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Identification and Analysis of Metro Foundation Construction Safety Risk Based on Fault Tree Analysis

Hongmei Liu*[a], Liang Liu[b], Xiaolei Ji[c]

[a]School of Architecture Engineering, Jiangsu Open University, No.832 Yingtian Street, Nanjing, Jiangsu Province, China
[b]Guangzhou Rail Transit Construction Management Co. Ltd.
[c]School of Architecture Engineering, Jiangsu Open University
184858472@qq.com

Fuzzy theory and Bayesian network theory were based on the fault tree. The fault tree analysis method improved the fault analysis to obtain number of event's exact problem. Considering the characteristics of the fuzzy risk analysis at the same time, it also solved the problem of scale fault analysis modeling. The theory is applied to the cost of construction shield tunnel risk analysis, floating shield tunnel segments, dislocation of failure risk analysis and deep station foundation construction risk analysis. By security risk identification and evaluation process, it can be improved to subway construction process of deep foundation pit hazard anticipation. Before construction accidents to avoid and resolve security risks, thereby improving overall system safety performance. Based on this, the paper depth study the theory and methods of security risk identification and security risk assessment, further enrich the security risk management theory, and put forward to deal with the security risk response countermeasures.

1. Introduction

With urban underground space development, construction and operation of the subway is a successful model, both to ease the pressure on urban traffic, but also to solve the congestion of urban population growth (He (2006)). Recently, almost all developed countries increased as the construction of urban subway traffic supply level, to address the underlying instruments city syndrome (Ferdous (2011)). Coupled with a large volume of traffic subway, safe, reliable, fast, comfortable and takes up little floor space, with the rapid development of the subway in the world (Tang (2016)), (Bortone (2015)). Usually by extending urban land to ease, and for the phenomenon of gradual tightening, available urban land area is concerned, relying solely on the development and utilization of urban land surface area. It has been far from meeting the transportation needs of the city, so people put major effort to invest in underground space of the city (Wu (2015)). Subway construction projects faced enormous challenges (Ding (2012)). Firstly, subway construction projects have a large extent affected by the underground construction environment, geology and hydrology. The area is prone to poor pit collapse gushing pit body piping and other accidents. Secondly, the urban underground space in pipelines criss-cross various natural gas, water supply and drainage, power cables, communication cables and other pipes are likely near a metro construction soil, likely to cause an accident because of damage caused by the pipeline, such as natural gas, coal gas rupture explosion, power line damage and so on (Tang (2016)). Thirdly, in the underground subway construction environment, whether it is to take cut and cover, shield tunneling and other excavation work method, they are prone to uneven soil subsidence, ground collapse or bulge like (Zhang (2013)). Finally, insecurity subway construction management in construction can also cause accidents, such as uneven ground subsidence, improper precipitation, foundation pit above the heap load caused by an irrational body collapse, construction workers carry kindling into the construction site causing a fire explosion and so on (Zhang (2014)). Fault analysis (FTA) is an integrated multidisciplinary technology, including a number of tools such as FMECA, FTA and ETA. By using a tool alone had produced great economic benefits, but its limitations also limit its advantages of further play (Zhou (2011)). Then consider by using the effective combination of multiple tool, both can make up for their deficiencies and produce greater economic benefits. Therefore, it will include FTA, a variety of fault tree analysis and other reliability. Security policy integration

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method applied has been an important research topic for researchers such as FMECA (failure mode, effects and criticality analysis), FTA fault tree analysis, improved the management system, providing enhanced reliability scientific basis, while those used in reliability analysis techniques and risk analysis system for the safe operation of the device (Choi (2008)). It is possible to achieve the production of equipment failure prediction, optimization of maintenance strategy, life cycle assessment and reliability and risk assessment, increase security, reduce losses, better ensure the normal operation of the company (Sadiq (2007)). Subway construction as a big security risk management background, combined in metro construction to carry the actual object of research, excavation of subway security risk identification and evaluation.

