research results (Gao et al. 2017). Xu et al. (2012) adopted the concepts of the membership, non-membership, and hesitancy degrees of intuitionistic fuzzy sets to flexibly and effectively deal with information ambiguity and uncertainty in the decision-making process of air target threat assessment, which exhibited improved applicability. Maheshwari & Srivastava (2016) used intuitionistic fuzzy sets to assist doctors in decision-making regarding disease diagnosis, which further proved that intuitionistic fuzzy sets had wide applicability in dealing with decision-making problems. Although these methods...
based on intuitionistic fuzzy sets have been widely used in
decision-making research, determining how to use a para-

parameterization tool to accurately calculate the target
membership is a key technical problem for the correct use
of intuitionistic fuzzy sets (Park et al. 2013). By the combi-
nation of intuitionistic fuzzy sets and soft sets, Maji et al.
(2001) inspired an object expression model. This new
model was able to express the membership degree of par-

ameters in a more flexible fuzzy form based on parameters
and characterized by fuzzy information, so it was widely
used in uncertain situations in various fields (Park et al.
2013).

Hence, this paper proposes a decision-making model
based on generalized intuitionistic fuzzy soft sets and
TOPSIS. The main contributions of this paper are as fol-

lows. (1) The certainty, uncertainty, and hesitancy of the
decision-making indicators of flood prevention emergency
plans during reservoir engineering are described by the
membership, non-membership, and hesitancy degrees in
the intuitive fuzzy sets. The membership degree of each
index is accurately calculated by the parameterization tool
of the soft sets. (2) In this paper, FOWA is used to calculate
the index weights, thereby avoiding the large number of
computational defects and fully considering the ambiguity
of experts’ judgment in the calculation of weights. (3) The
TOPSIS is expanded under generalized intuitionistic fuzzy
soft sets, thus effectively coordinating the intricate relation-

ship between multiple targets in the decision-making and
overcoming the difficulty of scientifically, effectively present-

ing the decision-making and evaluation levels. (4) This paper
reveals that full use of emergency materials and personnel is
the most important factor, which influences the decision-
making of flood prevention emergency plans during reser-

voir construction in the Wangjiazhou Reservoir Project.

**Evaluation Index System of Flood Prevention Emergency Plan during Reservoir Construction**

In the research of this paper, the index selection process
should not only meet the general requirements of the emer-
gency plan decision-making index system, but also fully
reflect the engineering practice characteristics and project
management needs of the decision-making of the reservoir
project during the flood season. The scientific and effective
decision-making of flood prevention emergency plans
during reservoir construction is focused on the selection of
scientific and operational evaluation indicators for emer-
gency plans. In addition, due to the strong uncertainty in
the occurrence, development, and spread of flood disasters,
emergency plans should have sufficient flexibility to adapt to
changes in flood disasters (Wang et al. 2019). In this work, 16
indicators were selected from the four aspects of scientific-

ity, operability, flexibility, and completeness to form a
decision index system of flood prevention emergency plans
during reservoir construction, as presented in Table 1. G1,
G2, G3, G4, G5, G9, G10, G11, G12, G13, G14, G15, and
G16 are qualitative indicators, the scores of which were
obtained by interviews with experts. Experts scored the
qualitative indicators based on their own experience. The
remaining indicators are quantitative indicators. The larger
the index score of benefit-oriented indicators, the better

