Evaluation on Cost Overrun Risks of Long-distance Water Diversion Project Based on SPA-IAHP Method

Yang Yuanyue\textsuperscript{1,2}, Li Huimin\textsuperscript{3}

\textsuperscript{1}College of Water Conservancy and Hydropower Engineering, Hohai University, Nanjing 210098, China;
\textsuperscript{2}Design Management Centre of South-to-North Water Diversion Project Commission, Beijing, 100038, China;
\textsuperscript{3}North China University of Water Resources and Electric Power, Zhengzhou 450011, China.

Abstract: Large investment, long route, many change orders and etc. are main causes for costs overrun of long-distance water diversion project. This paper, based on existing research, builds a full-process cost overrun risk evaluation index system for water diversion project, apply SPA-IAHP method to set up cost overrun risk evaluation mode, calculate and rank weight of every risk evaluation indexes. Finally, the cost overrun risks are comprehensively evaluated by calculating linkage measure, and comprehensive risk level is acquired. SPA-IAHP method can accurately evaluate risks, and the reliability is high. By case calculation and verification, it can provide valid cost overrun decision making information to construction companies.

1. Introduction
Currently, the shortage of water resources in China are very serious, and per capita availability is small. Besides, the spatial distribution of water resources is uneven. Therefore, it is necessary to adopt scientific, economical, and reasonable trans-regional water diversion to solve the unbalanced spatial distribution of water resources in China. However, trans-regional water diversion is far beyond category of pure water conservancy project in aspects of scale and contents. Therefore, uncertain factors during construction are more, which always cause cost overrun.

Many experts and scholars in China studied cost risks of project. Xie Chi, Zhang Juan and Sun Bai\textsuperscript{[1]} provided effective decision making information for cost control of construction companies by studying cost risks of large-scale hydropower engineering construction project. Wang Zhenqiang and Zhong Denghua\textsuperscript{[2]} proposed the method combining CIM model and Monte Carlo simulation technology, studied investment probability risks of large-scale water conservancy project, and provided experiences for cost analysis. Wei Jia\textsuperscript{[3]} evaluated “ultra budget, ultra estimate and extra final settlement” problem of engineering project based on AHP, and set up AHP-based project risk evaluation model. Xue Yao, Liu Yongqiang and Daiwei\textsuperscript{[4]} applied WBS-BRS to identify risks for full process management of water conservancy project, and could effectively control possible risks during ntire process of water conservancy project by study. This cost overrun studied in this paper means the settlement price is larger than budget price.
2. Establishment of Evaluation Index System
This paper, combining characteristics of long-distance water diversion project, selects WBS-RBS[4] and literature reading to identify cost overrun risk (settlement price larger than budget price) during entire process of long-distance water diversion project construction. WBS-RBS method is a favorable risk identification method which can analyze cost overrun risk details in project cycle, and master overall risks. By WBS-RBS and literature reading, this paper totally selects 28 risk evaluation indexes to set up index system from five stages of water diversion project. See Table 1.

Tab 1. Index System of Long-distance Water Diversion Project Cost Overrun Risks Evaluation Based on SPA-IAHP Method

| Construction stage          | Primary index | Secondary index                              |
|-----------------------------|---------------|----------------------------------------------|
| Decision making stage       | Decision risk A1 | Inaccurate investment estimate B11            |
|                             |               | Uneconomical water diversion project construction standard B12 |
|                             |               | Unfavorable water diversion route selection B13 |
|                             |               | Unreasonable water diversion project scale B14 |
| Design and investigation stage | Investigation risk A2 | Lack of investigation data of water diversion project B21 |
|                             |               | Wrong investigation data of water diversion project B22 |
|                             | Design risk B21 | Wrong water diversion project design B31      |
|                             |               | Design over or lower than standard B32       |
|                             |               | Design estimate and budget not prepared accurately B33 |
| Bidding stage               | Bidding risk A4 | Wrong bidding document preparation B41        |
|                             |               | Unreasonable bidding control price B42       |
|                             |               | Bid-winning price lower than settlement price B43 |
| Contract risk A5            | improper contract type B51                     |
|                             | Problematic pricing method of contract B52    |
|                             | Defective contract document contents B53     |
| Environmental risk A6       | Rise in price (labor, material, machine) B71  |
|                             | Policy change B72                             |
|                             | exchange rate change B73                     |
| Construction stage          | Management risk A8                            |
|                             | Construct not follow project procedure B81    |
|                             | Fake costing of constructor B82              |
|                             | Chaotic field management B83                  |
| Change risk A9              | Construction change risk B91                  |
|                             | Design change risk B92                       |
| As-built acceptance stage   | As-built acceptance risk A10                 |
|                             | Completion accounting risk B101              |
|                             | Completion settlement risk B102              |