2. Risk analysis based on fuzzy fault tree

2.1 Fuzzy probability influencing factors

It is assumed that factors the probability f1-f15 and p1-p15, so the probability of occurrence in the entire segment shield and tunnel segment construction accidents, namely floating shield tunnel segments, dislocation and cracking failure the top event probability:

$$P_{\tilde{A}} = 1 - \prod_{i=1}^{15} (1 - p_i) \tag{1}$$

Suppose N is triangular fuzzy number, and sign:

$$\tilde{f}_j = \left(m_j - a_j, m_j, m_j + b_j\right), j = 1 \sim N \tag{2}$$

Introducing the concept of representation theorem, the definition of hypothesis H:

$$\left(0,1\right] \to I_R, \lambda \mapsto H\left(\lambda\right) = \left[m_\lambda, n_\lambda\right] \neq \phi \tag{3}$$

And meet:

$$\lambda_1 < \lambda_2 \Rightarrow \left[m_{\lambda 1}, n_{\lambda 1}\right] \supseteq \left[m_{\lambda 2}, n_{\lambda 2}\right] \tag{4}$$

$$\begin{aligned}
&a. \tilde{A} = \bigcup_{\lambda \in [0,1]} \lambda H\left(\lambda\right), \tilde{A} \ is\ fuzzy\ number \\
&b. \tilde{A}_\lambda = \bigcap_{n=1}^{\infty} H\left(\lambda_n\right), \left(\lambda > 0\right), \left(\lambda_n = 1 - \frac{1}{n+1}\right) \\
&c. \tilde{A} = \left(\left[m_{\tilde{A}}, n_{\tilde{A}}\right], L_{\tilde{A}}, R_{\tilde{A}}\right) \\
&d. m_{\tilde{A}} = \lim_{n \to \infty} m_{\lambda_n}, n_{\tilde{A}} = \lim_{n \to \infty} n_{\lambda_n}, \left(\lambda_n = 1 - \frac{1}{n+1}\right) \\
&e. L_{\tilde{A}}\left(x\right) = \vee_{0<\lambda<1} \left\{\lambda \middle| m_\lambda < x\right\}, R_{\tilde{A}}\left(x\right) = \vee_{0<\lambda<1} \left\{\lambda \middle| n_\lambda \geq x\right\},
\end{aligned} \tag{5}$$

mλ indicates brother cut multiplied by the number of fuzzy sets off and the product range of left point expression; nλ indicates brother cut all multiplied by the number of fuzzy sets and the product range right end of the expression.

$$\begin{cases} m_\lambda = \prod_{j=1}^{N} \left[m_j - a_j\left(1 - \lambda\right)\right] \\ n_\lambda = \prod_{j=1}^{N} \left[m_j + b_j\left(1 - \lambda\right)\right] \end{cases} \tag{6}$$

At the same time, the triangular fuzzy numbers multiplied in operation:

$$m_A = n_A = \prod_{j=1}^{N} m_j \tag{7}$$

By Δij=Rij-Lij calculations, obtained the expert judgment of shield tunnel segments failure occurrence probability factors interval. Then use Table 1 as the range of confidence amended triangular fuzzy numbers.

Table 1: The correction range determined by confidence index and Interval

Interval (%)	Confidence index k									
	10	9	8	7	6	5	4	3	2	1
0.1	0	0.25	0.06	0.08	0.1	0.15	0.22	0.25	0.31	0.36
0.3	0	0.075	0.18	0.25	0.33	0.45	0.65	0.8	0.9	1.1
0.4	0	0.1	0.22	0.33	0.44	0.55	0.88	0.99	1.1	1.5
0.5	0	0.13	0.3	0.5	0.7	0.8	1.0	1.2	1.3	1.6
1	0	0.3	0.5	0.8	1	1.5	2.0	2.5	3.0	3.5
2	0	0.5	0.8	1.0	2	3.0	4.0	4.5	6.0	7.0
3	0	0.8	1.2	2.2	3	5.0	6.0	7.0	9.0	10.5
4	0	1	1.6	3.0	4	6.0	8.0	9.0	12	14.0
5	0	1.3	2.3	3.8	5.1	7.6	11	13	16	18
10	0	2.6	5	7.5	10	15	20	25	30	35
20	0	5.1	10	15	20	30	40	50	60	70
30	0	7.8	15	22.5	30	45				

K and confidence interval selected correction range for a long time, the first interval to interval 10% begin fitting the line ak, while according to the value of this line as a reference, and then calculate other table rows data. The table coating four shaded data, the probability of the event or fault tree tops fuzzy structure at the end of the event importance was only in [0-100%], because the confidence index of greater than or equal to 3, so the correction range gas ak <50%.

