

Key Risk Factors Assessment for Metropolitan Underground Project

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Abstract

Underground construction project in metropolis is more dynamic and risky. A key risk factors analysis will give project contractor a more rational basis on which to make decision. This study applies the fuzzy preference relations and incomplete linguistic preference relations to deal with the degree of impact and rank for the main risk factors of a metropolitan underground project.

Keywords: Metropolitan underground project, Risk factors analysis, Fuzzy preference relations, Incomplete linguistic preference relations

1. Introduction

Because of the economic growth, in order to satisfy the needs of the people, the urban area needs to invest for the corresponding public constructions. But due to the limitation of the land availability in the metropolitan/urban area, many public constructions are developed toward underground, such as the MRT, subways or sewers and so on. Also, the dynamic, risk, variation, challenge in executing underground public constructions are much higher than the common non-urban/rural constructions. Especially for the crowded population, congested traffic and dense pipelines, construction underground pub-

lic works will be qualified as high-risk constructions. If the contractors can't provide a suitable assessment and processing of the risk and uncertainty factors of the metropolitan underground constructions, it may result in time delay, over-budget and poor performance [1][2]. Next, it would cause loss to the contractor and owner (public-related sector). That is, the stakeholders of the project will have loss in finance and reputation due to the deficient risk assessment and management strategies. Under this circumstance, it is a must to have an overall assessment of the risk and uncertainty factors before executing underground metropolitan public works. The determination of significant risk factors and providing necessary management strategies to overcome these key risk factors is a big incentive to each of the stakeholders of the projects. In other words, how to let the key risk factors of the underground public works undergo a primary assessment and plan-out an appropriate management strategy is one important work for the execution of this project.

This research utilizes the literature review to adopt a well established structure of the risk factors of the underground project execution. After which, we introduce the concept of consistent fuzzy preference relations and even use numerical examples to plot out the process method of assessing the

project's key risk factors. Lastly, we provide a discussion of the problems observed and a conclusion.

2. Assessment of key risk factors

This section's goal is to describe a key risk factors assessment approach of the public underground construction that includes two parts: (1) introducing risk factors of the execution of the projects on underground public works and (2) determining the degree of impact of the key risk factors.

2.1. Introducing the risk factors structure of an underground project

This study mainly establishes a risk assessment method on the execution of public underground works. Also, with the results from the literatures, Ghosh and Jintanapakanont [3] used factor analysis approach on risk factors of Thailand's underground works and created a corresponding overall analysis. Thus this study adopts the established risk factors of the research as basic assessment for the key risk factors of metropolitan public underground works. These risk factors include 9 components: financial and economic risk, contractual and legal risk, subcontractor-related risk, operational risk, design risk, safety and social risk, force majeure risk, physical risk, and delay risk.

2.2. Determining the degree of impact of risk factors

The degree of impact here is based on the concept of Zhi [4] who shows the degree of seriousness when involuntary things happen and the scale of impact they cause on the project. Because each risk factor of the project has different importance and implication, therefore, we cannot assume the same results from each risk factor's degree of impact. Many

researchers apply the analytical hierarchy process (AHP) which was developed by Saaty [5] [6] as their analysis tool to solve multi-criteria decision problems. But, when the criteria and factors are much more, the pairwise comparison used will create complication and it is hard to have consistency for the researchers. Herrera-Viedma et al. [7] proposed the fuzzy preference relations to solve the inconsistency of the decision matrices of pairwise comparisons based on additive transitivity. Xu [8] proposed an operational laws of linguistic evaluation scale to deal with incomplete linguistic preference relations also by using the additive transitivity property. Because this study has to evaluate a lot of risk factors, therefore, we use the two approaches to calculate the weights of the risk factors as the degree of impact on the project case of the risk factors. We provide a basic introduction on the definition and steps of the two proposed methods which is shown below:

2.2.1 Consistent fuzzy preference relations

A multiplicative preference relation A on a set of alternatives/criteria X is represented by a matrix $A \subset X \times X$, where $A = (a_{ij})$, a_{ij} is the preference intensity ratio of alternative/criteria x_i to alternative/criteria x_j . Saaty [5][6] suggested measuring a_{ij} to be scaled from 1 to 9.