3. Establishment of Project Cost Overrun Risk Evaluation Model
SPA-IAHP[5, 6] is short for set pair analysis-interval analytic hierarchy process method, in which SPA, short for Set Pair Analysis, is a systematic analysis method proposed by Zhao Keqin, the Chinese Scholar in 1989 that certainty and uncertainty can be mutually converted, influenced and restricted by IDO theory; IAHP, short for Interval Analytic Hierarchy Process, is different from analytic hierarchy process method that the original and result data is expressed by interval number, which is relatively soft. The combination of SPA and IAHP can integrate quantitative and qualitative method, and be both objective and subjective[7].
3.1 Standards for cost overrun risk evaluation of long-distance water diversion project

According to former research, the risk probability and its influence degree affects risk scale. Therefore, this paper studies cost overrun risk of long-distance water diversion project through risk occurrence probability and its influence degree.

3.1.1 Standards for cost overrun risk probability of long-distance water diversion project. In accordance with the national standards of Risk Management – Risk Appraisal Technology [8], the cost overrun risks probability can be divided into five levels, seeing Table 2.

| Level | Qualitative description | Probability Interval | Estimated Value |
|-------|-------------------------|----------------------|-----------------|
| I     | Extremely low           | (0,0.10)             | 1               |
| II    | Low                     | (0.1,0.3)            | 2               |
| III   | Medium                  | (0.3,0.7)            | 3               |
| IV    | High                    | (0.7,0.9)            | 4               |
| V     | Extremely high          | (0.9,1)              | 5               |

3.1.2 Influence evaluation for cost overrun risk of long-distance water diversion project. In accordance with the national standards of Risk Management – Risk Appraisal Technology [8], the influence degree of overrun risk on costs is divided to five levels, seeing Table 3.

| Level | A       | B        | C        | D        | E        |
|-------|---------|----------|----------|----------|----------|
| Qualitative description | Extremely low | Low      | Medium   | High     | Extremely high |
| Estimated value           | 1         | 2        | 3        | 4        | 5         |

The risk scale is defined as product of risk occurrence probability and risk loss degree. Specific formula is as follows:

\[ R = G(p, r) = p \times r \]  

In formula (1), R is risk scale; p is risk occurrence probability; r is risk influence degree.

The size of risk scale can be acquired by this formula. This paper classifies risk degree by fuzzy interval theory for the convenience of set pair analysis and grading. See Table 4 for details.

| Risk Level | Risk Scale | Estimated Interval | Risk Decision |
|------------|------------|--------------------|---------------|
| I          | Low        | (0,3)              | Bearable      |
| II         | Medium     | (3,8)              | Bearable, but need follow-up control |
| III        | High       | (8,12)             | Unbearable, need to take measures to lower the risk |
| IV         | Higher     | (12,18)            | Unbearable, must adopt measures to lower the risk |

3.2 Confirming risk factor weight

Hire \( I \) experts to independently make comparison of \( x_i \) and \( x_j \) for relative importance degree. Suppose the \( k^{th} \) expert made comparison according to 1–9 scale of AHP, and the comparative interval acquired is \( \overline{A}_{ij} \)\(^{(r)}\) = \( [a_{ij}^{(r)}, a_{ji}^{(r)}] \). When the judgments of two experts are incompatible, i.e., \( \overline{A}_{ij} \)\(^{(r)}\) \( \cap \overline{A}_{ji} \)\(^{(r)}\) = \( \emptyset \), the indexes \( x_i \) and \( x_j \) will be compared again [9]. By comprehensively considering influential factors of different experts such as job experience and knowledge level, suppose own weight of expert is \( \omega_{e_k} = [\omega_{e_k}^{(1)}, \omega_{e_k}^{(2)}, \ldots, \omega_{e_k}^{(I)}] \), the calculation expression formula of all expert aggregative indicator judgment intervals confirmed shall be:
\[
\begin{align*}
a_{ij} &= \sum_{k=1}^{n} \omega_{ij}^{(k)} \cdot a_{ij}^{(p)} \\
a_{ji}^* &= \sum_{k=1}^{n} \omega_{ij}^{(k)} \cdot a_{ji}^{(p)}
\end{align*}
\] (2)

Then, the uncertain interval numbers judgment matrix will be:

\[
\begin{bmatrix}
[1,1] & [a_{12,1}, a_{12,2}] & \cdots & [a_{1m,1}, a_{1m,2}] \\
[1/a_{12}, 1/a_{12}] & [1,1] & \cdots & [a_{2m,1}, a_{2m,2}] \\
\vdots & \vdots & \ddots & \vdots \\
[1/a_{1m}, 1/a_{1m}] & [1/a_{2m}, 1/a_{2m}] & \cdots & [1,1]
\end{bmatrix}
\]

