Risk Assessment on Operating Tunnels of High-Speed Railway in Perilous and Mountainous Area

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Abstract: The project named "the rescue system and key technology of high-speed railway in perilous mountains" primarily focuses on current railway constructions and operations in China. To state the relationship between risk events and risk factors, we classified the risk sources of operating tunnels of high-speed railway in perilous and mountainous area and established a hierarchical assessment system by using the example of high-speed railway from Guangzhou to Guiyang. According to the risk acceptance criteria and risk level standard, we analyzed the risks of operating tunnels qualitatively and quantitatively by using AHP-Fuzzy method. As a result, the key risks were characterized and proposals were listed. Our study provides a framework for the risk analysis and management of operating tunnels of high-speed railway in perilous and mountainous area.

Keywords: AHP-fuzzy theory, perilous and mountainous area, risks in operational period, tunnels of high-speed railway.

1. INTRODUCTION

In the past decades, high-speed railway construction has made tremendous progresses in China. Due to the complex terrain in southwestern China, there are many challenges for railway constructions and operations. One of the typical examples is the high-speed railway from Guangzhou to Guiyang, which serves as an important connection between southwest China and the south coast of China. The total length of the railway is 833.3 km with 212 tunnels consisting of about 55.9% of the overall length. It also locates at a region that suffers high frequency geographical hazards such as earthquake and other disasters caused by the complex geological structures.

After the "7-23" incident in 2012, risk management of high-speed railway has become a crucial topic not only for researchers, but also for the public. Since the construction of the high-speed railway from Guangzhou to Guiyang will be completed, the risk management of this railway will become focus at the operational stage.

Currently, the main guideline of risk management is "The Temporary Provisions about Risk Analysis and Management of Railway Tunnels", which focuses on the assessment of tunnels at the design and operational stages [1]. However, the assessment of tunnels at the operational stage is not clarified in this guideline. Taking the features of high-speed railways into accounts, such as fast objectives, the huge hazard of rescue, the complex surroundings and high rates of tunnels, we classified risk sources and established an assessment system for risks of operating tunnels of high-speed railways in perilous and mountainous area. We took the high-speed railway from Guangzhou to Guiyang as example,

and analyzed the risks of the operating tunnels using AHP-Fuzzy method qualitatively and quantitatively.

2. RISK ASSESSMENT ON HIGH-SPEED RAILWAY TUNNEL AT THE OPERATING STAGE

2.1. Risk Definition

Risks of high-speed railway tunnels at the operating stage are defined as a combination of frequency and consequences of potential incidents, which consist of property losses, environmental damages, economic losses and construction delays.

2.2. Risk Identification

We identified all the potential risk sources which affect the operating tunnels of high speed railway in perilous and mountainous areas and listed risk factors which have profound effects on operating tunnels (Table **1**). To further confirm and classify the risk factors (risk incidents), we divided each risk assessment units to corresponding subunits (Table **1**).

2.3. Risk Estimation

To estimate the probability and consequences of the identified risk factors, risk probability distribution and the loss types and scales was given by using AHP-Fuzzy method [2-6].

2.4. Risk Assessment

Currently, assessment matrix and risk acceptance criteria are well accepted for evaluating the risk. Based on the risk estimation results and risk level standards described in "The Temporary Provisions about Risk Analysis and Management of Railway Tunnels", we defined the risk severity and its specific level. Accordingly, we also proposed a risk response strategy.
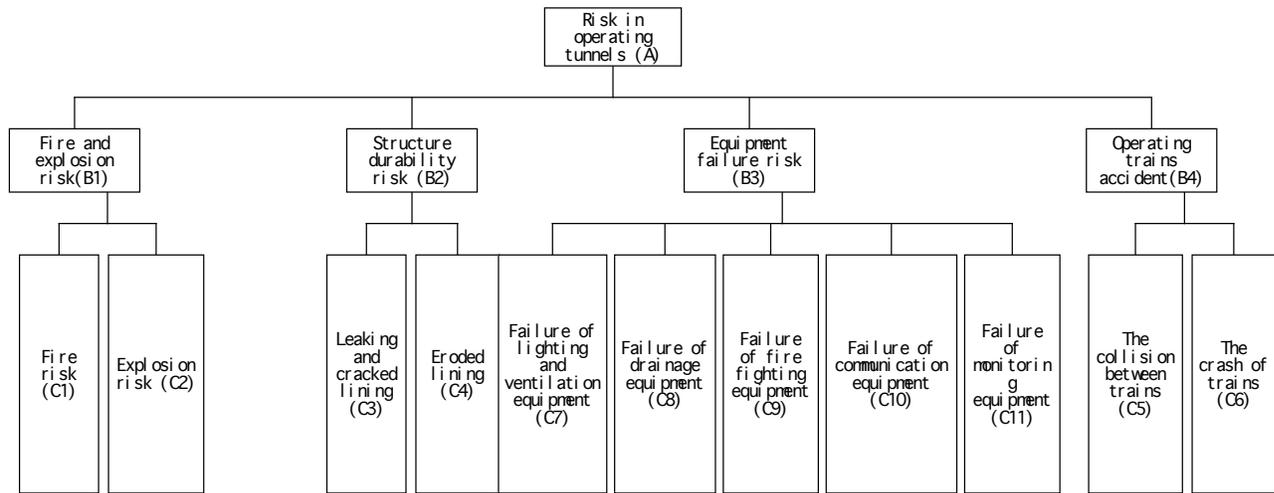
Fig. (1). Hierarchical structure of risk incident layers.

