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REVIEW ARTICLE

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Risk warning technologies and emergency response mechanisms in Sichuan–Tibet Railway construction

Abstract Safety is one of the most critical themes in any large-scale railway construction project. Recognizing the importance of safety in railway engineering, practitioners and researchers have proposed various standards and procedures to ensure safety in construction activities. In this study, we first review four critical research areas of risk warning technologies and emergency response mechanisms in railway construction, namely, (i) risk identification methods of large-scale railway construction projects, (ii) risk management of large-scale railway construction, (iii) emergency response planning and management, and (iv) emergency response and rescue mechanisms. After reviewing the existing studies, we present four corresponding research areas and recommendations on the Sichuan–Tibet Railway construction. This study aims to inject new significant theoretical elements into the decision-making process and construction of this railway project in China.

Keywords railway construction, risk warning technologies, emergency response mechanisms, Sichuan–Tibet Railway

1 Introduction

Since the last century, the safety management consciousness of large-scale railway construction projects has been increasing constantly. Practitioners and researchers worldwide attach great importance to the safety of railway engineering and propose various measures to ensure the safety of construction and transportation. Since 2000, China Railway Corporation has conducted numerous technical and management studies to ensure an optimum safety level in railway construction and transportation activities. However, with the increasing difficulties being experienced in engineering construction, the continuous deterioration of the natural environment and the complexity of mega-railway project environments made safety issues a prime concern. Therefore, strengthening risk warning technologies and improving the level of safety management are necessary.

In the safety management of international railway projects, on the one hand, increasing the investment in safety supervision technology and equipment is needed to continuously improve the safety level of infrastructure and technical equipment (Wuni et al., 2020). On the other hand, much attention should be paid to data processing and analysis of accidents in the process of engineering construction. By doing so, identifying risks and timely measures can be improved to ensure the safety of the construction project (Li et al., 2020). In China, to meet the needs of railway safety management, departments responsible for this task have formulated a highly efficient management system and conducted numerous studies in safety analysis and risk warning. Compared with railway safety management in western countries, there are still gaps in data processing and analysis, safety warning, emergency response, and other areas in China. The prominent problem is insufficient analysis and data utilization, as well as insufficient integration of risk warning technology and scientific management. These issues have resulted from a lack of sufficient investment in research. Therefore, Chinese management departments need to strengthen their research on risk warning technologies and emergency response mechanisms of large-scale railway construction to provide a basis for safety management and decision-making process.

The Sichuan–Tibet Railway is a large-scale project that

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is characterized by a long construction period, high technical specifications, and large investment. Conducting risk identification, assessment, and warning on railway engineering construction is important in theory and practice to promote the scientific and coordinated development of railway construction, as well as to reduce costs and ensure the safety of engineering activities. Based on the aforementioned background, this study first reviews some of the existing risk warning technologies and emergency response mechanisms in the railway construction industry. Furthermore, based on previous studies, this study brings in new significant theoretical elements into the decision-making process and construction of the Sichuan–Tibet Railway.

2 Related studies

The management of railway construction projects follows a four-step process, i.e., prevention → renovation → control → recovery, which represents the review flow of the present study. As shown in Fig. 1, we first examine several risk identification methods of large-scale railway project construction and then conduct risk management. Then, the related emergency plans are reviewed and the emergency response and rescue mechanisms are identified.

2.1 Risk identification methods of large-scale railway construction projects

At present, the research on risk identification in railway project construction mainly selects risk factors from a macro perspective. The main applied methods include the checklist, Delphi, analytical, decomposition, risk list, empirical data, and risk investigation methods, among others (see Fig. 2). Chen (2016) conducted the risk identification method by decomposing engineering risks, and a risk list was formed by identifying risk factors, events, and their consequences. The applicability of various risk identification methods was compared and analyzed, and the advantages and disadvantages of the industry environment in countries along the international corridor were analyzed through expert survey methods. At the same time, a micro-level project risk factor list was formed by using a work breakdown structure method to identify the risks involved in the international railway corridor construction project. Dong et al. (2018) took the construction of the China–Mongolia–Russia high-speed railway as an example and established a comprehensive risk assessment model to evaluate its economic, social, and ecological risks. Based on this approach, several corresponding risk control measures were proposed. Taking the South Korea high-speed railway project as an example, Suh (2000) classified the construction risk of a large-scale new railway project into design, infrastructure procurement, and system procurement risks.

The risk assessment methods of railway project construction mainly include the fuzzy evaluation method, analytic hierarchy process (AHP) method, fault tree analysis method, Monte Carlo method, and extrapolation method. At present, most of the analytical methods are still focused on qualitative analysis and expert experience, and lack support of quantitative system risk analysis and evaluation. For example, Chen (2016) focused on qualitative research, adopted the expert survey method, and combined it with different stages of project development. Moreover, Chen (2016) also recommended specific measures on how to conduct risk management and mitigation. Xie (2014) proposed a risk assessment method of railway construction projects combining fuzzy reasoning, fuzzy AHP, and comprehensive evaluation. Considering different stages of railway engineering projects, Li

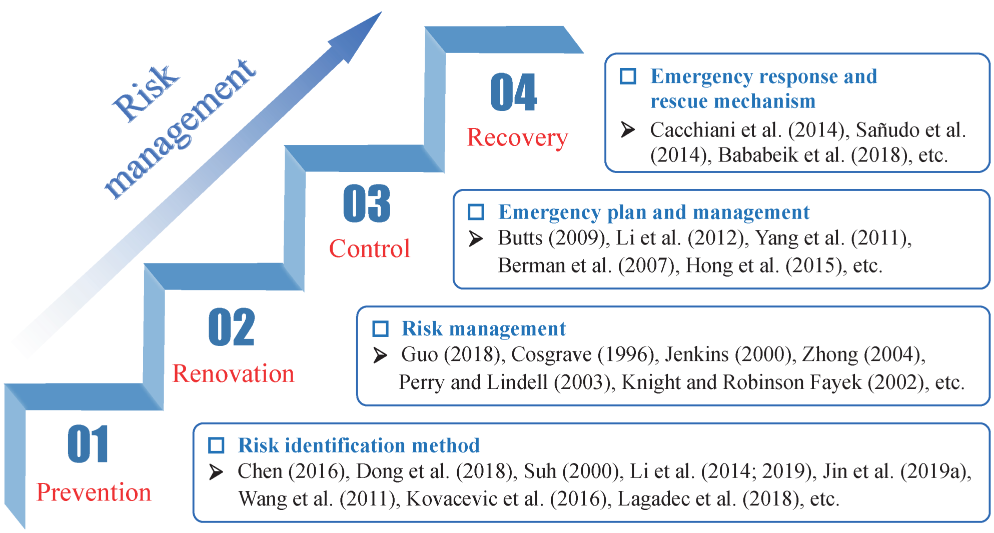

Fig. 1 Flowchart of management of railway construction projects.