The consistency numbers judgment matrix must meet requirements of opposition of set pair analysis (SPA), and is expressed as \( M = (m_{ij})_{mm} \), in which, the calculation formula of \( m_{ij} \) shall be:

\[
m_{ij} = \frac{2^{m}}{\prod_{j=1}^{m} a_{ik} a_{jk}}
\]

(4)

The weight vector \( M \) of consistency numbers judgment matrix shall be \( \omega = (\omega_1, \omega_2, \cdots, \omega_m) \), and \( \omega_j \) can be calculated by Formula (5):

\[
\omega = \frac{2^{m} \prod_{j=1}^{m} a_{ik} \omega_i}{\sum_{i=1}^{2^{m}} \prod_{j=1}^{m} a_{ik} a_{ij}}
\]

(5)

In the formula, \( i = 1, 2, \cdots, m \)

By judgment matrix \( \overline{A} \) and consistency number matrix \( M \), the range matrix on both sides are respectively acquired \( \Delta_1 M = \Delta_2 M \)

\[
\Delta_1 m_{ij} = m_{ij} - a_{ij}^*
\]

(6)

\[
\Delta_2 m_{ij} = a_{ij}^* - m_{ij}
\]

(7)

The weight of range matrix can be calculated by formula (8),

\[
(\Delta_k \omega_j)^2 = \frac{\sum_{i=1}^{m} (\Delta_k m_{ij})^2}{\left(\sum_{i=1}^{m} m_{ij}\right)^2}
\]

(8)

In the formula, \( k = 1, 2, 3, \cdots, m \).

According to the formula, the evaluation index weight can be calculated,

\[
\bar{\omega} = \left[\bar{\omega}_1^{(L)}, \bar{\omega}_1^{(R)}, \bar{\omega}_2^{(L)}, \bar{\omega}_2^{(R)}, \cdots, \bar{\omega}_m^{(L)}, \bar{\omega}_m^{(R)}\right]
\]

(9)

In the formula:

\[\omega_i^{(L)} = \omega_i - \Delta_1 \omega_i \quad \omega_i^{(R)} = \omega_i + \Delta_1 \omega_i\]

The weight confirmed by aforesaid formula is fuzzy. This Paper solves this problem by SPA method, and carries out normalization processing for weight interval confirmed\(^{10}\). According to the Identity—Difference-Opposition (IDO) theory of set pair analysis, \( \bar{\omega}_i \in [\omega_i^{(L)}, \omega_i^{(R)}] \) and \( \omega_i \in [0,1] \), set pairs of \( \bar{\omega}_i (i = 1, 2, \cdots, m) \) in interval \([0,1]\). The formed Identity—Difference-Opposition (IDO)
The connection number of evaluation set is as follows:

\[ u_j = a_j + b_j \left( i + c_j - 1 \right) + \left( \omega_j^{(R)} - \omega_j^{(L)} \right) i + \left( 1 - \omega_j^{(R)} \right) c_j \]

In the formula, \( a_j + b_j + c_j = 1 \), \( a_j = \omega_j^{(L)} \) means the identity (same) in the theory of SPA; \( b_j = \omega_j^{(R)} - \omega_j^{(L)} \) means difference (indefinite) in the theory of SPA; \( c_j = 1 - \omega_j^{(R)} \) means opposition (contrary) in the theory of SPA.

\( a_j, b_j \in [-1, 1], a_j + b_j \leq 1 \), so \( 1 + a_j - c_j \in [0, 1] \). Therefore, the certainty interval weight of evaluation index is expressed by \( 1 + a_j - c_j \), and uncertainty interval weight will be expressed by \( 1 - b_j \). After normalization processing,

\[
\omega_j^{(CE)} = \frac{1 + a_j - c_j}{\sum_{i=1}^{p} (1 + a_k - c_k)}
\]

\[
\omega_j^{(UNCE)} = \frac{1 - b_j}{\sum_{i=1}^{p} (1 - b_k)}
\]

To sum up, the comprehensive weight calculation formula of cost overrun risk evaluation index shall be:

\[
\omega_j = \frac{\omega_j^{(CE)} \cdot \omega_j^{(UNCE)}}{\sum_{k=1}^{n} (\omega_j^{(CE)} \cdot \omega_j^{(UNCE)})}
\]

According to formula (12), the comprehensive weight shall be \( \omega = (\omega_1, \omega_2, \cdots, \omega_m) \).