<table>
<thead>
<tr>
<th>Primary indicator</th>
<th>Secondary indicator</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientificity F1</td>
<td>Rationality of command organization G1</td>
<td>Benefit</td>
</tr>
<tr>
<td></td>
<td>ScientifiCity of methodology G2</td>
<td>Benefit</td>
</tr>
<tr>
<td></td>
<td>Conform to relevant regulations and policies G3</td>
<td>Benefit</td>
</tr>
<tr>
<td></td>
<td>Eco-friendliness G4</td>
<td>Benefit</td>
</tr>
<tr>
<td></td>
<td>ScientifiCity of emergency technology G5</td>
<td>Benefit</td>
</tr>
<tr>
<td>Operability F2</td>
<td>Implementation costs of the emergency plan G6</td>
<td>Cost</td>
</tr>
<tr>
<td></td>
<td>Implementation time G7</td>
<td>Cost</td>
</tr>
<tr>
<td></td>
<td>Number of people mobilized G8</td>
<td>Cost</td>
</tr>
<tr>
<td></td>
<td>Emergency relief materials G9</td>
<td>Cost</td>
</tr>
<tr>
<td>Flexibility F3</td>
<td>Flexibility to respond to changes in emergency response levels G10</td>
<td>Benefit</td>
</tr>
<tr>
<td></td>
<td>Flexibility to deal with secondary disasters G11</td>
<td>Benefit</td>
</tr>
<tr>
<td></td>
<td>Flexibility to deal with disasters G12</td>
<td>Benefit</td>
</tr>
<tr>
<td>Completeness F4</td>
<td>Clarified the specific goals of each measure G13</td>
<td>Benefit</td>
</tr>
<tr>
<td></td>
<td>Clarified specific implementers of each measure G14</td>
<td>Benefit</td>
</tr>
<tr>
<td></td>
<td>A complete command and communication system G15</td>
<td>Benefit</td>
</tr>
<tr>
<td></td>
<td>Full use of emergency materials and personnel G16</td>
<td>Benefit</td>
</tr>
</tbody>
</table>
the emergency plan; in contrast, the smaller the index score of cost-type indicators, the better the emergency plan.

DEcision-Making Model of Flood Prevention Emergency Plan During Reservoir Construction

Introduction to generalized intuitionistic fuzzy soft sets

Let \( U = \{x_1, x_2, \ldots, x_n\} \) be a non-empty universe of discourse, and let \( A \) be an intuitionistic fuzzy set; \( \mu_A(x_i) \) and \( e_A(x_i) \) are respectively the membership degree and non-membership degree of the element \( x_i \) to the intuitionistic fuzzy set \( A \) in \( U \). Furthermore, it is required that \( 0 \leq \mu_A(x_i) + e_A(x_i) \leq 1 \).

The intuitionistic fuzzy set (Luo et al. 2018) is then

\[
A = \{(x_i, \mu_A(x_i), e_A(x_i))|x_i \in U\} \tag{1}
\]

\( \pi_A(x_i) \) is the hesitancy degree of \( x_i \) to \( A \) in \( U \), and indicates the uncertainty of whether element \( x_i \) belongs in \( A \). The greater the hesitancy degree, the stronger the uncertainty. The hesitancy degree \( \pi_A(x_i) \) satisfies Equation (2):

\[
v_A(x_i) = 1 - \mu_A(x_i) - e_A(x_i) \tag{2}
\]

When mapping \( Q: A \rightarrow IFU \), \( IFU \) is the set of all intuitionistic fuzzy subsets of \( U \), and the generalized parameter \( \delta \) is an intuitionistic fuzzy subset of \( E \). Then, \( Q(e) \) is a generalized intuitionistic fuzzy soft set based on the soft set \( (U, E) \) (Agarwal et al. 2011):

\[
Q_\delta = (Q(e), \delta(e)), Q(e) \in IF^U, \delta(e) \in IF \tag{3}
\]

where the mapping \( Q_G: A \rightarrow IF^G \times IF; Q(e) \) is the membership degree of the elements in the intuitionistic fuzzy soft set, and \( \delta(e) \) is the possibility degree of the membership degree of the \( U \) elements in \( Q(e) \).

Based on the preceding analysis, the basic steps are as follows.

(1) According to the characteristics of the research object, quantitative calculations, expert interviews, and other methods are used to obtain all index scores \( [x_{ij}]_{n \times m} \), in which, \( x_{ij} \) is the index score of the \( j \) index of the \( i \) plan. Equations (4) and (5) are used to calculate the membership degree \( [\mu_{ij}]_{m \times n} \) and non-membership degree value of the \( j \) index of the \( i \) plan.

For benefit-oriented indicators:

\[
\mu_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \tag{4}
\]

For cost-oriented indicators:

\[
\mu_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \tag{5}
\]

(2) Referring to previous practices (Zhang & Liu 2011), the hesitancy degree is calculated by Equation (6):

\[
\pi_{ij} = 0.5 \ast (1 - \mu_{ij}) \tag{6}
\]

From Equation (6), it can be seen that the larger or smaller the membership degree of the index, the lesser the hesitancy degree. In other words, when the score of the index is larger or smaller, the hesitancy degree (uncertainty) of the index is smaller.

(3) Equation (2) is used to calculate the non-membership degree \( v_{ij} \) of each attribute of the target. According to \( \mu_{ij} \) and \( v_{ij} \), the intuitionistic fuzzy set decision matrix \( M_{non} = [\mu_{ij}, v_{ij}]_{m \times n} \) is obtained.