The assessed values and corresponding meaning are shown in table 1.

Table 1. Linguistic scale of the assessment of the degree of impact of risk factors

Degree of Importance	Values
Equal Importance	1
Weak Importance	3
Essential Importance	5
Very Strong Importance	7
Absolute Importance	9
Intermediate Values	2 , 4 , 6 , 8

In this case, the preference relation A is typically assumed to be multiplicative reciprocal,

$a_{ij} \cdot a_{ji} = 1 \quad \forall i, j \in \{1, \dots, n\}$. The fuzzy preference relation P generated by X is a fuzzy set of $X \times X$, that is characterized by a membership function $\mu_p : X \times X \rightarrow [0, 1]$. The preference relation may be conveniently represented by the $n \times n$ matrix, $P = P(p_{ij})$, where $p_{ij} = \mu_p(x_i, x_j) \quad \forall i, j \in \{1, \dots, n\}$,

p_{ij} is the degree of preference ration of alternatives/criteria x_i and x_j . Herein, $p_{ij} = 1/2$ means $x_i \sim x_j$; $p_{ij} > 1/2$ means $x_i \succ x_j$ etc., and $p_{ij} + p_{ji} = 1$ for $i, j \in \{1, \dots, n\}$. Suppose there have a set of alternatives/criteria $X = \{x_1, \dots, x_n\}$, and associated with the $n-1$ preference intensity ratio $\{a_{12}, a_{23}, \dots, a_{n-1n}\}$ of alternative X for $a_{ij} \in [1/9, 9]$. The corresponding reciprocal fuzzy preference relations $P = (p_{ij})$, $p_{ij} \in [0, 1]$ can be obtained by $p_{ij} = g(a_{ij}) = 1/2 \cdot (1 + \log_9 a_{ij})$. Then use the following formula (1) to obtain the other preference relations values of not belonging to $\{p_{12}, p_{23}, \dots, p_{n-1n}\}$.

$$p_{i(i+1)} + p_{(i+1)(i+2)} + \dots + p_{(j-1)j} + p_{ji} \\ = (j - i + 1)/2, \quad \forall i < j \quad (1)$$

However, all the necessary elements in the decision matrix will not all lie within $[0, 1]$ but will lie within $[-a, 1 + a]$, where $a = |\min\{p_{ij} \quad \forall i, j\}|$. Therefore the decision matrix with entries that can be obtained by transforming the obtained values using a transformation function that maintains reciprocity and additive consistency. The transformation function is:

$$f : [-a, 1 + a] \rightarrow [0, 1], f(x) = \frac{x + a}{1 + 2a} \quad (2)$$

The obtained assessment decision matrix shows the consistent reciprocal relation $P' = (p'_{ij})$. Finally, it can use the formula (3) to obtain the importance (weight) of each factor:

$$A_i = 1 / n(\sum_{j=1}^n p'_{ij}), \quad W_i = A_i / \sum_{i=1}^n A_i \quad (3)$$

2.2.2 Consistent incomplete linguistic preference relations

Let $S = \{s_\alpha \mid \alpha = -t, \dots, t\}$ be a finite and totally ordered discrete term set, whose cardinality value is odd one, such as 7 and 9.[?] Each term, s_i represents a possible value for a linguistic variable and has characteristics of $s_\alpha > s_\beta$ if and only if $\alpha > \beta$. S can be defined as:

$$\mathbf{S} = \left\{ \begin{array}{l} s_{-4} = \text{absolute less important,} \\ s_{-3} = \text{strong less important,} \\ s_{-2} = \text{essential less important,} \\ s_{-1} = \text{weak less important,} \\ s_0 = \text{equal important,} \\ s_1 = \text{weak important,} \\ s_2 = \text{essential important,} \\ s_3 = \text{strong important,} \\ s_4 = \text{absolute important} \end{array} \right\}$$