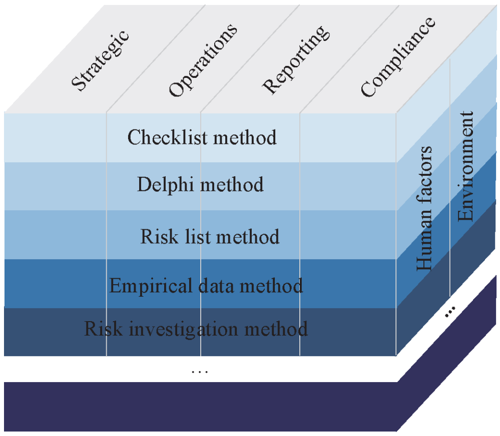

Fig. 2 Typical risk identification methods.

et al. (2019) used the AHP to determine the index weight of each factor and then constructed a risk assessment model based on a fuzzy comprehensive evaluation method. Jin (2019) studied an aspect of the “One Belt, One Road” international railway corridor construction project, including risk identification, risk assessment index system, risk assessment theory and method, risk quantitative evaluation model, and risk prevention measures. Furthermore, Jin et al. (2019a) evaluated various risk factors in overseas railway construction comprehensively, calculated the weight of indicators by AHP, evaluated the risk indicators by gray fuzzy evaluation method, and established the risk assessment model of railway project construction. Jin et al. (2019b) integrated various risk factors and analyzed the risk of railway construction projects in several countries in Asia and Europe by using back propagation (BP) neural network model. Wang et al. (2011) used a fault tree to identify the risks in railway engineering and proposed a relatively simple risk assessment method for a railway construction project. Peng (2011) evaluated the quality risk of Beijing–Shanghai high-speed railway construction projects by using Bayesian network combined with expert opinions.

The risk assessment of railway construction projects in foreign countries is relatively rare. Most of the assessments focus on the status of railway facilities and safety risks. For example, Leitner (2017) used historical data and expert evaluation to determine the frequency of dangerous accidents and used the method of accident scenario analysis to evaluate the risk of the Slovak railway system from the perspective of safety. Using the phased electrification detection method, Kovacevic et al. (2016) proposed a method to determine the parameters that affect the track performance and evaluated the embankment condition of the Croatian railway network. Moreover, Lagadec et al. (2018) used a surface runoff mapping method to evaluate the risk of the railway embankment.

The special research on risk warning of a railway construction project started late, and the corresponding research is relatively scarce. Liu and You (2011) considered a practical project experience to analyze the characteristics of the risk warning system of a railway construction project and build a risk warning system of the railway construction project based on discussing system composition and system operation mechanisms. According to the analysis of risk factors in the construction stage of railway engineering projects, Zhou (2016) constructed a risk early-warning index system and used AHP to weigh the indicators in this system. Li et al. (2014) established a railway construction project-quality risk management information system based on information technology and the risk management method of “one figure and four tables”, which achieved the visualization and risk control, dynamic tracking, automatic warning, and closed-loop management of the quality of railway construction projects.

2.2 Risk management of large-scale railway construction

In engineering construction, risk management refers to the practice of identifying potential risks in advance, analyzing them, and taking precautionary steps to mitigate them. The following steps are usually taken: Identification, assessment, review, control, mitigation, and monitoring (Fig. 3).

In emergency scenario construction, plan analysis and research, Guo (2018) analyzed the current situation and problems of railway emergency plan, discussed the plan design in railway emergency management, and proposed feasible measures to continuously improve the railway emergency management system and effectively raise the levels of operational efficiency and service quality. Considering experience from foreign emergency management combined with emergency management practice, Liu (2012) proposed theories and methods applicable to the basic concept, classification matrix, construction procedure, scenario framework structure, and element content of major emergency scenarios in China to provide technical support for the establishment of a “scenario response” emergency plan management mode. Cosgrave (1996) described the characteristics of emergency decision-making and decision-making problems and constructed a theoretical model of decision-making in emergencies. Jenkins (2000) studied the selection method of specific scenarios to reduce the serious consequences of emergencies.

With regard to emergency plan system design and emergency platform construction, Rong (2014) analyzed the main factors that affect the effectiveness of the emergency plan from two aspects of plan preparation and emergency response, established the hierarchy model of emergency risk structure, and then scientifically constructed the emergency response process, providing ideas for solving the existing problems in the construction of the

Fig. 3 Process of risk management.

emergency plan system. Fan (2007) conducted an in-depth study of the framework of national emergency management and emergency platform construction. Zhong (2004) systematically studied the framework and theory of national emergency science and technology support systems from the perspective of emergency management science and technology support. Deng et al. (2005) conducted pioneering research on China's emergency response, studied the evaluation index and method of urban major accident emergency response capacity, and constructed the evaluation system of urban emergency response capacity in China. Perry and Lindell (2003) provided relevant suggestions on how to prepare an emergency plan and the benchmark for evaluating its quality.

Scenario deduction is an important means of emergency decision support. According to the relationship between the system elements described by scenario construction, the future development trend of the system was analyzed by Zhang (2016). Mileti (1975) proposed the four-stage life cycle of disaster evolution: Response, recovery, preparation, and disaster reduction. Using the time series of a disaster evolution, Stallings and Quarantelli (1985) studied the impact of disasters before, during, and after their occurrence. Domestic researchers have adapted the scenario analysis method in emergency management. Liu (2017) proposed the scenario evolution method to prepare the contingency plan. Wang (2011) built a scenario reconstruction model for unconventional emergencies by combining scenarios with fuzzy mathematics and conducted a preliminary study on the rule-based reasoning of scenarios.

As the construction of the Sichuan–Tibet Railway is difficult due to many risk factors involved, establishing a corresponding emergency scenario deduction method is necessary for its specific environment and events. Zheng et al. (2015) studied the causes of traffic disasters and methods of establishing a traffic disaster warning system. After analyzing the accident mechanisms from the coupling effects between people, trains, tracks, and driving environment, Zhang (2014) investigated the causal mechanisms of railway emergencies and found the occurrence mechanism, diffusion effect, and formation mechanisms of secondary disasters. The possibility, impact intensity, and evolution process of the event are determined by using Geographic Information System (GIS) technology, investigation and statistics, calculation simulation, system analysis, and other methods (Li, 2010; Li et al., 2010).

The US Risk Management Association has established a good communication platform for risk management researchers in various fields by publishing academic journals and holding academic conferences. Compared with research on risk management in the US, the UK has its own characteristics. Sorrill (1987) studied the risk of large-scale projects and proposed to build a framework model to solve the problem of lack of technology in project risk analysis. After the 1980s, China's economic structure began to change, people's awareness of risk gradually increased, theoretical ideas and books on risk management were gradually introduced, and the research and application of risk management also started. From the development level of countries in the world, engineering risk management has achieved good application in aerospace, nuclear facilities management, and other technology-intensive industries (Ren, 2010). In railway construction engineering, China is gradually trying to incorporate risk assessment and risk management in the planning, design, and construction phases. For the risk assessment and management of railway construction projects, considering the influence of complex conditions in the entire dynamic process of the evaluation system is difficult. In recent years, the high-speed railway has been developing rapidly in operation scope and service quality. However, the research on its associated potential risks during construction is lagging, which has become an important factor that affects the quality of railway construction (Liang, 2011). Therefore, a scientific and reasonable way is needed to deal with the risks encountered in the process of railway construction.