Introduction to FOWA

The triangular fuzzy numbers are set as \( \tilde{a} = (a^L, a^M, a^U) \), \( \tilde{b} = (b^L, b^M, b^U) \), and the following algorithm is then employed (Golfam et al. 2019):

(1) \( \tilde{a} \oplus \tilde{b} = (a^L + b^L, a^M + b^M, a^U + b^U) \);

(2) \( \mu \otimes \tilde{a} = (\mu a^L, \mu a^M, \mu a^U), \mu \geq 0 \).

The formula for calculating the expected value \( E(\tilde{a}_{ij}) \) of the triangular fuzzy number \( \tilde{a}_{ij} = (a^{L}_{ij}, a^{M}_{ij}, a^{U}_{ij}) \) is

\[
E(\tilde{a}_{ij}) = [(1 - \lambda)a^{L}_{ij} + a^{M}_{ij} + \lambda a^{U}_{ij} / 2] \tag{7}
\]
where the value of $\lambda$ is determined by the risk attitudes of the decision-makers, and $\lambda = 0.5$ indicates that the decision-makers hold a risk-neutral attitude.

Let $F: D^p \rightarrow D$; if the function $F$ meets the following conditions (Golfam et al. 2019), then $F$ is called an $n$-dimensional FOWA operator:

1. $F(\hat{a}_1, \ldots, \hat{a}_n) = w_1 \otimes \hat{b}_1 \oplus w_2 \otimes \hat{b}_2 \oplus \cdots \oplus w_n \otimes \hat{b}_n$;
2. $W$ is the associated weighting vector, $w_i \in [0, 1], \sum w_i$;
3. $\hat{b}_j$ is the $j$-th largest element in a set of data $\hat{a}_i (\forall i \in N)$ given in the form of triangular fuzzy numbers.

The specific steps of the FOWA are as follows.

1. The influencing factor set $U = \{u_i\} = \{u_1, u_2, \cdots, u_n\}$ of the evaluation object is determined, in which $u_i$ is the $i$-th influencing factor and $n$ is the index number.
2. According to Equation (3), the corresponding complementary judgment matrix $\hat{A}$ is established by using the 0.1-0.9 scale method (Sun et al. 2019). In other words, the 0.1-0.9 scale is used to represent the relative importance of the two elements to the evaluation object. For instance, 0.9, (0.8, 0.9, 0.9), indicates that one factor is more important than the other factor. In contrast, factor $i$ is compared with factor $j$ to obtain $(a_{ij}^L, a_{ij}^M, a_{ij}^U)$, and then factor $j$ is compared with factor $i$ to obtain $(1 - a_{ij}^L, 1 - a_{ij}^M, 1 - a_{ij}^U)$.
3. The weighting vector $W = (w_1, w_2, \cdots, w_n)^T$ is determined, and $w_j$ can be calculated by the following equations (Golfam et al. 2019):

$$w_j = Q(j/n) - Q((j-1)/n), j \in N$$

$$Q(r) = \begin{cases} 
0, & r < a \\
\frac{r - a}{b - a}, & a \leq r \leq b \\
1, & r > b 
\end{cases}$$

where $i = 1, 2, \ldots, n$, and $w_j$ is the weighted value of the factors $U_i$. In this research, the ‘most’ fuzzy semantic quantization criterion is utilized, i.e., $(a, b) = (0.3, 0.8)$.

4. The expected value $E(\hat{a}_i)$ of each triangular fuzzy number $\hat{a}_i$ is calculated by Equation (7), and each row of the triangular fuzzy number complementary judgment matrix $\hat{A} = (\hat{a}_i)_{m \times n}$ is sorted according to the calculated expected value to obtain the matrix $\hat{B} = (\hat{b}_i)_{m \times n}$.