### 3.3 Calculation of linkage measure

The linkage measure (IDO)\(^{[10]}\) can evaluate risk level from angles of Identity, Difference and Opposition, and can favorably solve uncertainty when evaluation risk belongs to certain level, and improve accuracy of evaluation.

#### 3.3.1 Calculation of single factor linkage measure

This paper assumes there are \( p \) risk factors in certain stage of long-distance water diversion project, and there are \( q \) indexes for every risk factor. The index matrix is built as follows:

\[
Y = \begin{bmatrix}
y_{11} & y_{12} & \cdots & y_{1q} \\
y_{21} & y_{22} & \cdots & y_{2q} \\
\vdots & \vdots & \ddots & \vdots \\
y_{p1} & y_{p2} & \cdots & y_{pq}
\end{bmatrix}
\]

In the formula, \( y_{pq} \) is the \( q \)\(^{th}\) index measured value of the \( p \)\(^{th}\) risk.

Suppose risks of \( q \) indexes are divided to \( B \) risk levels, and the standard matrix value of evaluation index shall be,

\[
X_{q=B} = \begin{bmatrix}
x_{10} \sim x_{11} & x_{11} \sim x_{12} & \cdots & x_{1(q-1)} \sim x_{1B} \\
x_{20} \sim x_{21} & x_{21} \sim x_{22} & \cdots & x_{2(q-1)} \sim x_{2B} \\
\vdots & \vdots & \ddots & \vdots \\
x_{q0} \sim x_{q1} & x_{q1} \sim x_{q2} & \cdots & x_{q(q-1)} \sim x_{qB}
\end{bmatrix}
\]

5
In the formula, $x_{q_0} \sim x_{q_1}$ - index $q$ standard limit value shall be Level I; $x_{q_1} \sim x_{q_2}$ - index $q$ standard limit value shall be Level II; $x_{q(C-1)} \sim x_{q_C}$ - index $q$ standard limit value shall be B.

The sample index set get by expert investigation and evaluation standards form set pair. When certain index is in this level, it will be regarded as identity, and take value of 1; when the index is in level of over two levels, it will be deemed as opposition, and take value of -1; when the index is in adjacent levels, it will be deemed as difference and value interval shall be $[-1, 1]$. Firstly, four linkage measure functions shall be built, as follows:

1. **Level I risk linkage measure function**

   $$\mu_{(i)}_j = \begin{cases} 1 - \frac{1}{x_{j(1)} - x_{j(0)}} y_j \in [x_{j(0)}, x_{j(1)}] \\ 1 - \frac{2(y_j - x_{j(1)})}{x_{j(1)} - x_{j(0)}} y_j \in [x_{j(0)}, x_{j(1)}] \\ 1 - \frac{1}{x_{j(2)} - x_{j(1)}} y_j \in [x_{j(1)}, x_{j(2)}] \\ 1 - \frac{2(y_j - x_{j(2)})}{x_{j(2)} - x_{j(1)}} y_j \in [x_{j(1)}, x_{j(2)}] \end{cases} \quad (13)$$

2. **Level II risk linkage measure function**

   $$\mu_{(2)}_j = \begin{cases} 1 - \frac{1}{x_{j(1)} - x_{j(0)}} y_j \in [x_{j(0)}, x_{j(1)}] \\ 1 - \frac{2(y_j - x_{j(1)})}{x_{j(1)} - x_{j(0)}} y_j \in [x_{j(0)}, x_{j(1)}] \\ 1 - \frac{1}{x_{j(2)} - x_{j(1)}} y_j \in [x_{j(1)}, x_{j(2)}] \\ 1 - \frac{2(y_j - x_{j(2)})}{x_{j(2)} - x_{j(1)}} y_j \in [x_{j(1)}, x_{j(2)}] \end{cases} \quad (14)$$

3. **Level III risk linkage measure function**

   $$\mu_{(3)}_j = \begin{cases} 1 - \frac{1}{x_{j(2)} - x_{j(1)}} y_j \in [x_{j(1)}, x_{j(2)}] \\ 1 - \frac{2(y_j - x_{j(1)})}{x_{j(1)} - x_{j(0)}} y_j \in [x_{j(0)}, x_{j(1)}] \\ 1 - \frac{1}{x_{j(3)} - x_{j(2)}} y_j \in [x_{j(2)}, x_{j(3)}] \\ 1 - \frac{2(y_j - x_{j(2)})}{x_{j(2)} - x_{j(1)}} y_j \in [x_{j(1)}, x_{j(2)}] \end{cases} \quad (15)$$