2.2 Excavation safety risk factors analysis

Underground excavation project was a subsystem of subway construction projects in time and space is an open dynamic system. The construction of subway deep excavation safety factor complex, wide range of ridicule. From a macro point of view, subway excavation and the following four factors: people, technology, environment and management. Coordination of these four elements, in metro construction process it may not accidents. People are the core elements of management as one of control means to coordinate the human, technical, environmental mutual relations. State security and subway construction projects back to the risk of decision-makers, and promote change management plan to adjust, so that the project reaches subway was a safe state. Subway excavation construction safety management factors mainly refer to the manager in accordance with objective laws of deep excavation construction. Engineering construction related to implementation of human, financial, material, information and other resources, to carry out all the activities of risk control. Management factors including specific terms of team management, organizational management system, system construction management, construction methods, monitoring means. Management body builders and project managers, management object is human, material and financial resources, and information. Intrinsic safety management mobilize all forces and resources, the development of scientific and systematic safety management system play people's initiative to reduce accidents promote safe construction. Management methods include planning, organization, leadership, coordination. Management factor is an important factor in metro construction guarantee security. Regularly in metro construction of all levels of leadership, management operating personnel safety, ideological and political education and safety education, to improve the safety performance of construction system is important.

3. Experiments and results

3.1 Examples of engineering calculation

According to foundation pit accident characteristics and principle of fault tree, progressively drawing excavation fault tree was shown in Figure 1. Intermediate events deep excavation accidents are: B1 is the excavation site; B2 is a continuous wall construction field; B3 is the light rail reinforcement site; B4 is site; B5 is grouting construction site; B6 is on-site management at the end of the event. X1 is the surrounding buildings settlement; X2 support for the dismantling in reverse order; X3 is collapsing; X4 is a steel cage hoisting danger; X5 is collapse hole; X6 mechanical bumps pier, beam; X7 is large horizontal displacement piers; X8 for the light rail track uneven settlement; X9 underground pipeline rupture; X10 as a temporary enclosure unstable , windy weather collapsed; X11 is grouting equipment leakage; X12 is not the operator certificates, illegal operations; X13 is not strong reinforcement pit enclosure or connection failure; X14 is lifting operations chain of command is not clear; X15 is machinery illegal operations.