The risk analysis and coping strategies of engineering construction began half a century ago. In the past 20 years, a great number of new technologies have been introduced into the research on risk analysis and coping strategies, and are extensively applied in various engineering construction projects. Mulholland and Christian (1999) explored the research on the PERT (Program Evaluation and Review Technique) network in project schedule management, established a cost quality schedule model in large-scale integrated control projects, and conducted a corresponding risk analysis. Knight and Robinson Fayek (2002) used fuzzy fault tree technology to identify and evaluate the risk factors of design cost overrun. With regard to risk response strategies in domestic railway engineering construction, Wang (2009) combined the methods of risk identification, risk analysis, and risk decision-making in railway engineering projects by considering the complex external environment, various risk factors, and long construction period. Cai et al. (2010) studied and analyzed the risk management of China's high-speed railway construction project during construction phases, summarized the design risk factors in its construction process using a risk questionnaire, and verified the feasibility of its theoretical analysis. Zhang (2010) studied the management status and risk characteristics in the construction process of China's high-speed railway, summarized the basic problems of existing risk management, proposed dynamic risk management, and built a dynamic risk management model. Li (2015a) took the construction project of the Guangqing intercity railway as an example to study the construction schedule risk. First, the progress risk factors were identified by three kinds of risks: Technical, non-technical, and natural environment. Then, the progress risk factors were systematically evaluated and analyzed by fuzzy AHP. Finally, specific risk monitoring measures were proposed according to the risk evaluation results. Guo and Zhou (2015) took the Mombasa–Nairobi standard gauge railway in Kenya as an example to explore the main factors that affect the construction progress of overseas railway projects and corresponding management countermeasures.

2.3 Emergency response planning and management

Natural disasters, public health events, social security incidents, and other emergencies often have certain characteristics such as a wide range of impacts and strong destructive power. Usually, various levels of emergencies require different administrative divisions to respond, as shown in Fig. 4. The design of the emergency network is the basis of emergency prevention and control decision-making, and plays a crucial role in emergency rescue and reducing material, as well as personnel losses caused by emergencies. In recent years, many scholars in China and abroad have investigated this field. For example, Butts (2009) pointed out that establishing a complete, accurate, and dynamically adjustable network organization model has practical significance in guiding the planning before emergencies and the rescue after emergencies (including disaster events, security incidents, and others). Li and Wang (2012) established a network flow model based on dynamic user equilibrium to solve the problem of shelter location and rescue material planning under the influence of hurricanes in North Carolina, considering the influence factors such as road traffic congestion caused by crowd evacuation and route selection. Yang et al. (2011) aimed to solve the problem of mismatch between resource demand and supply in the emergency rescue process by defining the basic unit of the graphical evaluation and review technique (GERT) network in the emergency rescue process. The authors established an emergency rescue process GERT network that comprehensively considered the evolution process of the disaster itself and the relationship between external factors and provided an analytical framework and tool that combined qualitative and quantitative analysis for emergency resource allocation.

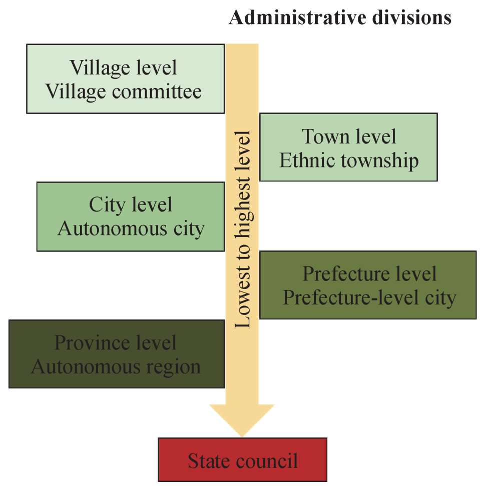

Fig. 4 Level of emergencies and administrative divisions.

In engineering management, the occurrence of emergencies has strong unpredictability, and accurately modeling them is a difficult task. Therefore, many scholars have studied the design and optimization of the emergency network under uncertain conditions. For example, Berman et al. (2007) established several network optimization models considering that all facilities in the system have certain failure risk, as well as summarized and compared the responsiveness of various network design schemes for emergency risk prevention and control. Hong et al. (2015) considered the reliability network design optimization model for risk protection under the conditions of uncertain demand and transportation facilities. They proposed a stochastic integer programming model based on the confidence criterion to optimize the probability of the network resistance to emergency risk under the condition that the demand reaches a certain probability. Zhang (2008) established an optimal design model of the equipment supply chain based on risk control. This model was meant for the forward supply network design of the army equipment supply chain based on quantitative analysis of risk and cost of the equipment supply chain, which realized the optimal network design scheme under the given risk confidence level. Salmerón and Apte (2010) studied the design of an emergency-oriented humanitarian material supply network and established a two-stage stochastic programming model. The first-stage model was used to optimize the expected transportation efficiency of the supply chain network. The second-stage model was used to optimize the material delivery scheme under different random airport scenarios. Liao (2019) established a mega-network risk prevention and control model for the international road transportation system by using the theory and method of hyper network. Andreas and Smith (2008; 2009) extended the network design problem under emergencies to the network optimization problem under dynamic uncertainty and established a two-stage stochastic integer programming model and designed an iterative solution algorithm based on the L-shaped method. Finally, Andreas and Smith (2009) proposed two kinds of improved cut plane inequalities according to the characteristics of the model to improve the efficiency of the solution.

In the optimization of the emergency plan, the location and inventory of material supply sites have always been a hot topic in academic and engineering circles. In recent years, many scholars have introduced uncertainty and dynamics into the material/facility location and inventory problems and applied it to the actual background of emergency facility location. In the field of facility location, Gao (2012) used uncertain variables to describe the uncertainty of nodes, proposed two types of single-facility location problems, and discussed their application scenarios. Jena et al. (2015) considered the multi-stage facility location problems with capacity constraints and proposed a class of general functions to describe the cost changes caused by capacity variation. Castro et al. (2017) analyzed the structural characteristics of multi-stage facility location problems and designed a set of methods based on Benders decomposition and interior point method to efficiently solve large-scale facility location problems with capacity constraints. Ortiz-Astorquiza et al. (2019) studied the multi-level facility location problem, analyzed the characteristics of commodity flow between different levels, and designed a method based on Benders decomposition. In the field of inventory, Shi et al. (2007) established a multi-period stochastic demand production/inventory model and designed an optimal production and inventory control algorithm by analyzing the characteristics of the model cost function, which effectively reduced the average cost. When the demand fluctuation is difficult to describe using random variables, Qin and Kar (2013) and Gao et al. (2013) introduced expert data to estimate the demand fluctuation and constructed an uncertain inventory model.

