Operation Environmental Risk Warning of Beijing-Zhangjiakou High-Speed Railway Based on Bayesian Networks

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Abstract. The Beijing-Zhangjiakou high-speed railway is an important transportation facility for the 2022 Beijing Winter Olympics. The Winter Olympics is about to be held, and there is an urgent need for the management, control and early warning of operation environmental risks in the Beijing-Zhangjiakou high-speed railway. This paper sorts out the causal relationship between hazards, hidden dangers and accidents in the Beijing-Zhangjiakou high-speed railway operation environment, and builds a Bayesian network model to calculate the probability of safety accidents. Also, this paper used the probabilistic safety evaluation method to calculate the risk coefficients in the corresponding scenarios, and achieved graded early warning of risks in the operating environment of the Beijing-Zhangjiakou high-speed railway.

Keywords: Beijing-Zhangjiakou high-speed railway · Bayesian network · Risk warning

1 Introduction

In recent years, high-speed railway has developed rapidly in China. However, since operation, high-speed railway safety accidents have occurred from time to time due to environmental factors such as meteorological disasters, geological disasters, and intrusion. On March 30, 2020, when the T179 passenger train passed through the Yongxing County section of Hunan Province on the Beijing-Guangzhou line, a sudden landslide caused the train to hit a landslide and derail, resulting in 1 death and 127 injuries. In August 2020, two train derailments occurred on the Daqin line within a week due to heavy rain. In order to ensure the safety of high-speed railway operation and prevent or reduce losses caused by environmental risk factors, it is necessary to study the environmental risk factors that exist during high-speed railway operation. The Beijing-Zhangjiakou high-speed railway is an important transportation facility for the 2022 Beijing Winter Olympics. The Winter Olympics is about to be held, and there is an urgent need for the

J. Liang et al. (Eds.): EITRT 2021, LNEE 867, pp. 201–208, 2022.
https://doi.org/10.1007/978-981-16-9909-2_22

management, control and early warning of environmental safety risks in the operation of the Beijing-Zhangjiakou high-speed railway.

Zhang Wanqiu [1] used fuzzy mathematics evaluation methods in the study of the rail fracture risk assessment model of Shenshuo Railway, which effectively fits the nonlinear relationship between various hazard factors and the possibility of high-speed rail risk events. When studying the safety of the high-speed rail catenary system, Wang Hongde [2] established a cloud evaluation model to realize the mutual conversion between qualitative and quantitative evaluation indicators. From the perspective of "people-equipment-environment-management", Feng Yunqing [3] used the structural equation model to analyze the correlation between the various factors that affect the safety of high-speed rail, and provided a theoretical direction for the in-depth study of high-speed rail safety. In general, risk analysis has formed a relatively complete system, but it is still immature in the application of high-speed rail. Most of the safety risk assessment studies for high-speed rail are based on a holistic perspective, and there are few detailed studies on environmental risks.

This article will comb through the actual situation to sort out the environmental hazards that affect the operation safety of the Beijing-Zhangjiakou high-speed railway, qualitatively analyze the hidden dangers of various hazards and the possible consequences of the accident, and analyze the causal relationship between hazards-hidden dangers-accidents. Then, based on the causality relationship, a Bayesian network topology with a safe operating environment for the Beijing-Zhangjiakou high-speed railway is established, and the Bayesian network is used to calculate the probability of accidents. Finally, the probability safety assessment method is used to calculate the risk value, and the risk level is judged to realize the environmental safety early warning of the Beijing-Zhangzhou high-speed railway.

2 Risk Analysis

2.1 Hazard Analysis

The hazard refers to the root cause or status factor that may cause personal injury or disease, material and property damage, damage to the working environment, or a combination of these conditions. Its essence is a potentially dangerous source or location, which is the source of an outbreak.

Severe weather such as wind, rain, thunder, electricity, snow, sand damage, freezing and hail are all dangerous sources that affect the safety of high-speed railways. Natural disasters such as earthquakes, floods, and mudslides are also sources of danger, which will affect the normal operation of high-speed railway fixed equipment and mobile equipment. In addition, foreign objects other than line equipment, such as plastic bags, falling rocks, small animals, garbage, quicksand, etc., are also environmental hazards that endanger driving safety.

Through on-site investigations of the Beijing-Zhangjiakou high-speed railway and observation of the surrounding environment of the Beijing-Zhangjiakou high-speed railway, this paper identified wind, rain, snow, haze, earthquakes, mudslides, landslides, and intrusion as dangerous sources that affect the operating environment of the Beijing-Zhangjiakou high-speed railway.

2.2 Hidden Danger Analysis

Hidden dangers refer to unsafe behaviors, unsafe conditions of objects, and management defects that may lead to accidents in production and business activities. According to the domestic and foreign high-speed rail accident reports in recent years, the environmental hazards mentioned in Sect. 2.1 will induce a series of hidden accidents to a certain extent. This article summarizes them as track and pavement problems, facility failures, and train control problems.