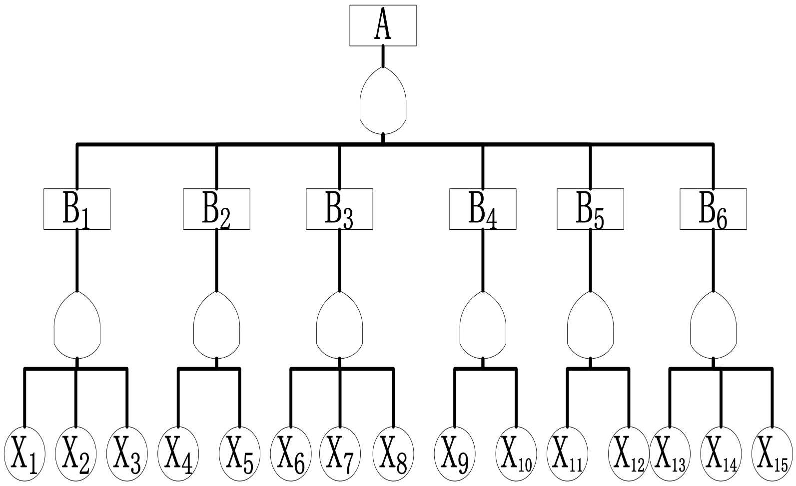

Figure 1: Progressively drawing excavation fault tree

According to the fault tree excavation system, constructed network model, was shown in Figure 2. In this example, some of the intermediate event is considered to be the same case in the construction of Bayesian network model. Based on Bayesian network fault tree analysis of the factors causing subway station excavation accidents, to give a more accurate result, more important is whether the expression level of complexity or the calculation speed significantly better than the traditional fault tree model, and easier to find the weak links in the system. Example analysis shows that fault tree analysis based on Bayesian networks is easier and more practical than the traditional fault tree analysis, while addressing the traditional fault tree model, the scale of the problem and the problem of modeling after important applications in engineering.

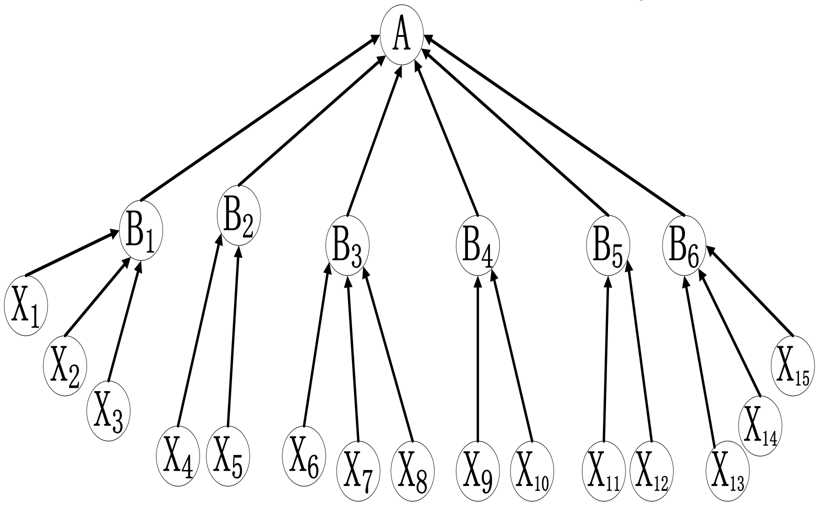

Figure 2: The fault tree excavation system constructed by Bayesian network model

Bayesian network fault tree analysis and fault tree analysis on traditional construction method and reasoning mechanism exists similarity. Bayesian network modeling of fault tree analysis fault tree based on traditional forms simpler and flexible the system fault tree once built a good, traditional fault tree. It difficult to make adjustments based on conditional probability and Bayesian network fault tree simply adjust by the Bayesian network table to solve the traditional fault tree analysis achievements after adjustment. Traditional fault tree analysis showed an increasing scale of the problem with the exponential growth, and increase based on Bayesian network fault tree analysis with the size of the problem only increases linearly, so that fault tree based on Bayesian network can better handling of complex systems.

3.2 WBS-RBS

Coupled by subway deep excavation WBS and safety risks RBS, subway deep excavation construction process safety risks identified. WBS-RBS coupling matrix specific procedure was shown in Table 2.

Table 2: Subway deep foundation pit engineering WBS-RBS Matrix Coupling

		W1						W2	W3	W4	W5
		W11	W12	W13	W14	W15	W16				
R1	R11	0	0	1	1	0	0	0	1	0	0
	R12	0	0	1	1	0	0	0	0	1	0
R2	R21	0	1	0	0	0	0	1	0	0	0
	R22	0	1	0	0	0	0	0	0	1	0
	R23	0	0	0	0	0	0	0	0	0	0
	R24	1	1	1	0	1	1	1	1	1	0
	R25	0	1	1	1	1	0	1	1	1	1
R3	R31	0	0	0	0	0	0	0	1	0	1
	R32	0	0	0	0	0	0	0	1	0	0
	R33	0	0	0	0	0	0	0	0	0	0

Subway deep excavation WBS and RBS structure coupling structure can be drawn from deep underground excavation process of building a major security. Risk factors are vertical deviation (W11R24, W12R24), the groove wall collapse (W12R21), envelope structure buried deep enough (W12R22), bottom sediment too thick (W12R25), casualties (W13R11, W14R11, W13R12, W14R12), concrete flow around (W13R24, W13R25), brush the wall is not complete (W14R25), pouring uneven (W15R24), stripping tube too fast (W15R25), grouting is not in place (W16R24), reinforcing effect is poor (W2R21), drilling block is not dense (W2R25), over-excavation (W3R11), improper selection gradient (W3R22).