In addition, many scholars integrate location and inventory into one model. Tang et al. (2008) proposed a multi-stage stochastic location inventory model, which considers not only the benefit of the risk allocation but also the uncertainty of parameters in the entire multi-stage strategic cycle by using scenario planning. The goal of the model is to find an optimal solution that minimizes the total expected cost (including inventory, transportation, and location costs) of the entire strategic cycle. Liu (2014) studied the robust facility location problem with the unknown probability distribution of uncertain parameters, discussed the impact of uncertain factors on location decision and location cost, and in combination with the inventory problem, extended the traditional location model. In recent years, some scholars have applied the research results of location and inventory to the background of emergency facility location. By analyzing the risk characteristics of emergencies, Wei et al. (2009) constructed a multi-objective decision-making model to find the optimal selection point of emergency facilities by comprehensively considering the efficiency, fairness, and cost of emergency facilities' location. To solve the problems of multi-point simultaneous demand and multiple demands in response to major emergencies, Ge et al. (2011) studied the coverage problem in the layout of emergency service facilities for responding to major emergencies. According to the characteristics of emergency response to major emergencies, the concepts of maximum and minimum critical distance are introduced. Based on the stepped coverage quality level, multiple quantities and quality coverage models are established.

Due to the sudden, destructive, and unpredictable characteristics of disasters, to reduce the losses caused by disasters, the rescue materials must be delivered to the affected areas as soon as possible under limited time and space conditions. Therefore, the transportation route planning of emergency rescue materials has always been the focus of research. Wei et al. (2013) used the improved Dijkstra algorithm to find the critical value, determine when to change the rescue route, and solve the problem that the rescue route is not adjusted in real time according to the time-varying information of the road network. The authors concluded that the various changes in traffic flow have different effects on the pre-selected optimal path. Cai et al. (2010) adopted the least consumption method to solve the problem in which the shortest path is not necessarily the least time-consuming path. Zhao (2016) divided the emergency rescue stage into the emergency stage and mitigation stage according to the different characteristics before and after the emergency rescue, and constructed a multi-objective vehicle path optimization model to generate vehicles in different stages. According to the timeliness and safety of the emergency rescue, Sun (2012) established a bi-level programming model for the emergency rescue path optimization and applied the Paramics software platform for simulation analysis to verify the rationality of the model. Duan et al. (2017) established a public transport evacuation based on the emergency rescue vehicle route selection model. Zhu et al. (2019) proposed a route reliability measurement method for emergency rescue path planning and then constructed a multi-objective mathematical planning model, designed an improved ant colony optimization algorithm to solve the problem, and verified the effectiveness of the proposed method by taking Ludian earthquake as an example.

Özdamar et al. (2004) established a planning model integrated into the natural disaster logistics decision support system to solve the dynamic time-varying transportation problem that needs to be solved repeatedly in a given time interval during the delivery of continuous assistance. Taking the Izmit earthquake as an example, the researchers verified the rationality of the model. Tan and Gong (2015) proposed a planning model integrated into the decision-making support system of natural disaster logistics. For the two-stage optimization model of path planning, the data envelopment analysis (DEA) cross-evaluation model is introduced to analyze the decision-making utility, and the improved ant colony optimization algorithm is applied to solve the problem. Zhang (2013) established a mathematical model of emergency distribution problems for emergency rescue path-planning problem based on real-time information and designed an improved Dijkstra algorithm to improve the model. Han (2017) established a single-cycle static decision-making bi-level programming model for road repair and material distribution. Furthermore, a nested genetic algorithm and ant colony algorithm were designed to solve the emergency material scheduling problem under the condition of a damaged road network in disaster areas and the effectiveness of the model and algorithm were validated by taking the Wenchuan earthquake as an example.

Once an emergency occurs in railway construction, dispatching various materials is necessary. As these materials are often distributed in multiple rescue sites, and the types and quantities of the materials in each rescue site are different, how to dispatch emergency materials efficiently and quickly has become an important research topic in railway engineering emergency management. In the literature, Tufekci and Wallace (1998) concluded that emergency management resource scheduling is a complex multi-objective optimization problem. In the case of emergency resource constraints, solving the problem of efficient utilization of resources is necessary. Dai and Da (2000) established a mathematical model of multi-resource combination emergency scheduling problem for sudden disasters and provided the corresponding optimal scheme. Based on the multi-stage optimization model, Li (2015b) designed an optimization method for power emergency material scheduling under natural disaster scenarios. Guo (2017) studied the emergency material scheduling problem of hydropower enterprises under sudden natural disasters based on the improved particle swarm optimization algorithm. Liu et al. (2002) introduced the concept of fuzzy set to consider the uncertainty of emergency rescue resources and used the fuzzy optimization method to study the multi-emergency rescue material scheduling scheme with resource demand constraints. Lin (2007) established a two-stage model of multi-accident point-resource scheduling problem based on dynamic game technology and presented a numerical example that is close to reality. Gu (2009) discussed the scheduling problem of emergency materials after the occurrence of disasters. Considering that the demand for emergency materials is large and the time is relatively short, the mathematical models for single and multi-variety emergency material scheduling under certain conditions are established and the solving algorithm is designed.

According to the characteristics of railway emergency rescue work, Niu et al. (2009) established the resource scheduling model of multiple emergency points for railway emergencies, and designed the corresponding solution method to minimize the emergency resource scheduling time on the premise of meeting the resource demand of emergency points. Xie (2010) studied the problem of railway emergency resource allocation, established the resource allocation optimization model with the shortest emergency rescue time and lowest cost, and set up the corresponding solution algorithm. According to the characteristics of railway emergencies, Song (2011) studied the emergency scheduling strategies with fixed and dynamic resource demands and designed a solution algorithm based on hierarchical sequence ideas to minimize the end time of emergency rescue and the scheduling costs related to emergency rescue.

2.4 Emergency response and rescue mechanisms

In terms of the rescue mechanisms, domestic scholars have conducted extensive research. The development of the rescue mechanisms mainly considers the rationality, reliability, and vulnerability of these mechanisms, which use high-tech equipment such as satellites, terminals, control centers, and emergency beacons, as shown in Fig. 5. The research content mainly includes the establishment of an emergency management system, emergency capacity evaluation, emergency plan, and scheme evaluation. In many years of operation practice, China's railway has gradually established an emergency management system characterized by "one case, three systems", including emergency plan system, emergency management system, emergency management mechanisms, and emergency management legal system (Liu, 2017). Tang and Li (2013) applied the group gray AHP to the vulnerability evaluation of the emergency rescue management system and conducted a corresponding assessment for the emergency rescue system. After analyzing and summarizing the characteristics of railway emergencies, Li et al. (2012) concluded that the intervention of artificial intelligence and modern decision-making theory is needed to improve the ability of the emergency rescue system. Xing (2012) completed the modeling of the railway emergency plan evaluation method by using the neural network combination evaluation and fuzzy neural network evaluation methods. To improve the rescue skills of railway rescue equipment operators, Xu et al. (2018)

Fig. 5 High-technology system for rescue.

proposed a crane training system based on virtual reality (VR) and designed a visualization platform based on the PhysX engine to reconstruct the real railway accident scene.