The decision maker compares each pair of alternatives/criteria $X = \{x_1, \dots, x_n\}$ by using the discrete term set \mathbf{S} , and constructs a linguistic preference relation $\mathbf{A} = (a_{ij})_{n \times n}$, where a_{ij} indicates the preference degree or intensity for the alternative/criteria x_i over x_j , and $a_{ij} \in \mathbf{S}$, $a_{ij} \oplus a_{ji} = s_0$, $a_{ii} = s_0$, for all i, j . If the decision maker is unable to provide preference values for all pairs of alternatives/criteria, then \mathbf{A} is called an incomplete linguistic preference relation. If \mathbf{A} was constructed an acceptable incomplete linguistic preference relation with only $n-1$ judgments $a_{12}, a_{23}, \dots, a_{n-1n}$, then, we can use the known elements in \mathbf{A} and formula (4) to determine all the other unknown elements in \mathbf{A} , and thus get a consistent complete linguistic preference relation $\mathbf{A}' = (a'_{ij})_{n \times n}$.

$$a_{ij} = a_{ik} \oplus a_{kj}, \quad \text{for all } i, j, k \quad (4)$$

Finally, it can fuse all the preference degrees $a'_{ij} (j=1, 2, \dots, n)$ in the i th line of the \mathbf{A}' by using the linguistic averaging operator as formula (5), and then get the averaged one \bar{a}_i of the i th alternative/criterion over all the other alternatives/criteria.

$$\bar{a}_i = \frac{1}{n} a'_{i1} \oplus \frac{1}{n} a'_{i2} \oplus \dots \oplus \frac{1}{n} a'_{in}, \quad \text{for all } i \quad (5)$$

Lastly, it can base on this assessment results to understand the rank of the importance on the alternatives/criteria.

3. Numerical examples

This study applies the two approaches to assess the importance of the 9 key risk factors on underground project of Ghosh and Jintanapakanont [3]: (F_1)financial and economic risk, (F_2)contractual and legal risk, (F_3)subcontractor-related risk, (F_4)operational risk, (F_5)design risk, (F_6)safety and social risk, (F_7)force majeure risk, (F_8)physical risk, (F_9)delay risk.

As the first approach, it has to inquire the project managers who have ten years experience on the local construction to rankly compare the degree of impact (importance) of the 9 risk factors in Taipei's underground project. Namely F_1 compare with F_2 , F_2 compare with F_3 , F_3 compare with F_4 ... to make inference. Lastly, we compare F_8 and F_9 . All these need to compare 8 preference relations and the corresponding complements that are shown below:

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9
F_1	1	7							
F_2	1/7	1	1/5						
F_3		5	1	4					
F_4			1/4	1	1/6				
F_5				6	1	7			
F_6					1/7	1	1/7		
F_7						7	1	5	
F_8							1/5	1	3
F_9								1/3	1

Fig. 1: Fuzzy preference relations of risk factors ordered pairwise comparisons

For the second approach, the results of Fig. 1 will be changed to the outcomes of Fig. 2. For example,

$$\begin{aligned} a_{12} = a_{56} = 7 &\rightarrow a_{12} = a_{56} = s_3, \\ a_{23} = 1/5 &\rightarrow a_{23} = s_{-2}, a_{34} = 4 \rightarrow a_{34} = s_{1.5}, \\ a_{45} = 1/6 &\rightarrow a_{45} = s_{-2.5}, \\ a_{67} = 1/7 &\rightarrow a_{67} = s_{-3}, a_{78} = 5 \rightarrow a_{78} = s_{-2}, \\ a_{89} = 3 &\rightarrow a_{89} = s_1 \end{aligned} \quad P=$$

$$A= \begin{matrix} & F_1 & F_2 & F_3 & F_4 & F_5 & F_6 & F_7 & F_8 & F_9 \\ \begin{matrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ F_7 \\ F_8 \\ F_9 \end{matrix} & \begin{bmatrix} S_0 & S_3 & & & & & & & \\ S_{-3} & S_0 & S_{-2} & & & & & & \\ & S_2 & S_0 & S_{1.5} & & & & & \\ & & S_{-} & S_0 & S_{-} & & & & \\ & & & S_{2.5} & S_0 & S_3 & & & \\ & & & & S_{-3} & S_0 & S_{-3} & & \\ & & & & & S_3 & S_0 & S_2 & \\ & & & & & & S_{-2} & S_0 & S_1 \\ & & & & & & & S_{-1} & S_0 \end{bmatrix} \end{matrix}$$