3. RESEARCH OF RISK ASSESSMENT ON OPERATING TUNNELS OF HIGH-SPEED RAILWAYS IN THE PERILOUS AND MOUNTAINOUS AREA

According to the risk definition and criteria mentioned above, we determined the risk sources and categories, and established an index for risk assessment. The index shows the relationship between risk factors and risk incidents of high-speed railway tunnels at operational stage.

3.1. Risk Incidents

Based on the public data, the risks of high-speed railway tunnels at the operating stage could be divided into five types of risk incidents, including the risk of fire and explosion in tunnels, the risk of structure durability in tunnels, the risk of equipment failure and the risk of operation accident. Each type of incident was considered as the primary level of incidents and was further divided into sub-risk incidents by using AHP method. The hierarchical structure of risk incidents was illustrated in Fig. (**1**).

3.2. Risk Factors

Risk factors of operating tunnels of high-speed railway in perilous and mountainous area also consist of three primary types (Infrastructure, external environment and artificial damage).

3.2.1. Risk Factors from Infrastructure

Risks from the infrastructure factor contain civil infrastructure risk and operating equipment risk. Civil infrastructure could be affected by cracked lining, leaking lining and eroded lining, while operating equipment risks are mainly cause by failures of equipment that is designed for ventilation, lighting, firefighting, communication, monitoring, waterproof and drainage.

3.2.2. Risk Factors from External Environment

Risk factors from External environment comprise meteorological disaster, geological hazard and earthquake. Typhoon, rainstorm, high and low temperature, heavy fog, thunderstorm, gale, sand storm, hail snow are all considered as risk facts of meteorological disaster [7]. Collapse, landslide, land subsidence, ground fissure, water and mud bursting, debris flow, falling rock at tunnel portal are all accounted as risk factors from geological disaster. The last major risk factor is seismic risk factors which are primary caused by earthquakes or secondary effects from earthquakes.

3.2.3. Risk Factors from Artificial Damage

Risk factors from artificial damages contain factors such as the risk of a war, the risk of management, the risk of terrorist attack, the legacy risk of design and construction, and so on [8]. For instances, loopholes of management may come from organization settings, regulations, team spirit, professional quality, education, emergency measures and the effectiveness of decision [9, 10]. As a terrorist attack, it could be an explosive attack, an incendiary attack, a biochemical attack or a kinetic energy attacks. The legacy risk of design and construction could be consequences from non-comprehensive design, mistakes in designs, poor quality of constructions.

As a brief summary, risk incidents and risk factors taken accounted in our assessment system are listed in Table **1**.

4. THE RISK ANALYSIS ON OPERATING TUNNELS OF HIGH-SPEED RAILWAY IN PERILOUS MOUNTAINS BASED ON AHP-FUZZY THEORY

4.1. Comprehensive Assessment on the Second Level of Risk Incidents based on AHP-Fuzzy Theory

To quantitatively assess the risks of operating tunnels of Guangzhou-Guiyang high-speed railway, we applied the AHP-Fuzzy method to analyze the risk incidents categorized in the third level of risk incident to evaluate the risk incident of the second level (Fig. **1**) [11].

4.1.1. Comment Sets and Factor Sets

Comment sets contain probability assessment sets and consequence assessment sets.

The probability assessment set = {extremely possible, possible, occasionally, impossible, extremely impossible}

Table 1.   Index of risk assessments.

Risk Incident	The Type of Risk Factors	Risk Factors
Fire and Explosion Risk Structure Durability Risk Operating Equipment Risk Operating Train's Accident Risk	External Environment Risk	Meteorological Disaster
		Geological Disaster
		Earthquake
	Artificial Damage Risk	War
		Terrorist Attack
		Management Risk
		The Legacy Risk of Design and Construction
		Human Error
		The Quality of Material and Equipment

The Consequence assessment set = {catastrophic, very serious, serious, less serious, light}

Factor sets are fire (*C1*), explosion (*C2*), cracked lining (*C3*), eroded lining (*C4*), the collision between trains (*C5*), trains crash (*C6*), ventilation lighting equipment fault (*C7*), waterproof and drainage equipment failure (*C8*), firefighting equipment fault (*C9*), communication equipment fault (*C10*), monitoring equipment fault (*C11*).

4.1.2. Determination of the Weight Vector

The hierarchical structure (Fig. **1**) was set up based on AHP method. The "probability vector" and "consequence vector" were acquired by using characteristic roots and consistency test.

"Probability weight vector"

W_{PB1} = (0.8333, 0.1667); W_{PB2}= (0.6667, 0.3333); W_{PB3}= (0.1429, 0.8571); W_{PB4}= (0.31, 0.1791, 0.2, 0.2448, and 0.0662).