4. **Level IV risk linkage measure function**

   $$\mu_{(4)}_j = \begin{cases} 1 - \frac{1}{x_{j(3)} - x_{j(2)}} y_j \in [x_{j(2)}, x_{j(3)}] \\ 1 - \frac{2(y_j - x_{j(2)})}{x_{j(2)} - x_{j(1)}} y_j \in [x_{j(1)}, x_{j(2)}] \\ 1 - \frac{1}{x_{j(4)} - x_{j(3)}} y_j \in [x_{j(3)}, x_{j(4)}] \end{cases} \quad (16)$$

### 3.3.2 Calculation risk comprehensive linkage measure and evaluation risk level.

1. **Evaluation of single-level SPA**

   The product of single-level evaluation index system linkage measure and index weight will be the total risk linkage measure, seeing Table 5.
Tab 5. Single-level SPA

| Risk Level | 1       | 2       | ... | m       | Total linkage measure |
|------------|---------|---------|-----|---------|-----------------------|
| I          | \(\mu_1^{(1)}\) | \(\mu_2^{(1)}\) | ... | \(\mu_m^{(1)}\) | \(\sum_{i=1}^{m} \omega_i \mu_i^{(1)}\) |
| II         | \(\mu_1^{(2)}\) | \(\mu_2^{(2)}\) | ... | \(\mu_m^{(2)}\) | \(\sum_{i=1}^{m} \omega_i \mu_i^{(2)}\) |
| III        | \(\mu_1^{(3)}\) | \(\mu_2^{(3)}\) | ... | \(\mu_m^{(3)}\) | \(\sum_{i=1}^{m} \omega_i \mu_i^{(3)}\) |
| IV         | \(\mu_1^{(4)}\) | \(\mu_2^{(4)}\) | ... | \(\mu_m^{(4)}\) | \(\sum_{i=1}^{m} \omega_i \mu_i^{(4)}\) |

(2) Multilevel SPA evaluation
The evaluation of long-distance water diversion project cost overrun risk is a multilevel SPA evaluation \(^{[11, 12]}\). The calculation method is to evaluate every type of risk element of evaluation indexes according to single level, and synthesize the evaluation conclusion according to weight in higher level, finish high level evaluation based on low level comprehensive evaluation, and gradually calculate to finally form multilevel SPA evaluation.

4. Case study
The total length of trunk canal of certain long-distance water diversion project is 1276km, involving 1055 buildings with different sizes. The total investment is 201.3 Billion Yuan, in which, static investment is 162.5 Billion Yuan (in which, 155.5 Billion Yuan is for main project, 7 Billion is for reservoir and upstream water pollution prevention and water and soil preservation project), and dynamic investment is 38.8 Billion Yuan.

(1) Confirm and rank index weight
This paper takes risk factors in decision making stage as computational example, and calculates and rank weights of four indexes including inaccurate investment estimate \(B_{11}\), uneconomical water diversion project construction standard \(B_{12}\), unfavorable water diversion route selection \(B_{13}\), and unreasonable water diversion project scale \(B_{14}\). Five experts in relevant field judged importance, and acquired comparative interval of risk index importance, as follows:

\[
\begin{align*}
\vec{A}^{(1)} &= \begin{bmatrix}
[1,1] & [3,4] & [2,3] & [4,5] \\
1 & \frac{1}{4} & \frac{1}{5} & \frac{1}{3} \\
\frac{1}{3} & 1 & \frac{1}{2} & 1 \\
\frac{1}{2} & 1 & \frac{1}{3} & 1 \\
\frac{1}{1} & \frac{1}{2} & \frac{1}{3} & 1 \\
\end{bmatrix} \\
\vec{A}^{(2)} &= \begin{bmatrix}
[1,1] & [2,4] & [2,3] & [3,5] \\
\frac{1}{4} & \frac{1}{2} & \frac{1}{3} & 1 \\
\frac{1}{3} & \frac{1}{2} & 1 & \frac{1}{3} \\
\frac{1}{2} & 1 & \frac{1}{3} & 1 \\
\frac{1}{1} & \frac{1}{2} & \frac{1}{3} & 1 \\
\end{bmatrix} \\
\vec{A}^{(3)} &= \begin{bmatrix}
[1,1] & [2,4] & [2,3] & [4,6] \\
\frac{1}{4} & \frac{1}{2} & \frac{1}{3} & 1 \\
\frac{1}{3} & \frac{1}{2} & 1 & \frac{1}{3} \\
\frac{1}{2} & 1 & \frac{1}{3} & 1 \\
\frac{1}{1} & \frac{1}{2} & \frac{1}{3} & 1 \\
\end{bmatrix} \\
\vec{A}^{(4)} &= \begin{bmatrix}
[1,1] & [3,4] & [2,4] & [4,6] \\
\frac{1}{4} & \frac{1}{2} & \frac{1}{3} & 1 \\
\frac{1}{3} & \frac{1}{2} & 1 & \frac{1}{3} \\
\frac{1}{2} & 1 & \frac{1}{3} & 1 \\
\frac{1}{1} & \frac{1}{2} & \frac{1}{3} & 1 \\
\end{bmatrix}
\end{align*}
\]
According to comparative judgment matrix aforesaid, $A^{(i)}$, $A^{(2)}$, $A^{(3)}$, $A^{(4)}$ and $A^{(5)}$, there is no $A^{(i)} \cap A^{(j)} = \emptyset$. Senior experts in relevant field granted index weight coefficient, such as $\omega_{exp} = (0.3, 0.2, 0.2, 0.15, 0.15)$. Combining formula (2) and (3), the uncertain interval number judgment matrix is acquired, and consistency judgment matrix is acquired combining formula (4), as follows:

$$
\begin{bmatrix}
1,1 & 2.6, 3.75 & 1.65, 2.85 & 3.8, 5.51 \\
0.27, 0.38 & 1,1 & 0.42,1 & 1.235 \\
0.35, 0.61 & 1.238 & 1,1 & 1.3, 2.65 \\
0.18, 0.26 & 0.43,1 & 0.38, 0.77 & 1,1
\end{bmatrix}
$$

According to formula (10), (11) and (12), the relative weight of certain part, weight of uncertain part, and comprehensive weight of both, as follows:

$$
\omega_{CE} = (0.45, 0.17, 0.27, 0.11)
$$

According to formula (8) and (9), the interval weight of four indexes under decision risk factor shall be $[0.408, 0.510]$, $[0.133, 0.210]$, $[0.214, 0.334]$ and $[0.096, 0.116]$. Since this interval weight is uncertain at this time, four index linkage measures are built; the SPA is used to transfer interval weight to accurate weight value and make ranking, as follows:

$$
\begin{align*}
\mu_i &= 0.408 + (0.510 - 0.408)i + (1 - 0.51)j = 0.408 + 0.102i + 0.49j \\
\mu_2 &= 0.133 + (0.210 - 0.133)i + (1 - 0.21)j = 0.133 + 0.077i + 0.79j \\
\mu_3 &= 0.214 + (0.334 - 0.214)i + (1 - 0.334)j = 0.214 + 0.12i + 0.666j \\
\mu_4 &= 0.096 + (0.116 - 0.096)i + (1 - 0.116)j = 0.096 + 0.02i + 0.884j
\end{align*}
$$

Similarly, comprehensive weight of cost overrun risk factors in other construction stage can be seen in Table 6.
### Tab 6. Index weight and ranking of cost overrun risk evaluation of long-distance water diversion project

| Construction stage | Primary index | Secondary index | Comprehensive weight | Risk ranking |
|--------------------|---------------|-----------------|----------------------|--------------|
| **Decision making stage** | Decision risk A₁ | Inaccurate investment estimate B₁₁ | 0.63 | 1 |
| | | Uneconomical water diversion project construction standard B₁₂ | 0.09 | 3 |
| | | Unfavorable water diversion route selection B₁₃ | 0.25 | 2 |
| | | Unreasonable water diversion project scale B₁₄ | 0.03 | 4 |
| **Investigation risk A₂** | | Lack of investigation data of water diversion project B₂₁ | 0.25 | 1 |
| | | Wrong investigation data of water diversion project B₂₂ | 0.22 | 3 |
| **Design risk B₂₃** | | Wrong water diversion project design B₃₁ | 0.17 | 4 |
| | | Design over or lower than standard B₃₂ | 0.13 | 5 |
| | | Design estimate and budget not prepared accurately B₃₃ | 0.23 | 2 |
| **Bidding stage** | Bidding risk A₄ | Wrong bidding document preparation B₄₁ | 0.25 | 1 |
| | | Unreasonable bidding control price B₄₂ | 0.18 | 3 |
| | | Bid-winning price lower than settlement price B₄₃ | 0.12 | 5 |
| **Contract risk A₅** | | Improper contract type B₅₁ | 0.21 | 2 |
| | | Problematic pricing method of contract B₅₂ | 0.16 | 4 |
| | | Defective contract document contents B₅₃ | 0.08 | 6 |
| **Environmental risk A₆** | | Harsh field construction conditions B₆₁ | 0.15 | 2 |
| | | Construction environmental pollution B₆₂ | 0.18 | 1 |
| | | Harsh geological and hydrological conditions B₆₃ | 0.05 | 10 |
| **Policy risk A₇** | | Rise in price (labor, material, machine) B₇₁ | 0.09 | 5 |
| | | Policy change B₇₂ | 0.06 | 9 |
| | | Exchange rate change B₇₃ | 0.07 | 8 |
| **Management risk A₈** | | Construct not follow project procedure B₈₁ | 0.07 | 7 |
| | | Fake costing of constructor B₈₂ | 0.08 | 6 |
| | | Chaotic field management B₈₃ | 0.02 | 11 |
| **Change risk A₉** | | Construction change risk B₉₁ | 0.12 | 3 |
| | | Design change risk B₉₂ | 0.11 | 4 |
| **As-built acceptance stage** | As-built acceptance risk A₁₀ | Completion accounting risk B₁₀₁ | 0.46 | 2 |
| | | Completion settlement risk B₁₀₂ | 0.54 | 1 |