5. The influence degree $\hat{d}_i$ of each influencing factor on the evaluation object as compared with the other factors is calculated:

$$\hat{d}_i = F(\hat{a}_1, \ldots, \hat{a}_m) = \left( \sum_{k=1}^{n} w_k^L b_{kij}^L + \sum_{k=1}^{n} w_k^M b_{kij}^M + \sum_{k=1}^{n} w_k^U b_{kij}^U \right)$$

$$= (d_i^L, d_i^M, d_i^U)$$

(10)

6. The expected value $\hat{d}_i^{(j)}$ of $\hat{d}_i$ is calculated according to Equation (7):

$$\hat{d}_i^{(j)} = \frac{1}{2} \times [(1 - \lambda) \times d_i^L + d_i^M + \lambda d_i^U]$$

(11)

7. Each expected value $\hat{d}_i^{(j)}$ calculated by Equation (11) is normalized, and the obtained result is the weight of all risk factors $W = (w_1, w_2, \cdots, w_n)$:

$$w_j = \frac{\hat{d}_i^{(j)}}{\sum_{j=1}^{n} \hat{d}_i^{(j)}}$$

(12)

where $j = 1, 2, \ldots, n$.

**TOPSIS under generalized intuitionistic fuzzy soft sets**

TOPSIS is a widely used multi-scheme decision-making method. Its main principle is to sort based on the closeness of a limited number of evaluation objects and idealized targets to choose a better decision-making method. In this paper, interval language intuitionistic fuzzy sets were used to describe the attribute values of each index, so it was necessary to extend the TOPSIS method under interval language intuitionistic fuzzy sets. The key of the TOPSIS method is to find the positive (negative) ideal scheme and calculate the distance between the scheme to be decided and the positive (negative) ideal scheme.

1. Referring to previous practices (Wu & Su 2015), the weighted decision matrix $[f_{ij}]_{m \times n}$ is calculated according to Equation (13):

$$f_{ij} = w_j \ast \mu_{ij}, v_{ij} = (1 - (1 - \mu_{ij})^2, \nu_{ij}) = (\mu_{ij}, \nu_{ij})_{m \times n}$$

(13)
where \( w_j \) is the weight of the \( j \)-th index, \( m \) is the number of schemes, and \( n \) is the number of indicators.

(2) Equation (14) is used to calculate the optimal solution \( \mu^+_j \) and most unfavorable solution \( \mu^-_j \) of the membership degree, and the optimal solution \( v^+_j \) and most unfavorable solution \( v^-_j \) of the non-membership degree:

\[
\begin{align*}
\mu^+_j &= \max_{1 \leq i \leq m} \{\mu_{ij}\} \\
v^+_j &= \min_{1 \leq i \leq m} \{v_{ij}\} \\
\mu^-_j &= \min_{1 \leq i \leq m} \{\mu_{ij}\} \\
v^-_j &= \max_{1 \leq i \leq m} \{v_{ij}\}
\end{align*}
\]

Equation (14) is used to calculate the optimal solution

(3) The positive ideal solution \( C^+ \) and the negative ideal solution \( C^- \) of the matrix \( [F_{ij}]_{m \times n} \) are calculated. The intuitionistic fuzzy set vectors are

\[
\begin{align*}
C^+ &= (\mu^+_1, v^+_1, \mu^+_2, v^+_2, \ldots, \mu^+_n, v^+_n)^T \\
C^- &= (\mu^-_1, v^-_1, \mu^-_2, v^-_2, \ldots, \mu^-_n, v^-_n)^T
\end{align*}
\]

(4) Equations (16) and (17) are used to calculate the distance between each solution \( P_i (i = 1, 2, \ldots, m) \) and the positive and negative ideal solutions:

\[
D_i^+ = \sqrt{\frac{1}{2} \sum_{j=1}^{n} [(\bar{a}_{ij} - \mu^+_j)^2 + (\bar{a}_{ij} - v^+_j)^2 + (\bar{b}_{ij} - \mu^-_j)^2 + (\bar{b}_{ij} - v^-_j)^2]}
\]

\[
D_i^- = \sqrt{\frac{1}{2} \sum_{j=1}^{n} [(\bar{a}_{ij} - \mu^-_j)^2 + (\bar{a}_{ij} - v^-_j)^2 + (\bar{b}_{ij} - \mu^+_j)^2 + (\bar{b}_{ij} - v^+_j)^2]}
\]

where \( \bar{a}_{ij} = 1 - \mu_{ij} - v_{ij} \), \( \bar{b}_{ij} = 1 - \mu_{ij} - v_{ij} \), and \( i = 1, 2, \ldots, n \).

(5) The relative closeness degree of each scheme \( P_i (i = 1, 2, \ldots, m) \) to the negative ideal solution \( C^- \) is calculated by Equation (18):

\[
\varphi_i = \frac{D_i^-}{D_i^- + D_i^+}
\]

The larger the value of \( \varphi_i \), the better the corresponding plan \( P_i \). Therefore, according to the order of \( \varphi_i \) from greatest to least, the priority of the scheme is determined.