In emergency response, the research contents mainly include arranging rescue locomotive and rescue personnel, adjusting train timetables, and allocating emergency resources. Cheng and Liang (2014) studied the problem of railway emergency systems and urban ambulance rescue locations and proposed a multi-objective strategic planning model considering the rescue probability of demand and the corresponding risk level of railway sections. To improve the sustainable rescue capacity in emergency rescue management, Zhang et al. (2019) established a multi-objective three-stage stochastic programming model with minimum transportation time, transportation cost, and unsatisfied demand as the objectives to solve the problem of emergency resource allocation by considering the correlation between the first and second disasters. Törnquist Krasemann (2012) designed a greedy algorithm based on optimization to ensure that the train could quickly adjust the timetable when encountering interference. Cacchiani et al. (2014) reviewed the recovery model and algorithm of railway interference and interruption management, including real-time adjustment of the train timetable, and real-time arrangement of rolling stock and crew. Sañudo et al. (2014) established a train-stop selection model in an accident or a specific area of an accident according to the discrete selection model and random utility theory, considering the influence of train stops and the timetable. Zheng (2018) studied the problem of how to arrange a group of emergency trains in the scheduled high-speed railway timetable and distinguished three solutions to the problem: Ideal, quasi-ideal, and feasible solutions according to the disturbance degree of the timetable. Numerical experiments showed that the method is effective for emergency response, and the method was successfully applied to a chemical explosion rescue operation in Tianjin in 2015. Bababeik et al. (2018) studied the optimal location and configuration of rescue trains to improve the elastic level of the railway network and established an optimization model by using the double objective programming method. Through the actual case analysis, the researchers found that the model can provide a more economical and effective rescue train scheme compared with the traditional maximum coverage model.

The aftermath of the accident is mainly organized according to various laws and regulations, including proper accommodation, transfer, ticket refund, and other services for stranded personnel. At the same time, learning from the accident helps to improve safety and prevent similar incidents. Fan et al. (2015) analyzed the “7.23 Yongwen railway accident” by using the system thinking method, which determined the system elements and drew the cause-and-effect cycle diagram. The study also revealed how a potential system structure ultimately led to major accidents and could help railway managers fundamentally prevent such accidents.

Corresponding studies have also been conducted on emergency management and rescue for major engineering construction projects in China. Yang and Zhang (2017) studied the allocation of emergency resources in the Three Gorges Reservoir area. Based on a discussion of the emergency resource allocation mechanisms of the water rescue base in the Three Gorges Reservoir area, a robust optimal allocation model of the emergency resources of the water rescue base in this area was constructed to minimize the total loss and total time of the emergency resource allocation. Luo (2017) constructed a layout model of the water emergency rescue base in the Three Gorges Reservoir area considering that the water emergency rescue base was divided into three levels. According to the characteristics and site selection emphasis of the water emergency rescue bases in the Three Gorges Reservoir area, various site selection models were constructed and corresponding algorithms were proposed to solve the model. Zhang (2013) studied the transportation organization of the Qinghai–Tibet Railway in case of emergency and proposed the basic types and characteristics of the emergencies on this railway system.

3 Research suggestions for Sichuan–Tibet Railway

Based on the preceding literature review, this paper provides suggestions that can be considered as future research directions of the Sichuan–Tibet Railway construction.

As known, most of the related existing studies apply to low-dimensional data that directly represent the characteristics of the external variables of the object, and they have not considered all types of risk factors. Therefore, considering all complex risk factors is impossible. The risk assessment and warning mechanisms of the railway engineering construction projects are based on experience and rules, and mainly adopt qualitative analysis methods, which make this type of research unable to fix real-world problems. Therefore, solving basic theoretical and key technical problems of the risk assessment and warning mechanism in the Sichuan–Tibet Railway construction is difficult.

According to the characteristics of the railway emergencies, the existing literature mainly highlights the emergency material scheduling problem under deterministic demand and designs of the corresponding solution algorithm. However, a few factors such as environmental sensitivity, frequent disasters, and abrupt climate change faced by railway infrastructure are considered. Due to the environmental difficulties and complexities faced by the Sichuan–Tibet Railway project, the key issues to address are the robust optimization strategy for emergency material scheduling under the interference of various uncertain factors, and designing the solution algorithm to meet the requirements of rapid response, as well as coordinating the multi-emergency resource allocation (of multiple emergency stations).

The existing literature either theoretically analyzes the problem of the facilities location and inventory management or applies the relevant theoretical results to the emergency management of urban emergencies. Few studies has been conducted on emergency management in railway engineering. The geological activities along the Sichuan–Tibet Railway project are frequent, and the ecological environment is fragile. Thus, the possibility of terrorist attacks on key nodes cannot be ruled out. This type of emergency material/facility location and inventory problems have distinct and unique engineering characteristics and strategic needs that require urgent solutions.

For various types of deterministic and uncertain emergencies, the existing literature mainly focuses on the optimization design of the emergency network under a single transportation mode (such as highway transportation). However, studies seldom consider the design and collaborative optimization of multi-regional highway, railway, and air transportation networks under multiple transportation organization modes during the construction of the Sichuan–Tibet Railway. This railway project is unique both at national and global levels. An in-depth study on the formulation of the corresponding network design optimization model is needed for emergency prevention and control measures.

Furthermore, the existing literature mainly focuses on the route planning problem of emergency rescue for the transportation of the materials under real-time information and uncertainty. However, researchers rarely consider the state of the rescue materials, the robustness of the rescue path, and the relationship between the rescue scenario and the rescue path. Owing to the various requirements of the emergency rescue path for large-scale railway engineering construction projects, especially in a complex and dangerous environment, an emergency rescue path fitness evaluation and application scenario matching set has to be established. Also, a robust path generation model that adapts to different emergency rescue scenarios has to be built. Furthermore, an efficient solution algorithm has to be designed.

As this review has shown, most studies are still in the stage of qualitative description. Quantitative model analyses based on data are relatively limited. Thus, establishing the emergency scenario deduction method in the construction of the Sichuan–Tibet Railway is necessary. Furthermore, to identify the key elements of the scenario according to the current state, constructing the scenario of future development of the event has to be solved.

Finally, compared with the rapid development of China's railway situation, the country's railway traffic emergency management is still at the initial stage. The development is relatively slow. In a strong, complex, and dangerous construction environment, any equipment failure and safety accident in a mega engineering system may lead to disastrous consequences. A worthwhile subject of study is how to create a perfect, reasonable, and robust emergency rescue plan, and how to eliminate the effects of all types of emergencies on railway transportation before an emergency occurs.

In summary, the corresponding research suggestions for the Sichuan–Tibet Railway construction are proposed in Fig. 6. The technical route is from data collection and technology convergence to management decision-making.