(2) Linkage measure calculation
Firstly, five experts are hired to carry out primary risk evaluation on 28 secondary indexes during long-distance water diversion project construction period. Based on evaluation index classification standards and linkage measure function formula (13)–(16), the risk linkage measure and risk level of every index can be acquired. See Table 7.
Table 7. Linkage measure and risk evaluation of cost overrun risk factors of long-distance water diversion project

| Construct stage | Primary index | Secondary index | I  | II  | III | IV  | Risk level |
|-----------------|---------------|-----------------|----|-----|-----|-----|------------|
| Decision making stage | Decision risk $A_1$ | Inaccurate investment estimate $B_{11}$ | -1 | 0.92 | 1 | -0.92 | High |
|                  |                | Uneconomical water diversion project construction standard $B_{12}$ | -1 | 0.91 | 1 | -0.91 | High |
|                  |                | Unfavorable water diversion route selection $B_{13}$ | -1 | 0.9 | 1 | -0.9 | High |
|                  |                | Unreasonable water diversion project scale $B_{14}$ | -0.68 | 1 | 0.68 | -1 | Medium |
| Total linkage measure |              |                | -0.99 | 0.92 | 0.99 | -0.92 | High |
| Design and investigation stage | Investigation risk $A_2$ | Lack of investigation data of water diversion project $B_{21}$ | -0.13 | 1 | 0.13 | -1 | Medium |
|                  |                | Wrong investigation data of water diversion project $B_{22}$ | -1 | 0.78 | 1 | -0.78 | High |
|                  | Design risk $B_2$ | Wrong water diversion project design $B_{23}$ | -1 | -0.34 | 1 | -0.34 | High |
|                  |                | Design over or lower than standard $B_{24}$ | 0.04 | 1 | -0.04 | -1 | Medium |
|                  |                | Design estimate and budget not prepared accurately $B_{25}$ | -0.9 | 1 | 0.9 | -1 | Medium |
| Total linkage measure |              |                | 0.62 | 0.88 | 0.62 | -0.88 | Medium |
| Bidding stage | Bidding risk $A_4$ | Wrong bidding document preparation $B_{41}$ | -0.64 | 1 | 0.64 | -1 | Medium |
|                  |                | Unreasonable bidding control price $B_{42}$ | -0.34 | 1 | 0.34 | -1 | Medium |
|                  |                | Bid-winning price lower than settlement price $B_{43}$ | -1 | 0.43 | 1 | -0.43 | High |
| Total linkage measure |              |                | -0.67 | 0.83 | 0.67 | -0.83 | Medium |
| Environmental stage | Environmental risk $A_6$ | Harsh field construction conditions $B_{61}$ | -0.6 | 1 | 0.6 | -1 | Medium |
|                  |                | Construction environmental pollution $B_{62}$ | -0.27 | 1 | 0.27 | -1 | Medium |
|                  |                | Harsh geological and hydrological conditions $B_{63}$ | -0.17 | 1 | 0.17 | -1 | Medium |
| Policy risk $A_7$ | Rise in price (labor, material, machine) $B_{71}$ | -1 | -1 | 0.81 | 1 | Higher |
|                  | Policy change $B_{72}$ | 0.85 | 1 | -0.85 | -1 | Medium |
|                  | Exchange rate change $B_{73}$ | 0.58 | 1 | -0.58 | -1 | Medium |
| Manage ment risk $A_8$ | Construct not follow project procedure $B_{81}$ | -0.83 | 1 | 0.83 | -1 | Medium |
|                  | Fake costing of constructor $B_{82}$ | -0.84 | 1 | 0.84 | -1 | High |
|                  | Chaotic field management $B_{83}$ | -0.71 | 1 | 0.71 | -1 | Medium |
| Change risk $A_9$ | Construction change risk $B_{91}$ | -1 | -1 | 0.81 | 1 | Higher |
|                  | Design change risk $B_{92}$ | -1 | -1 | 0.83 | 1 | Higher |
| Total linkage measure |              |                | -0.46 | 0.36 | 0.46 | -0.36 | High |
| As-built acceptance stage | As-built acceptance risk $A_{10}$ | Completion accounting risk $B_{101}$ | -0.65 | 1 | 0.65 | -1 | Medium |
|                  | Completion settlement risk $B_{102}$ | -0.67 | 1 | 0.67 | -1 | Medium |
| Total linkage measure |              |                | -0.66 | 1 | 0.66 | -1 | Medium |