Fault tree analysis method was underground continuous wall seepage, A1, A2 support instability and landslides A3 soil pit these three items on the event fault tree analysis to construct the above-mentioned three accidents. The top event of the fault tree was shown in Figure 3.

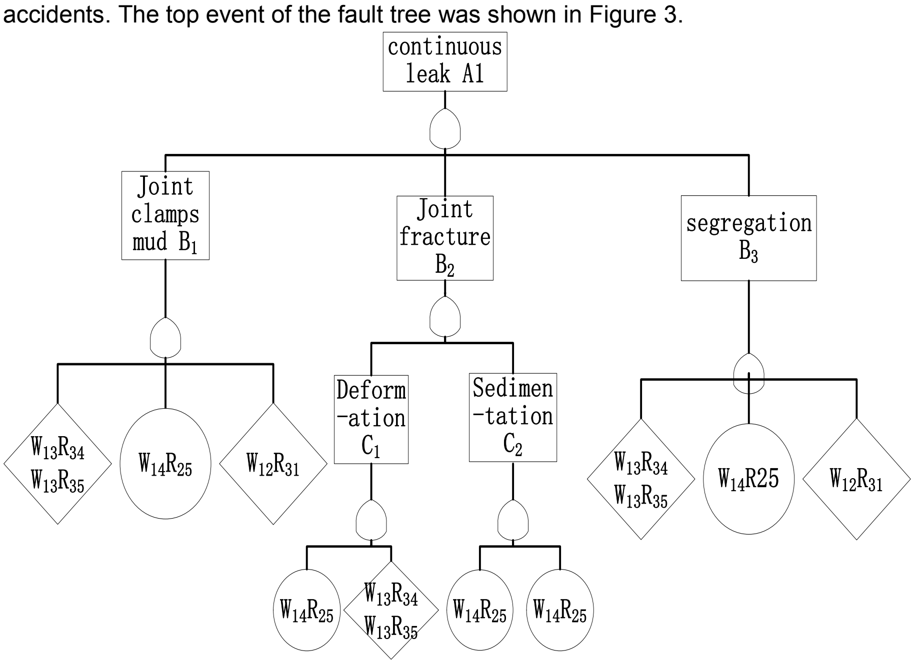

Figure 3: Underground continuous wall seepage fault tree analysis

On the basis of risk identification method for use in metro works on the security risk identification based on WBS-RBS fault tree analysis. According to the characteristics of deep excavation, analysis of the survey on the basis of security incidents is the establishment in metro engineering fault tree. Fault tree and use of safety risk factors were evaluated in this risk-sensitive basis. The fault tree methods break the shackles of traditional fault tree method which is contrary to the traditional top-down approach in the use of human thought process. WBS-RBS constructed fault tree analysis has a comprehensive, easy to operate features than the traditional fault tree method, which is more suitable for risk assessment.

4. Conclusions

Underground excavation safety risk management perspective of this study in metro construction was proceeding. Like a subway construction process of other areas such as security risk identification and evaluation of the work of shield construction, tunnel construction. Other aspects of the line can also be further deepening subway construction safety risk management as a great background. Deep excavation of metro construction carried the actual object of study of subway deep excavation safety risk identification and evaluation. Subway construction paper was a big security risk management background, combined in metro construction to carry the actual object of research, excavation of subway security risk identification. Through the security risk identification and assessment process, it can be enhanced in metro construction process hazard anticipation before construction accidents to avoid security risks and resolve to improve the safety performance of the entire system. Based on this, the paper depth study of the theory and methods of security risk identification and security risk assessment, further enrich the security risk management theory.

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