4 Conclusions

This study reviewed four critical areas of the risk warning technologies and emergency response mechanisms in railway construction. Based on this approach, four corresponding research areas for the Sichuan–Tibet Railway are outlined as follows:

First, one research direction is combining the actual engineering data of the Sichuan–Tibet Railway and comprehensively applying new technologies such as big data, artificial intelligence, and machine learning to

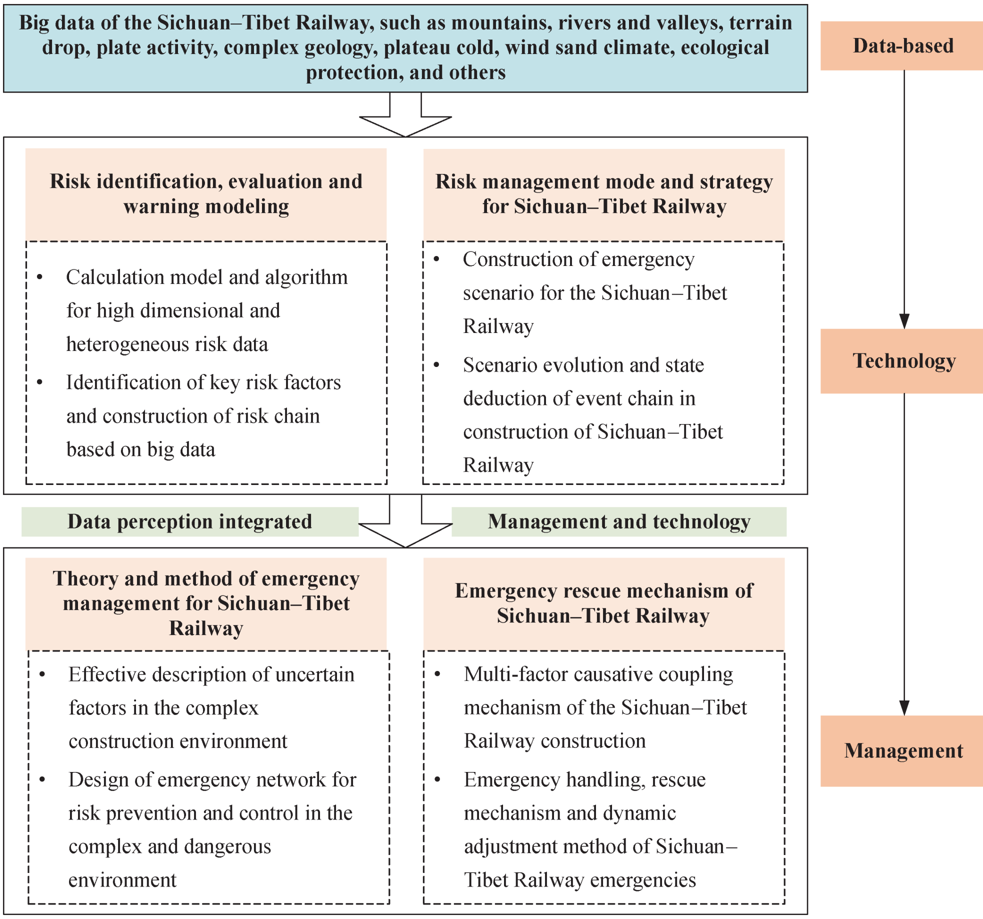

Fig. 6 Research suggestions for Sichuan–Tibet Railway.

construct the risk identification, evaluation, and early warning model of the railway project construction, as well as applying the existing innovative theories on it.

Second, given the existing risks in the construction process of the Sichuan–Tibet Railway, one can propose the scenario deduction-oriented risk management mode of the railway project and formulate the risk management strategy of the scenario response. This is the key scientific problem for the effective integration of technology and management.

Third, accurately describing the characteristics of uncertain factors in the construction of the Sichuan–Tibet Railway is a significant task. At the same time, one can construct the emergency pipeline network system of the railway by considering its complex and dangerous environment, including the design of the optimal emergency material reserve scheme, emergency path generation strategy, and emergency material scheduling method.

Finally, considering the Sichuan–Tibet Railway emergencies, researchers face the critical task of studying the coupling mechanisms of multiple factors, building the emergency rescue network for these emergencies, and establishing the dynamic decision-making model based on emergency response. In this case, one can formulate the emergency disposal procedure, rescue mechanisms, and dynamic adjustment technologies to address the emergencies in this railway system.

References

Andreas A, Smith C (2008). Mathematical programming algorithms for two-path routing problems with reliability considerations. INFORMS Journal on Computing, 20(4): 553–564

Andreas A, Smith C (2009). Decomposition algorithms for the design of a non-simultaneous capacitated evacuation tree network. Networks, 53(2): 91–103

Bababeik M, Khademi N, Chen A (2018). Increasing the resilience level of a vulnerable rail network: The strategy of location and allocation of emergency relief trains. Transportation Research Part E: Logistics and Transportation Review, 119: 110–128

Berman O, Krass D, Menezes M (2007). Facility reliability issues in network *p*-median problems: Strategic centralization and co-location effects. Operations Research, 55(2): 332–350

Butts C T (2009). Revisiting the foundations of network analysis. Science, 325(5939): 414–416

Cacchiani V, Huisman D, Kidd M, Kroon L, Toth P, Veelenturf L, Wagenaar J (2014). An overview of recovery models and algorithms for real-time railway rescheduling. Transportation Research Part B: Methodological, 63: 15–37

Cai M, Deng Y, Tang Z (2010). An optimal spatio-temporal path algorithm for urban emergency rescue. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 38: 1–5

Castro J, Nasini S, Saldanha-da-Gama F (2017). A cutting-plane approach for large scale capacitated multi-period facility location using a specialized interior-point method. Mathematical Programming, 163(1–2): 411–444

Chen F (2016). SJKZ Construction Engineering Project as An Example of Railway Construction Project Risk Management. Dissertation for the Master's Degree. Jinan: Shandong University (in Chinese)

Cheng Y, Liang Z (2014). A strategic planning model for the railway system accident rescue problem. Transportation Research Part E: Logistics and Transportation Review, 69: 75–96

Cosgrave J (1996). Decision making in emergencies. Disaster Prevention and Management, 5(4): 28–35

Dai G, Da Q (2000). The study of combinatorial scheduling problem in emergency systems. Systems Engineering-Theory & Practice, 20(9): 52–55 (in Chinese)

Deng Y, Zheng S, Liu G, Liu T (2005). Study on city emergency capability assessment system. Journal of Safety Science and Technology, (6): 33–36 (in Chinese)

Dong S, Yang Y, Li F, Cheng H, Li J, Bilgaev A, Li Z, Li Y (2018). An evaluation of the economic, social, and ecological risks of China–Mongolia–Russia high-speed railway construction and policy suggestions. Journal of Geographical Sciences, 28(7): 900–918

Duan M, Chen G, Dong B, Li S (2017). Emergency rescue path selection model under uncertain information. Journal of Transportation Systems Engineering and Information Technology, 17(4): 173–181 (in Chinese)

Fan W (2007). Thoughts and suggestions on scientific problems in national emergency management during emergency crisis. Bulletin of National Natural Science Foundation of China, (2): 71–76 (in Chinese)

Fan Y, Li Z, Pei J, Li H, Sun J (2015). Applying systems thinking approach to accident analysis in China: Case study of "7.23" Yong–Tai–Wen high-speed train accident. Safety Science, 76: 190–201

Gao Y (2012). Uncertain models for single facility location problems on networks. Applied Mathematical Modelling, 36(6): 2592–2599