Fig. 2: Incomplete linguistic preference relations value of risk factors ordered pairwise comparisons

From the ordered pairwise comparison of Fig. 1, we compute their preference relations value a_{ij} by the function $p_{ij} = g(a_{ij}) = 1/2 \cdot (1 + \log_s a_{ij})$ and the formula (1). The a_{ij} can be transformed to p_{ij} , where p_{ij} lies within $[0, 1]$ as show in the results below:

$$P= \begin{matrix} & F_1 & F_2 & F_3 & F_4 & F_5 & F_6 & F_7 & F_8 & F_9 \\ \begin{matrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ F_7 \\ F_8 \\ F_9 \end{matrix} & \begin{bmatrix} 0.500 & 0.943 & 0.577 & 0.892 & 0.484 & 0.927 & 0.484 & 0.851 & 1.101 \\ 0.057 & 0.500 & 0.134 & 0.449 & 0.041 & 0.484 & 0.041 & 0.408 & 0.658 \\ 0.423 & 0.866 & 0.500 & 0.815 & 0.408 & 0.851 & 0.408 & 0.774 & 1.024 \\ 0.108 & 0.551 & 0.185 & 0.500 & 0.092 & 0.535 & 0.092 & 0.459 & 0.709 \\ 0.516 & 0.959 & 0.592 & 0.908 & 0.500 & 0.943 & 0.500 & 0.866 & 1.116 \\ 0.073 & 0.516 & 0.149 & 0.465 & 0.057 & 0.500 & 0.057 & 0.423 & 0.673 \\ 0.516 & 0.959 & 0.592 & 0.908 & 0.500 & 0.943 & 0.500 & 0.866 & 1.116 \\ 0.149 & 0.592 & 0.226 & 0.541 & 0.134 & 0.577 & 0.134 & 0.500 & 0.750 \\ -0.101 & 0.342 & -0.024 & 0.291 & -0.116 & 0.327 & -0.116 & 0.250 & 0.500 \end{bmatrix} \end{matrix}$$

Fig. 3: Reciprocal fuzzy preference relations of risk factors

From the matrix above, we can clearly observe that there are some values that lies outside the range $[0,1]$. Therefore, we need to use formula (2) to process transformation in order to guarantee the reciprocity and additive consistency of the whole matrix. The transformed consistent reciprocal fuzzy preference relation matrix is as follows:

$$P'= \begin{matrix} & F_1 & F_2 & F_3 & F_4 & F_5 & F_6 & F_7 & F_8 & F_9 \\ \begin{matrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ F_7 \\ F_8 \\ F_9 \end{matrix} & \begin{bmatrix} 0.500 & 0.859 & 0.562 & 0.818 & 0.487 & 0.847 & 0.487 & 0.785 & 0.987 \\ 0.141 & 0.500 & 0.203 & 0.459 & 0.128 & 0.487 & 0.128 & 0.425 & 0.628 \\ 0.438 & 0.797 & 0.500 & 0.756 & 0.425 & 0.785 & 0.425 & 0.722 & 0.925 \\ 0.182 & 0.541 & 0.244 & 0.500 & 0.169 & 0.528 & 0.169 & 0.466 & 0.669 \\ 0.513 & 0.872 & 0.575 & 0.831 & 0.500 & 0.859 & 0.500 & 0.797 & 1.000 \\ 0.153 & 0.513 & 0.215 & 0.472 & 0.141 & 0.500 & 0.141 & 0.438 & 0.641 \\ 0.513 & 0.872 & 0.575 & 0.831 & 0.500 & 0.859 & 0.500 & 0.797 & 1.000 \\ 0.215 & 0.575 & 0.278 & 0.534 & 0.203 & 0.562 & 0.203 & 0.500 & 0.703 \\ 0.013 & 0.372 & 0.075 & 0.331 & 0.000 & 0.359 & 0.000 & 0.297 & 0.500 \end{bmatrix} \end{matrix}$$

Fig. 4: Final decision matrix of the first approach

Lastly we apply formula (3) to obtain the corresponding degree of impact (weights) and rank the importance of the risk factors (see Table 2.)