Track and pavement problems refer to roadbed and track failures. Facility failure mainly refers to the equipment failure of power supply system, electrical service system, EMU and other systems. Train control problems mainly refer to the interference of human behavior under the influence of the external environment, which will further lead to control errors or invalid operations.

2.3 Accident Analysis

Accidents refer to an unexpected situation that causes death, disease, injury, damage, or other losses. Railway traffic accidents refer to accidents that affect the normal operation of railways such as conflicts, derailments, fires, explosions, etc. during the operation of railway rolling stock, including accidents that occur during related operations that affect the normal operation of railways; or railway rolling stocks during operation Accidents that collide with pedestrians, motor vehicles, non-motor vehicles, livestock and other obstacles are all railway traffic accidents.

According to the high-speed rail accident report and related documents, the accidents of high-speed rail operation mainly include train congestion, train conflict, train collision, train derailment, train fire, and train explosion. This article will focus on the three most common accidents of obstruction, collision, and derailment [4].

3 Risk Assessment

3.1 Calculate the Probability of an Accident

Bayesian network is a graphical network based on probabilistic reasoning based on the Bayesian conditional probability formula [5]. It expresses variables with nodes, the directed relationship between variables with directional connections, and quantitatively expresses the causal relationship between variables with conditional probability, so as to realize the quantitative expression of system causality, and it can draw the possibility and possible occurrence of events. Probability estimation of the status and possible consequences has strong applicability.

Build a Bayesian Network. Combining the related analysis in Sect. 2, this article has identified the nodes in the Bayesian network. The node information is shown in Table 1 [6]. The Bayesian network topology structure shown in Fig. 1, in which the top node is the root. The root node represents the basic event, which is the hazard, and the rest of the nodes are non-root nodes, which include various hidden dangers and specific accident types.

Table 1. Bayesian network node information

Node	Node type	Description
R1	Root	Wind
R2	Root	Rain
R3	Root	Snow/ice
R4	Root	Fog
R5	Root	Earthquake
R6	Root	Debris flow/landslide
R7	Root	Intrusion
I1	Intermediate	Track/roadbed problem
I2	Intermediate	Facility failure
I3	Intermediate	Train operation problem
D1	Leaf	Derailment
D2	Leaf	Collision
D3	Leaf	Obstruction

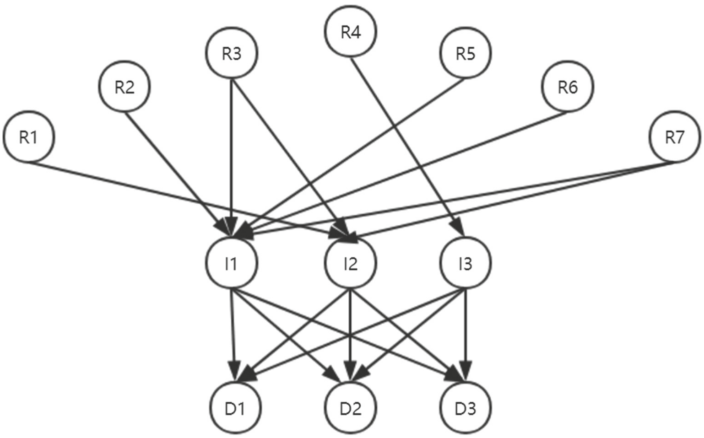

Fig. 1. Bayesian network.

Set Bayesian Network Node. In order to evaluate the operation environmental risk of the Beijing-Zhangjiakou high-speed railway, it is necessary to set the node parameters of the Bayesian network, that is, the conditional probability of the non-root node and the prior probability of the root node. And then the Bayesian network infers the final result. The reasoning process is completed by Netica [7].

The Prior Probability of the Root Node. The prior probability of the root node refers to the probability of the occurrence of basic events. The occurrence of the root node is not affected by other nodes and is only related to the state of the root node itself. Table 2 shows the description and fuzzification of the meteorological disaster level. Table 3 shows the description and fuzzification of intrusion.

Table 2. Description and fuzzification of meteorological disaster level.

Meteorological disaster grade	Warning signal	Risk assessment description	Quantify the probability of risk
None	White	Very low	0
IV	Blue	Low	0.25
III	Yellow	Medium	0.5
II	Orange	High	0.75
I	Red	Very high	1

Table 3. Description and fuzzification of intrusion.

Object	Warning signal	Risk assessment description	Quantify the probability of risk
Falling rocks	White	Low	0.25
Human	Blue	Very high	1
Animals	Yellow	High	0.75
Car/train	Orange	Very high	1
Light floater	Red	Medium	0.5

The Conditional Probability of Non-root Nodes. The conditional probability of a non-root node refers to the probability of occurrence of a child node when the parent node occurs [8]. This article uses the conditional probability of the non-root node according to the accident/fault data recorded by the operating unit and the natural disaster monitoring data for benchmark determination, the specific expression is as follows.

$$P(X_1|X_2) = \frac{P(X_1 \cap X_2)}{P(X_2)} \tag{1}$$

According to the actual data analysis, the conditional probability P of each non-root node is obtained $P(X_1|X_2)$. In addition, it can also be derived from the Bayes theorem. First, the expert obtains $P(X_2|X_1)$ according to their experience, and then according to the formula get $P(X_1|X_2)$.

$$P(X_1|X_2) = \frac{P(X_2|X_1) \times P(X_1)}{P(X_2)} \tag{2}$$

The expert evaluation language description and fuzzification are shown in Table 4.