Gao Y, Wen M, Ding S (2013). (s, S) policy for uncertain single period inventory problem. International Journal of Uncertainty, Fuzziness and Knowledge-based Systems, 21(6): 945–953

Ge C, Wang X, Guan X (2011). A multi-covering model and its algorithm for facility location response for large-scale emergencies. Operations Research and Management Science, 20(5): 50–56 (in Chinese)

Gu Y (2009). The Study of Regional Emergency Material Reserve and Dispatching Facing Major Emergencies. Dissertation for the Doctoral Degree. Wuhan: Wuhan University of Technology (in Chinese)

Guo J (2018). Discussion on pre-plan design in railway emergency management. Shandong Industrial Technology, 266(12): 211 (in Chinese)

Guo R, Zhou F (2015). Study of the progress control of the oversea EPC railway project. Value Engineering, 34(32): 71–73 (in Chinese)

Guo X (2017). The study of emergency material dispatching of hydropower enterprises under sudden natural disasters. Dissertation for the Master Degree. Chongqing: Chongqing University (in Chinese)

Han H (2017). Emergency Material Dispatch Method Taking into Account Road Conditions. Dissertation for the Master's Degree. Wuhan: Wuhan University (in Chinese)

Hong X, Lejeune M A, Noyan N (2015). Stochastic network design for disaster preparedness. IIE Transactions, 47(4): 329–357

Jena S D, Cordeau J F, Gendron B (2015). Dynamic facility location with generalized modular capacities. Transportation Science, 49(3): 484–499

Jenkins L (2000). Selecting scenarios for environmental disaster planning. European Journal of Operational Research, 121(2): 275–286

Jin J (2019). Research on Risk Evaluation of International Railway Corridors Construction among Countries along "The Belt and Road". Dissertation for the Doctoral Degree. Beijing: China Academy of Railway Sciences (in Chinese)

Jin J, Li Z, Zhu L, Yang C (2019a). A research on risk assessment of China railway "Go-Global" project construction. Railway Transport and Economy, 41(2): 82–87 (in Chinese)

Jin J, Li Z, Zhu L, Tong X, Yang C (2019b). Application of BP neural network in risk evaluation of railway construction. Journal of Railway Engineering Society, 36(3): 103–109 (in Chinese)

Knight K, Robinson Fayek A (2002). Use of fuzzy logic for predicting design cost overruns on building projects. Journal of Construction Engineering and Management, 128(6): 503–512

Kovacevic M S, Gavin K, Oslakovic S, Bacic M (2016). A new methodology for assessment of railway infrastructure condition. Transportation Research Procedia, 14: 1930–1939

Lagadec L R, Moulin L, Braud I, Chazelle B, Breil P (2018). A surface runoff mapping method for optimizing risk assessment on railways. Safety Science, 110: 253–267

Leitner B (2017). A general model for railway systems risk assessment with the use of railway accident scenarios analysis. Procedia Engineering, 187: 150–159

Li A, Nozick L, Xu N, Davidson R (2012). Shelter location and transportation planning under hurricane conditions. Transportation Research Part E: Logistics and Transportation Review, 48(4): 715–729

Li H (2010). Research on new model of the emergency management phase theory. Journal of Safety Science and Technology, 6(5): 18–22 (in Chinese)

Li H (2015a). Research of Electric Power Emergency Materials Scheduling Optimization Model under Natural Disasters. Dissertation for the Master's Degree. Beijing: North China Electric Power University (in Chinese)

Li H (2015b). A Research on Construction Schedule Risk of Railway Engineering Project. Dissertation for the Doctoral Degree. Nanchang: Jiangxi University of Science and Technology (in Chinese)

Li L, Wang F Z (2012). Railway incident and emergency decision-making research. Journal of Institute of Disaster Prevention, 14(3): 58–63 (in Chinese)

Li Q, Liu R, Zhang J, Sun Q (2014). Quality risk management model for railway construction projects. Procedia Engineering, 84: 195–203

Li S, Liu J, Wang B, Xiao L (2010). Unconventional incident management research based on scenarios—"The First International Forum on Incident Management" (IFIM09) overview. Journal of University of Electronic Science and Technology of China (Social Sciences Edition), 12(1): 1–3, 14 (in Chinese)

Li S, Tian Y, Wu Y (2019). Research on the risk assessment of railway engineering project based on FAHP model. Journal of Railway Engineering Society, 36(7): 92–99 (in Chinese)

Li Y, Peng S, Li Y, Jiang W (2020). A review of condition-based maintenance: Its prognostic and operational aspects. Frontiers of Engineering Management, 7(3): 323–334

Liang X (2011). Research on Safety Management Information System of Railway Construction Project. Dissertation for the Master's Degree. Beijing: Beijing Jiaotong University (in Chinese)

Liao R (2019). Modeling and simulation of risk prevention and control of TIR system based on super-network. Journal of Shanghai Maritime University, 40(1): 51–58 (in Chinese)

Lin X (2007). Research on Resource Scheduling of Emergency Management in Emergencies. Dissertation for the Master's Degree. Xiamen: Xiamen University (in Chinese)

Liu C, Shi J, Li C (2002). Selection of the combinatorial optimal scheme for fuzzy emergency system. Journal of Industrial Engineering and Engineering Management, 16(2): 25–28 (in Chinese)

Liu H (2014). Research on Robustness of Network Facilities Location under Uncertainty. Dissertation for the Doctoral Degree. Wuhan: Huazhong University of Science and Technology (in Chinese)

Liu M, You D (2011). Research on construction mode of risk early warning system of railway construction project. Project Management Technology, 9(8): 58–63 (in Chinese)

Liu T (2012). Study on scenario planning and construction of major emergencies. China Emergency Management, (4): 18–23 (in Chinese)

Liu X (2017). Research on Assistant Decision Method of Railway Emergency Management. Dissertation for the Doctoral Degree. Beijing: China Academy of Railway Sciences (in Chinese)

Luo X (2017). Research on Location Model of Water Emergency and Rescue Comprehensive Base in the Three Gorges Reservoir Area. Dissertation for the Doctoral Degree. Wuhan: Wuhan University of Technology (in Chinese)

Mileti D S (1975). Natural Hazard Warning Systems in the United States: A Research Assessment. Boulder, CO: Institute of Behavioral Science, University of Colorado

Mulholland B, Christian J (1999). Risk assessment in construction schedules. Journal of Construction Engineering and Management, 125(1): 8–15

Niu H, Li P, Wang F (2009). Research on modeling and simulation of multi-emergency-areas model for emergency resource dispatch in railway emergency events. Railway Computer Application, 18(12): 20–22 (in Chinese)

Ortiz-Astorquiza C, Contreras I, Laporte G (2019). An exact algorithm for multilevel uncapacitated facility location. Transportation Science, 53(4): 1085–1106

Özdamar L, Ekinci E, Küçükyazici B (2004). Emergency logistics planning in natural disasters. Annals of Operations Research, 129(1–4): 217–245

Peng B (2011). Quality Risk Analysis of Beijing–Shanghai High-Speed Railway Construction Project Based on Bayesian Network. Dissertation for the Master's Degree. Chengdu: Southwest Jiaotong University (in Chinese)