**Decision-making model based on generalized intuitionistic fuzzy soft sets and TOPSIS**

The flow chart for the decision-making model is shown in Figure 1.

In the study of the decision-making of flood prevention emergency plans for reservoir engineering, \( P = (P_1, P_2, \ldots, P_m) \) is designated as the set of emergency plans formulated by decision-makers, where \( P_i (i = 1, 2, \ldots, m) \) represents the flood prevention emergency plan for the \( i \)-th reservoir engineering. \( G = (G_1, G_2, \ldots, G_n) \) is the set of evaluation indicators for emergency plans, where \( G_j (j = 1, 2, \ldots, n) \) represents the \( j \)-th evaluation indicator. \( D = (D_1, D_2, \ldots, D_k) \) is a set of decision-makers participating in the flood prevention emergency plan during reservoir engineering, where \( D_q (q = 1, 2, \ldots, k) \) represents the \( q \)-th decision-maker.

The detailed steps are as follows.

Step 1. Collecting decision-making information to obtain the average score \( [x_{ij}]_{m \times n} \) of all indicators, where \( m \) is the number of schemes and \( n \) is the number of indicators. The intuitionistic fuzzy set decision matrix \( M_{x_{ij}} = [\mu_{ij}, v_{ij}]_{m \times n} \) is calculated using Equations (4)–(6).

Step 2. According to the 0.1–0.9 scale method (Sun et al. 2019), the complementary judgment matrix \( \bar{A} \) of the importance of each index is determined, and the index weight calculation model is executed based on FOWA to determine the index weight \( W = (w_1, w_2, \ldots, w_n) \).

Step 3. Using Equation (15), the decision matrix \( M_{x_{ij}} = [\mu_{ij}, v_{ij}]_{m \times n} \) and the index weight vector \( W = (w_1, w_2, \ldots, w_n) \) are assembled into a decision matrix after weighting \( [f_{ij}]_{m \times n} \).

Step 4. The TOPSIS method is executed with generated intuitionistic fuzzy soft sets, and the positive ideal solution \( C^+ \), the negative ideal solution \( C^- \), the distance between each plan \( P_i (i = 1, 2, \ldots, m) \), and the positive (negative) ideal solutions are calculated. The relative closeness degree \( \varphi_i \) of each evaluation plan is ultimately obtained.
Step 5. According to the value of the relative closeness degree $\varphi_i$, the ranking of plan $P = (P_1, P_2, \ldots, P_m)$ is determined.

**CASE STUDY**

**Case background**

The Wangjiazhou Reservoir Project is located in the upper reaches of Zhexi, Zhongxin Town, Pucheng County, China, and its total investment is 282 million yuan. The basin area above the dam site is 73.6 km², the normal water-storing level of the reservoir is 413 m, and the total volume is 20.93 million m³. In the early morning of June 7, 2019, according to the local meteorological station forecast of Pucheng County, the Zhexi area upstream of the Wangjiazhou Reservoir Project was forecast to have multiple rainstorms around June 11. According to the actual situation, the project managers formulated three emergency plans $P_1$, $P_2$, and $P_3$. $P_1$ was to concentrate resources on the construction of the dam. $P_2$ was to the overflow rock-fill dam and $P_3$ was the temporary cross-section. To make decisions on the flood prevention emergency plans as scientifically and effectively as possible, and to reduce losses, four experts D1, D2, D3, and D4 in different fields were invited to evaluate the emergency plans.

**Calculation results and analysis of index weights**

In combination with the existing research on the importance of the influencing factors of emergency plan decision-making and the questionnaire data of the four experts on the importance of the indicators listed in Table 1, a triangular fuzzy number complementary judgment matrix was established. The triangular fuzzy number complementary
judgment matrix was substituted into Equations (7)–(12), and the calculated results of the indicator weights are reported in Table 2.

The calculation results reported in Table 2 demonstrate that the comprehensive weight of the full use of emergency materials and personnel (G16) was 0.1134, and was the most important factor. The weights of having clarified the specific goals of each measure (G13) and implementation costs of the emergency plan (G6) were also greater. In contrast, eco-friendliness (G4) and scientifi city of emergency technology (G5) had the least weights. In addition, among the primary indicators, completeness (F4) had the largest weight, which was the key factor in the management of emergency plans.