Table 4. The description and fuzzification of expert evaluation language.

Probability of accident	Risk assessment description	Quantify the probability of risk
Very low	Very low	0
Low	Low	0.25
Medium	Medium	0.5
High	High	0.75
Very high	Very high	1

The Probability of an Accident. After determining the Bayesian network topology and the parameters of each node, use Netica software for parameter training, and adjust the root node parameters according to the actual situation, you can get the probability distribution of each node, and calculate the probability of various accidents.

3.2 Quantify the Degree of Accident Loss

When quantifying the loss of various types of accidents, this article refers to the accident reports of the Federal Railroad from 1975 to the present. We use the average property loss and casualties per accident under various accidents as the standard to classify the degree of accident loss. The grading principle is the weighted summation after dimensionless, and the weights are 0.5 respectively. The expression of the degree of accident loss after dimensionless is as follows.

$$C_i = \sum \frac{X_i}{\max}$$

From this, the accident loss levels of train congestion, train collision, and train derailment are respectively obtained as shown in Table 5.

Table 5. Quantification of accident loss.

Type of accident	Derailment	Collision	Obstruction
The degree of accident loss	1	0.16	0.53

3.3 Calculate the Safety Risk Value

The risk value calculation is carried out according to the formula principle of R = PC, and the specific formula is as follows.

$$R = \sum \mathrm{p_i} * c_i$$

In the formula, R represents the risk coefficient, pi represents the probability of occurrence of an accident, $\mathrm{C_i}$ represents the degree of accident loss, and i corresponds to the operating environment risk index i, which represents the risk factor currently being monitored. The risk level standard is shown in Table 6.

Table 6. Risk level standard.

Level of risk warning	Range of risk value
First-level warning	0–25
Second-level warning	0.25–0.5
Third-level warning	0.5–0.75
Forth-level warning	0.75–1.05

3.4 Simulate and Analyze Cases

Suppose the weather warning conditions at a certain moment are as follows: R1 is a yellow warning, R2 is a blue warning, R3 is a yellow warning, R4 is an orange warning, R5 is a white warning, R6 is a white warning, and R7 is a light warning. Figure 2 shows the calculation results of the NETICA.

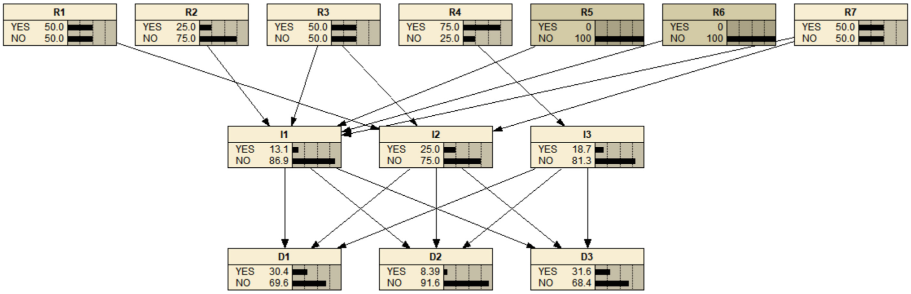

Fig. 2. Calculation results of NETICA.

After calculation, the overall risk factor of the high-speed rail operating environment in this state is 0.48. According to the risk level table, the risk level of high-speed rail operations in this state is level two. It is necessary to focus on preventing train derailment (D1) accidents and train congestion (D3) accidents. When investigating hidden accidents, attention should be paid to the problem of facility failures.

4 Discussion

In order to conduct a more systematic and effective operation environment risk assessment of the Beijing-Zhangjiakou high-speed railway, prevent accidents, and carry out risk early warning of accidents, this paper analyzes the hazards, hidden dangers, and operation accidents in the operation environment of the Beijing-Zhangjiakou high-speed railway, and uses Bayesian The network calculates the probability of accidents. The Beijing-Zhangjiakou high-speed railway operating environment risk assessment model proposed in based on the Bayesian network can give a quantitative risk assessment result after the event occurs, taking into account the uncertainty of risk factors, as an aid in determining the level of the event Decision information. It can also carry out corresponding emergency preparedness based on specific scenarios and combined with the analysis of risk factors before an incident occurs. Effectively improve the scientificity and accuracy of the environmental safety risk assessment of the Beijing-Zhangjiakou high-speed rail operation, which is conducive to the realization of the classified management of the environmental safety risk of the Beijing-Zhangjiakou high-speed railway operation, and provides dynamic real-time security risk alarms.

Acknowledgments. The work was supported in part by the National Key R&D Program of China under Grant (No. 2020YFF0304104) and Research Project of China Academy of Railway Sciences Corporation Limited (2019YJ112).

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