Perry R W, Lindell M K (2003). Preparedness for emergency response: Guidelines for the emergency planning process. Disasters, 27(4): 336–350

Qin Z, Kar S (2013). Single-period inventory problem under uncertain environment. Applied Mathematics and Computation, 219(18): 9630–9638

Ren X (2010). Engineering Risk Management. Beijing: Beijing Jiaotong University Press

Rong L (2014). Research on the construction method of emergency plan system. China Emergency Management, (8): 23–29 (in Chinese)

Salmerón J, Apte A (2010). Stochastic optimization for natural disaster asset prepositioning. Production and Operations Management, 19(5): 561–574

Sañudo R, Bordagaray M, dell'Olio L, Ibeas Á (2014). Discrete choice models to determine high-speed passenger stop under emergency conditions. Transportation Research Procedia, 3: 234–240

Shi W, Yan H, Wang Z (2007). Control method for multi-period production/inventory model under random demands. Control and Decision, 22(9): 994–999 (in Chinese)

Song Q (2011). Research on Emergency Resource Dispatching Problem of Railway Emergencies. Dissertation for the Master's Degree. Chengdu: Southwest Jiaotong University (in Chinese)

Sorrill C M (1987). Risk analysis for large projects: Models, methods and cases. Journal of the Operational Research Society, 38(12): 1217

Stallings R A, Quarantelli E L (1985). Emergent citizen groups and emergency management. Public Administration Review, 45: 93–100

Suh S D (2000). Risk management in a large-scale new railway transport system project: Evaluation of Korean high speed railway experience. IATSS Research, 24(2): 53–63

Sun W (2012). Research on Route Selection of Emergency Rescue Vehicle under Sudden Disaster. Dissertation for the Master's Degree. Changchun: Jilin University (in Chinese)

Tan X, Gong K (2015). Emergency rescue route optimization based on decision utility analysis. Systems Engineering, 33(4): 131–135 (in Chinese)

Tang K, Yang C, Yang J (2008). Research on multi-stage random location inventory model. Journal of Wuhan University of Technology (Information & Management Engineering), 30(5): 795–799 (in Chinese)

Tang S, Li X (2013). Study on method for assessment of vulnerability of railway emergency rescue system. Journal of the China Railway Society, 35(7): 14–20 (in Chinese)

Törnquist Krasemann J (2012). Design of an effective algorithm for fast response to the re-scheduling of railway traffic during disturbances. Transportation Research Part C: Emerging Technologies, 20(1): 62–78

Tufekci S, Wallace W A (1998). The emerging area of emergency management and engineering. IEEE Transactions on Engineering Management, 45(2): 103–105

Wang D (2009). Study on railway construction project risk management. Inner Mongolia Science Technology & Economy, (11): 75–76 (in Chinese)

Wang L, Li Y, Wang E (2011). Research on risk management of railway engineering construction. Systems Engineering Procedia, 1: 174–180

Wang Y (2011). Research on Context Reconstruction Model of Unconventional Emergency. Dissertation for the Doctoral Degree. Harbin: Harbin Institute of Technology (in Chinese)

Wei R, Chen J, Yang L (2009). A decision-making model for the location of emergency rescue facilities. Industrial Safety and Environmental Protection, 35(11): 50–52 (in Chinese)

Wei X, Lv W, Song W (2013). Rescue route reselection model and algorithm for the unexpected accident. Procedia Engineering, 62: 532–537

Wuni I Y, Shen G Q, Hwang B G (2020). Risks of modular integrated construction: A review and future research directions. Frontiers of Engineering Management, 7(1): 63–80

Xie T (2014). Research on Risk Assessment and Management of Railway Construction Engineering. Dissertation for the Master's Degree. Chengdu: Southwest Jiaotong University (in Chinese)

Xie X (2010). Study on the scheduling problem of railway emergency materials. Technology & Economy in Areas of Communications, 12 (2): 52–55 (in Chinese)

Xing X (2012). Research on Combined Evaluation Method of Railway Emergency Plan for Emergency. Dissertation for the Master's Degree. Lanzhou: Lanzhou Jiaotong University (in Chinese)

Xu J, Tang Z, Yuan X, Nie Y, Ma Z, Wei X, Zhang J (2018). A VR-based the emergency rescue training system of railway accident. Entertainment Computing, 27: 23–31

Yang B, Fang Z, Liu S, Guo B (2011). Optimal resources allocation model for emergency rescue process based on the GERT network. Chinese Journal of Management, 8(12): 1879–1883 (in Chinese)

Yang J, Zhang W (2017). Research on robust optimal allocation of emergency resources in the Three Gorges Reservoir area. Journal of Chongqing Jiaotong University (Natural Science), 36(11): 71–77 (in Chinese)

Zhang H (2008). Optimum design model of equipment supply chain network based on risk control. Journal of Ordnance Engineering College, 20(3): 11–14 (in Chinese)

Zhang H (2013). Study on the Emergency Vehicle Distribution Rrouting Optimization Problem Which Is Based on the Real-Time Information. Dissertation for the Master's Degree. Xi'an: Chang'an University (in Chinese)

Zhang J, Liu H, Yu G, Ruan J, Chan F T S (2019). A three-stage and multi-objective stochastic programming model to improve the sustainable rescue ability by considering secondary disasters in emergency logistics. Computers & Industrial Engineering, 135: 1145–1154

Zhang M (2016). Study on Unconventional Emergency Scenario Reasoning Method the Case-Based. Dissertation for the Doctoral Degree. Wuhan: Huazhong University of Science and Technology (in Chinese)

Zhang X (2010). Study of the dynamic risk-managing model for high-speed railway construction projects. Traffic Engineering and Technology for National Defence, 8(6): 42–44, 38 (in Chinese)

Zhang Z (2014). Research on Construction of Emergency Scenarios and Dynamic Deduction Technology for Railway Emergencies. Dissertation for the Doctoral Degree. Lanzhou: Lanzhou Jiaotong University (in Chinese)

Zhao L (2016). Research on Vehicle Routing Optimization Problem in Different Stages of Natural Disaster Emergency Rescue. Dissertation for the Master's Degree. Beijing: Beijing Jiaotong University (in Chinese)

Zheng Y (2018). Emergency train scheduling on Chinese high-speed railways. Transportation Science, 52(5): 1077–1091

Zheng Y, Zhang M, Ling H, Chen S (2015). Emergency railway transportation planning using a hyper-heuristic approach. IEEE Transactions on Intelligent Transportation Systems, 16(1): 321–329

Zhong S (2004). A framework of the state emergency S&T system. Forum on Science and Technology in China, (5): 33–36 (in Chinese)

Zhou Y (2016). Research on Risk Early Warning Management of Railway Engineering Construction Stage that Based on AHP. Dissertation for the Master's Degree. Dalian: Dalian University of Technology (in Chinese)

Zhu J, Liu S, Ghosh S (2019). Model and algorithm of routes planning for emergency relief distribution in disaster management with disaster information update. Journal of Combinatorial Optimization, 38(1): 208–223