Based on the preceding weight analysis results, some suggestions can be provided. The compilation and decision-making of the emergency plan should focus on the full use of emergency materials and personnel, clarifying the specific goals of each measure, and the implementation costs of the emergency plan. In addition, the preceding calculation process does not include a consistency test, as does the AHP; this reflects the advantage of the small calculation amount of the FOWA.

Decision-making results and analysis of emergency plans

Using the method of expert interviews, four experts were invited to score the qualitative indexes of G1, G2, G3, G4, G5, G9, G10, G11, G12, G13, G14, G15, and G16 of the three emergency plans in the range [0,100] according to their own experience. And these indicators have the following characteristics: the greater the score, the better the qualitative index. The implementation costs, the implementation time, and the number of people mobilized for the three plans were calculated and obtained by professional engineers on the project site. The scores of all indexes were averaged, as presented in Table 3. The unit of G6 is RMB, G7 is days, and G9 is %.

The membership degrees of the indexes were calculated by Equations (4) and (5), the non-membership degrees were calculated by Equation (6), the hesitancy degrees were

---

**Table 2** Calculation results of secondary indicator weights

<table>
<thead>
<tr>
<th>Indicator weight</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>G5</th>
<th>G6</th>
<th>G7</th>
<th>G8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicator weight</td>
<td>0.2640</td>
<td>0.1925</td>
<td>0.2574</td>
<td>0.1430</td>
<td>0.1430</td>
<td>0.3252</td>
<td>0.2878</td>
<td>0.2278</td>
</tr>
<tr>
<td>Comprehensive weight</td>
<td>0.0628</td>
<td>0.0458</td>
<td>0.0612</td>
<td>0.0340</td>
<td>0.0340</td>
<td>0.0883</td>
<td>0.0781</td>
<td>0.0618</td>
</tr>
<tr>
<td>Ranking</td>
<td>7</td>
<td>12</td>
<td>9</td>
<td>15</td>
<td>16</td>
<td>3</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indicator weight</th>
<th>G9</th>
<th>G10</th>
<th>G11</th>
<th>G12</th>
<th>G13</th>
<th>G14</th>
<th>G15</th>
<th>G16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicator weight</td>
<td>0.1592</td>
<td>0.2820</td>
<td>0.2856</td>
<td>0.4324</td>
<td>0.3037</td>
<td>0.1378</td>
<td>0.2092</td>
<td>0.3493</td>
</tr>
<tr>
<td>Comprehensive weight</td>
<td>0.0432</td>
<td>0.0468</td>
<td>0.0474</td>
<td>0.0718</td>
<td>0.0986</td>
<td>0.0447</td>
<td>0.0679</td>
<td>0.1134</td>
</tr>
<tr>
<td>Ranking</td>
<td>14</td>
<td>11</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>13</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 3** Scores of indexes for three emergency plans

<table>
<thead>
<tr>
<th>Emergency plan</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>G5</th>
<th>G6</th>
<th>G7</th>
<th>G8</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>66.25</td>
<td>81.25</td>
<td>82.5</td>
<td>70</td>
<td>70</td>
<td>326,700</td>
<td>3.125</td>
<td>17.5</td>
</tr>
<tr>
<td>P2</td>
<td>83.75</td>
<td>88.75</td>
<td>76.25</td>
<td>75</td>
<td>72.5</td>
<td>731,200</td>
<td>2.375</td>
<td>28.75</td>
</tr>
<tr>
<td>P3</td>
<td>77.5</td>
<td>65</td>
<td>63.75</td>
<td>67.5</td>
<td>80</td>
<td>212,320</td>
<td>1.5</td>
<td>32.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emergency plan</th>
<th>G9</th>
<th>G10</th>
<th>G11</th>
<th>G12</th>
<th>G13</th>
<th>G14</th>
<th>G15</th>
<th>G16</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>38.75</td>
<td>50</td>
<td>53.75</td>
<td>56.25</td>
<td>52.5</td>
<td>65</td>
<td>65</td>
<td>67.5</td>
</tr>
<tr>
<td>P2</td>
<td>81.25</td>
<td>70</td>
<td>86.25</td>
<td>76.25</td>
<td>82.5</td>
<td>70</td>
<td>72.5</td>
<td>80</td>
</tr>
<tr>
<td>P3</td>
<td>63.75</td>
<td>77.5</td>
<td>76.25</td>
<td>87.5</td>
<td>90</td>
<td>82.5</td>
<td>77.5</td>
<td>77.5</td>
</tr>
</tbody>
</table>
calculated by Equation (2), and the decision-maker evaluation decision matrix was obtained. Using Equation (13), the decision-maker evaluation decision matrix and the index weight vectors in Table 2 were assembled into a weighted decision matrix, and the calculation results are reported in Table 4.