PB_1 is denoted as the unit of risk incidents in the second level defined in Fig. (**1**).

"Consequence weight vector"

W_{CB1} = (0.7101, 0.2899); W_{CB2}= (0.7101, 0.2899); W_{CB3}= (0.8, 0.2); W_{CB4}= (0.2722, 0.1285, 0.4069, 0.1030, and 0.0894).

CB_1 is denoted as the unit of risk incidents in the second level defined in Fig. (**1**).

4.1.3. Comprehensive Judgment

To determine the fuzzy judgment matrix $R = (r_{ij})_{m \times n}$ a function $f(u_i)$ was generated to judge each factor u_i, then a map called "*f*" from U to V was established to induce a relationship called "$R_f \in F(U \times V)$".

Then we conduct a compound operation between A and R by using the model $M(*, +)$ to get the assessment on elements of risk incident on the second layer:

"Probability"

$$R_{PB}^1 = \begin{matrix} 0.3033 & 0.2883 & 0.2333 & 0.1583 & 0.0167 \\ 0.3333 & 0.3167 & 0.2 & 0.1 & 0.05 \\ 0.0971 & 0.1386 & 0.3413 & 0.3057 & 0.1029 \\ 0.1427 & 0.2358 & 0.3057 & 0.1771 & 0.0694 \end{matrix}$$

"Consequence"

$$R_{CB}^1 = \begin{matrix} 0.2145 & 0.4065 & 0.25 & 0.129 & 0 \\ 0.0855 & 0.1355 & 0.2565 & 0.2645 & 0.258 \\ 0.198 & 0.264 & 0.282 & 0.244 & 0.012 \\ 0.1124 & 0.1804 & 0.2301 & 0.321 & 0.169 \end{matrix}$$

A risk incident level and acceptance criteria were generated (Table **2**). Therefore, we concluded that the highest risk incident level came from the fire and explosion risk, which was followed by the incident risks from the structure durability, and the operating equipment risk. The operating train accident was relatively small.

Therefore, in terms of the risk acceptance criteria table in "Contemporary Regulations on risk assessment and management of Railway Tunnels, the fire and explosion risk should catch the special attention during evaluation and preparation for the incidents of accidents, to avoid or at least reduce the risk to an undesired degree. For the tunnel structural risk and operating equipment risk failure, measurements must be taken to reduce the risk and enhance the monitoring. Finally, the train accident risk can be not a big cons relatively, but must be monitored.

Table 2.   The evaluation of risk level.

Risk Incident	Risk Level	Acceptance Criteria
Fire and explosion risk	Sky-high	Non-accept
Structure durability risk	Very high	Non-expect
Operating equipment risk	high	Non-expect
Operating train accident	medium	accept

4.2. Assessment of Risk Incidents on the Primary Level based on AHP-Fuzzy Method

4.2.1. Evaluation Set and the Factor Set

Probability evaluation set = {probably, likely, occasionally, unlikely, impossible}[12]

Consequences evaluation set = {catastrophic, very serious, serious, superior, minor}

Factor sets are fire and explosion risk (B_1), structure durability risk (B_2), operating equipment risk (B_3), Operating train accident (B_4)

4.2.2. The Weight Vector of Risk Incidence on the Primary Level of Risk Incident

"Probability weight vector":

$W_{PA} = (0.1358, 0.3619, 0.4355, 0.0668)$

"Consequence weight vector":

$W_{CA} = (0.5536, 0.1061, 0.0513, 0.2890)$

4.2.3. AHP-Fuzzy Comprehensive Assessment

We conducted the compound operation between "A" and "R", by using the model $M\ (\bullet, +)$ and the results of comprehensive judgment on the second level of risk incidents.

Assessment result of "probability"

$R_{PA} = (0.2136, 0.2299, 0.2762, 0.2026, 0.0698)$

Assessment result of "consequence":

$R_{CA} = (0.1705, 0.3051, 0.2466, 0.2048, 0.0768)$

Based on the principle of maximal degree of membership and the evaluation results, we considered the probability of operating tunnels level as "occasionally" and consequences as "very serious". Therefore, according to the level of risk criteria we determine the risk level of the operating tunnels of high-speed railway in perilous and mountainous area as "high".

4.3. Suggestions

According to the results above, we proposed the following suggestions.

1) Establish an efficient operation mechanism and improve the responsibility mechanism [13, 14].

2) Set up reasonable refuges [15].

3) Increase the frequency of safety inspection to ensure hidden trouble could be handled immediately [16, 17].

4) Set up rescue guide signs for evacuation [18].

5) All high-speed trains should be equipped with adequate supplies for self-rescue, and disseminate self-rescue guide [19, 20].

CONCLUSION AND LIMITATION

In this paper, all possible identified risk events and risk factors was in accordance with the specific situations of the high-speed railway from Guiyang to Guangzhou, which was the whole base for our risk assessment on operating tunnels of high-speed railway in perilous and mountainous area. In addition, risk assessment and risk management are dynamic processes. Our evaluation model is also limited by currently technologies for equipment detections.

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