Table 2. The importance of the risk factors for the first approach

Risk Factor	Degree of Impact	Rank
financial and economic risk	0.156	2
contractual and legal risk	0.076	7
subcontractor-related risk	0.143	3
operational risk (F_4)	0.086	5
design risk (F_5)	0.159	1
safety and social risk (F_6)	0.079	6
force majeure risk (F_7)	0.159	1
physical risk (F_8)	0.093	4
delay risk (F_9)	0.048	8

For the second approach, utilize the known elements in Fig. 2 and formula (4) to determine all the unknown elements in A. We get the corresponding consistent complete linguistic preference relations as following:

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9
F_1	S_0	S_3	S_1	$S_{2.5}$	S_0	S_3	S_0	S_2	S_3
F_2	S_{-3}	S_0	S_{-2}	S_{-1}	S_{-3}	S_0	S_{-3}	S_{-1}	S_0
F_3	S_{-1}	S_2	S_0	$S_{1.5}$	S_{-1}	S_2	S_{-1}	S_1	S_2
F_4	S_{-1}	$S_{0.5}$	S_{-1}	S_0	S_{-1}	$S_{0.5}$	S_{-1}	S_{-1}	S_{-1}
F_5	S_0	S_3	S_1	$S_{2.5}$	S_0	S_3	S_0	S_2	S_3
F_6	S_3	S_0	S_{-2}	S_{-1}	S_{-3}	S_0	S_{-3}	S_{-1}	S_0
F_7	S_0	S_3	S_1	$S_{2.5}$	S_0	S_3	S_0	S_2	S_3
F_8	S_{-2}	S_1	S_{-1}	$S_{0.5}$	S_{-2}	S_1	S_{-2}	S_0	S_1
F_9	S_{-3}	S_0	S_{-2}	S_{-1}	S_{-3}	S_0	S_{-3}	S_{-1}	S_0

Fig. 5: Final decision matrix of the second approach

Utilize formula (5) to fuse all the preference degrees $a'_{ij} (j = 1, 2, \dots, 9)$ in the i th line of the A' , and then get the averaged one \bar{a}_i of the i th risk factors over all the other risk factors:

$$\begin{aligned} \bar{a}_1 &= s_{1.61}, & \bar{a}_2 &= s_{-1.39}, & \bar{a}_3 &= s_{0.61}, \\ \bar{a}_4 &= s_{-0.89}, & \bar{a}_5 &= s_{1.61}, & \bar{a}_6 &= s_{-1.39}, \\ \bar{a}_7 &= s_{1.61}, & \bar{a}_8 &= s_{-0.39}, & \bar{a}_9 &= s_{-1.39} \end{aligned}$$

Rank all the risk factors in accordance with the values of \bar{a}_i :

$$F_1 \sim F_5 \sim F_7 \succ F_3 \succ F_8 \succ F_4 \succ F_2 \sim F_6 \sim F_9$$

From the simulated values above, we can note that after obtaining the assessment of experienced experts, we can find that there are somewhat different between the two approaches. For the first approach, the design risk and force majeure risk are the highest degree of impact on Taipei's underground project. This result is the same as the second approach, but considers the financial and economic risk also to be the most important. Furthermore, both approaches consider the lowest degree of impact is the delay risk. Therefore, if we execute an underground project in Taipei, we can more or less give attentions on the most significant factors before the construction, so as to come up with good risk control strategies. Because of time and page limit, this study isn't able to assess the occurrence probability of each risk factor. Therefore, we can include this part in future research and after that integrate with these results to calculate the risk level or risk degree of each risk factor.

4. Conclusion

In the traditional AHP comparisons, if there are n items have to assess, we need to compare them in $n(n-1)/2$ times. After Herrera-Viedma et al. [7] and Xu [8] proposed the method of fuzzy preference relations and incomplete linguistic preference relations, the

number of pairwise comparisons can be reduced by $n - 1$ times. Not only does it simplify the designing and answering of the questionnaires, but also it can maintain preference consistence. There is no need to spend extra time to solve or investigate the question of consistency. Especially, when assessing a lot of risk factors or criteria, a better result will be then obtained. Therefore, this study utilizes this two assessment methods so that those who are unfamiliar with the complicated process of AHP will be given a big ease.

5. References

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