According to the calculation results of Equations (14) and (15), the positive ideal solutions and the negative ideal solutions were obtained. According to Equations (16) and (17), the distances from each target to the positive and negative ideal solutions, as well as the relative closeness degree of each target to the positive ideal solution, were calculated. The results are presented in Table 5.

The ranking of the three schemes was $P_2 > P_3 > P_1$. In other words, the plan for passing flood season for the make-shift asphalt facing, allow flood to the overflow rock-fill dam of the Wangjiazhou Reservoir Project on June 11, 2019, should have been adopted.

**DISCUSSION**

When index weights are calculated based on FOWA, the parameter $\lambda$ representing the risk attitude of the decision-maker is of significance. In the case study reported in this research, $\lambda = 0.5$ was selected to indicate that the decision-makers held a risk-neutral attitude. In this section, the parametric analysis of $\lambda$ is performed. Table 6 reports the calculation results of each secondary indicator when different values were used. Among the investigated values, $\lambda = 0.1$ indicates that the risk attitude is extremely conservative, $\lambda = 0.3$ indicates that the risk attitude is conservative, $\lambda = 0.5$ indicates that the risk attitude is neutral, $\lambda = 0.7$ indicates that the risk attitude is aggressive, and $\lambda = 0.9$ indicates that the risk attitude is risk-taking.

The calculation results in Table 6 demonstrate that, regardless of the risk attitude of the decision-makers, the ranking of the indexes did not change, and only the weights of the indexes changed. The weights of some indexes, namely scientifi city of emergency technology ($G_5$), implementation costs of the emergency plan ($G_6$), implementation time ($G_7$), flexibility to deal with disasters ($G_{12}$), and a complete command and communication system ($G_{15}$), gradually decreased as the risk attitude of $\lambda$ increased.

**Table 4** Decision-maker evaluation decision matrix after weighting

<table>
<thead>
<tr>
<th>Plan</th>
<th>$G_1$</th>
<th>$G_2$</th>
<th>$G_3$</th>
<th>$G_4$</th>
<th>$G_5$</th>
<th>$G_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>$&lt;0.957&gt;$</td>
<td>$&lt;0.051,0.919&gt;$</td>
<td>$1.0&gt;$</td>
<td>$&lt;0.014,0.963&gt;$</td>
<td>$&lt;0.977&gt;$</td>
<td>$&lt;0.026,0.906&gt;$</td>
</tr>
<tr>
<td>$P_2$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;0.104,0.837&gt;$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;0.01,0.967&gt;$</td>
<td>$&lt;1.0&gt;$</td>
</tr>
<tr>
<td>$P_3$</td>
<td>$&lt;0.063,0.897&gt;$</td>
<td>$&lt;0.969&gt;$</td>
<td>$&lt;0.933&gt;$</td>
<td>$&lt;0.977&gt;$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;0.930&gt;$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plan</th>
<th>$G_7$</th>
<th>$G_8$</th>
<th>$G_9$</th>
<th>$G_{10}$</th>
<th>$G_{11}$</th>
<th>$G_{12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;0.951&gt;$</td>
<td>$&lt;0.965&gt;$</td>
<td>$&lt;0.962&gt;$</td>
<td>$&lt;0.962&gt;$</td>
<td>$&lt;0.0943&gt;$</td>
</tr>
<tr>
<td>$P_2$</td>
<td>$&lt;0.069,0.873&gt;$</td>
<td>$&lt;0.096,0.859&gt;$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;0.069,0.896&gt;$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;0.083,0.864&gt;$</td>
</tr>
<tr>
<td>$P_3$</td>
<td>$&lt;0.958&gt;$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;0.044,0.922&gt;$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;0.064,0.9&gt;$</td>
<td>$&lt;1.0&gt;$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plan</th>
<th>$G_{13}$</th>
<th>$G_{14}$</th>
<th>$G_{15}$</th>
<th>$G_{16}$</th>
<th>$-$</th>
<th>$-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>$&lt;0.922&gt;$</td>
<td>$&lt;0.946&gt;$</td>
<td>$&lt;0.946&gt;$</td>
<td>$&lt;0.911&gt;$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td>$P_2$</td>
<td>$&lt;0.171,0.765&gt;$</td>
<td>$&lt;0.071,0.879&gt;$</td>
<td>$&lt;0.071,0.879&gt;$</td>
<td>$&lt;1.0&gt;$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td>$P_3$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;1.0&gt;$</td>
<td>$&lt;0.194,0.734&gt;$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
</tbody>
</table>