The higher level factors of single-factor linkage measure calculation risks are inaccurate investment estimate $B_{11}$, uneconomical water diversion project construction standard $B_{12}$, unfavorable water diversion route selection $B_{13}$, wrong investigation data of water diversion project $B_{22}$, wrong water diversion project design $B_{23}$, bid-winning price lower than settlement price $B_{43}$, defective contract document contents $B_{63}$, fake costing of constructor $B_{82}$; higher level factors are rise in price (labor, material, machine) $B_{71}$, construction change risk $B_{91}$, and design change risk $B_{92}$; other risk factors belong to medium level.

In accordance with total linkage measure, in five stages of the construction period, the cost overrun risks in decision making stage and construction stage are of higher level. The higher level risks are unacceptable risks, and are the major causes for cost overrun. The construction party must adopt corresponding measures to transfer to avoid risks; the overrun risks in design stage, bidding stage and completion stage belong to medium level. Although they are acceptable, in order to prevent
them developing into high or higher levels, follow-up observation of cost control measures is necessary.

5. Conclusion
This paper carries out comprehensive and systematic analysis on cost overrun risks of long-distance water diversion project by WBS-RBS and literature reading, sets up evaluation index system for cost overrun of long-distance water diversion project, adopts SPA-IAHP method to calculate weight of cost overrun risk index weight of long-distance water diversion project, and finally calculate risk level of every risk factor combining linkage measure.

Calculation results show that the cost overrun risk of the water diversion project mainly occurred in decision making and construction stages. Combining actual situations, the water diversion project has completed largely and overrun is serious. Besides, the main cause for cost overrun is that risks are not avoided and transferred in decision making and construction stage.

It is concluded that the conclusion is consistent with the actual situation through the study, which means that this study has certain practical significance. Meanwhile, the author wishes to provide certain effective cost overrun risk decision making information to construction party by study so as to prevent from cost overrun and save investment for construction department.

Reference
[1] XIE Chi, ZHANG Juan, SUN Bai. Study on risk assessment and factor priorities recognition for large hydropower project construction cost [J]. Journal of Hydroelectric Engineering, 2010, 29(3): 63-68.
[2] WANG Zhenqiang, ZHANG Denghua Risk analysis on investment of large-scale water project [J]. Journal of Hydraulic Engineering, 2004, (7): 1–6.
[3] Wei jia. Research on risk control of "premium" in engineering cost based on Analytic Hierarchy Process [D]. Nanchang: Jiangxi University of Science and Technology, 2010.
[4] XUE Yao, LIU Yong-qi, DAI Wei. Risk Identification of Water Conservancy Projects in the Whole Process of WBS-RBS Method [J]. China Rural Water and Hydropower, 2014, (2):71-74.
[5] ZHAI Weifei, JIN Yongqiang, LOU Yiqing. Dam safety evaluation based on IAHP and SPA [J]. Engineering and Construction, 2008, (5): 606-611.
[6] TIAN Junfeng, CAO Chengying. Study on safety assessment method of tailings dam based on IAHP and SPA [J]. Gansu Science and Technology, 2013, 29(12): 28-29.
[7] CHANG Yongjuan. The Research of SPA Comprehensive Evaluation Method and its Application in the Electric Power System[D]. Beijing: North China Electric Power University, 2013.
[8] GB/T 27921-2011, Risk Management and Risk Assessment [S]. Beijing: STADARDS PRESS OF CHINA.
[9] WEN Jie. Research on project cost assessment by SPA [D]. Changsha: HUNAN UNIVERSITY, 2013.
[10] Li Deshun. Research on System Risk Assessment Based on General Set Pair Analysis [D]. Shenyang: NORTHEASTERN UNIVERSITY, 2010.
[11] ZHANG Weiwei. METHODS of Urban Systems Based on SPA and FAHP [D]. Hefei: Hefei University of Technology, 2007.
[12] ZHAO Shu-qi, LI Yong, WANG Chun-li. A dynamic comprehensive judgement method for transmission network planning based on SPA and AHP [J]. Journal of North China Electric Power University, 2009, 36(5): 17-21.