**Table 5** The values of $D^+, D^-, \phi_i$ of each plan under the new model and the classical TOPSIS

<table>
<thead>
<tr>
<th>Plan</th>
<th>$D^+$</th>
<th>$D^-$</th>
<th>$\phi_i$</th>
<th>$D^+$</th>
<th>$D^-$</th>
<th>$\phi_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>3.6334</td>
<td>1.3804</td>
<td>0.2753</td>
<td>8.1332</td>
<td>3.4969</td>
<td>0.0176</td>
</tr>
<tr>
<td>$P_2$</td>
<td>2.7223</td>
<td>2.5983</td>
<td>0.4883</td>
<td>3.0017</td>
<td>9.1005</td>
<td>0.0310</td>
</tr>
<tr>
<td>$P_3$</td>
<td>2.8197</td>
<td>2.5936</td>
<td>0.4791</td>
<td>7.9026</td>
<td>2.7579</td>
<td>0.0302</td>
</tr>
</tbody>
</table>
the decision-makers was changed from conservative to risky. In contrast, the weights of the other indicators gradually increased as the risk attitude of the decision-makers was changed from conservative to risky.

To verify the reliability and effectiveness of the proposed decision-making model of flood prevention emergency plans during reservoir construction based on generalized intuitionistic fuzzy soft sets and TOPSIS, the data reported in Tables 2 and 3 were substituted into the classical TOPSIS method to obtain the values of $D^+$, $D^-$, and $q_i$ of the three plans, as presented in Table 5.

As can be seen from Table 5, the order by the classical TOPSIS method was also $P_2 > P_3 > P_1$. However, because the classical TOPSIS method did not consider the information of the uncertainty of the indexes during the evaluation, the relative closeness degree of $P_2$ and $P_3$ was very close, and the reliability and effectiveness of the final ranking result were difficult to guarantee. In contrast, the proposed decision-making model based on generalized intuitionistic fuzzy soft sets and TOPSIS fully describes all the certainty, uncertainty, and hesitancy information about the target attribute, and the membership degree of indexes is accurately calculated by the parameterized tools of soft sets. As compared with the classical TOPSIS method, the description of target attribute information by the proposed method is more comprehensive and accurate.

### CONCLUSIONS

Due to incomplete information and strong uncertainty involved in the decision-making of flood prevention emergency plans during reservoir construction, the certainty, uncertainty, and hesitancy of the decision-making indicators were described in this work by the membership, non-membership, and hesitancy degrees in intuitive fuzzy sets. The membership degree of each index was accurately calculated by the parameterization tool of the soft sets, which reduced the unscientific decision results of the traditional single-determination value. In this work, FOWA was used to calculate the index weights, thereby avoiding the large number of computational defects and fully considering the ambiguity of experts’ judgment in the calculation of weights. To overcome the difficulty of the scientific and effective presenting of the decision-making and evaluation levels, the TOPSIS method was expanded under generalized intuitionistic fuzzy soft sets, and the intricate relationships among multiple targets in the decision-making were effectively coordinated. The results of a case study demonstrate that the compilation and decision-making of emergency plans should focus on the full use of emergency materials and personnel, clarifying the specific goals of each measure and implementation costs of the emergency plan. Moreover, the plan, allowing flood to the overflow rock-fill dam of the Wangjiazhou Reservoir Project, should be adopted. As compared with the classical TOPSIS method, the model proposed in this paper was found to have better reliability and effectiveness. Further research on determining how to accurately portray the authority of different experts can be carried out based on the research presented in this article.

### ACKNOWLEDGEMENTS

This paper is supported by the Science and Technology Project of Wuhan Urban and Rural Construction Bureau, China (201943).
CONFLICT OF INTEREST

The authors declare there is no conflict of interest.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

REFERENCES


First received 4 June 2020; accepted in revised form 27 July 2020. Available online 10 August 2020.