Research on safety control technology of high-speed railway combined test based on threatening event analysis

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Received 13 September 2024
Revised 26 September 2024
Accepted 26 September 2024

Abstract

Purpose – Safety management is a key point and poses a challenge in joint testing. To detect and address potential accidents' hidden dangers early, this paper conducts research on the safety control technology for high-speed railway joint tests by incorporating the concept of hazardous events.

Design/methodology/approach – Aiming at ensuring the safety of high-speed railway combined inspections and trials, this paper starts from the dual prevention mechanism. It introduces the concept of threatening events, defines them and analyzes the differences between threatening events and railway accidents. The paper also proposes a cause model for threatening events in high-speed railway combined inspections and trials, based on three types of hazard sources. Furthermore, it conducts research on the control strategies for these threatening events.

Findings – The research on safety control technology for high-speed railway combined operation and testing, based on the analysis of threatened events, offers a new perspective for safety management in these operations. It also provides theoretical and practical support for the transition from passive prevention to active risk pre-control, which holds significant theoretical and practical value.

Originality/value – The innovation mainly includes the following three aspects: (1) Building on the traditional dual prevention mechanism, which includes risk hierarchical management and control as well as hidden danger investigation and management, a triple prevention mechanism is proposed. This new mechanism adds the management of threatening events as the third line of defense. The aim is to more comprehensively identify and address potential security risks, thereby enhancing the efficiency and effectiveness of security management. (2) In this paper, the definition of a railway threatening event is clarified, and the causative model of a high-speed railway threatening event based on three kinds of danger sources is proposed. (3) This paper puts forward the control strategy of the high-speed railway combined operation and trial, which includes five key links: identification, reporting, analysis, rectification and feedback, which provides a new perspective for the safety management of the high-speed railway combined operation and trial and has important theoretical and application value.

Keywords High-speed railway, Joint investigation and test, Threatening event, Source of danger, Control strategy

Paper type Research paper

The author(s) disclosed the receipt of the following financial support for the research, authorship, and/or publication of this article: Research on key technologies of high-speed railway combined test and higher speed comprehensive test at 400 km/h (2024YJ296).

Declaration of conflicting interests: The author(s) declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Railway Sciences
Vol. 3 No. 6, 2024
pp. 731-745
Emerald Publishing Limited
e-ISSN: 2755-0915
p-ISSN: 2755-0907
DOI 10.1108/RS-09-2024-0039

1. Introduction

The commissioning and testing are key links in the dynamic acceptance phase before the opening of a new high-speed railway, where comprehensive and specialized test trains, along with related detection equipment, are used to test the functions, performance, and compatibility of the various systems of the high-speed railway, and to optimize the overall system to ensure it meets the design requirements. The commissioning and testing of high-speed railways mainly include track, subgrade, bridges, tunnels, communication, signaling, power traction power supply, passenger services, natural disasters and foreign object intrusion, comprehensive grounding, electromagnetic environment, vibration and noise, and safety gates (Li, 2024). From the commissioning and testing of the Beijing-Tianjin Intercity Railway (Beijing South – Tianjin) in 2008 to the end of 2023, China has seen the commissioning and testing of over 45,000 km of high-speed railways, including over 20,000 km of lines with speeds of 300 km/h or above. Through the practical applications of railway commissioning and testing, China has successfully developed a comprehensive testing system, exemplified by the 400 km/h high-speed integrated test train and a series of digital and networked testing equipment. It has also proposed system analysis and evaluation methods and established a set of comprehensive technical and management systems that align with the characteristics of China's high-speed railway construction (Xie *et al.*, 2023).

High-speed railway joint commissioning and trials are a huge and complex system project with high test standards, many professions involved, a wide range of participating units, and a short test period. Especially when a project has just been completed, there are many defects in equipment and facilities; organizing and coordinating becomes difficult. Therefore, the strengthening of safety management has become the focus and difficulty during the joint commissioning and trials (Zhou & Xu, 2022). It can be found from a large number of accident investigations that every safety accident does not happen accidentally without warning. Before an accident occurs, there will be many small incidents without damage or loss, that is, danger events (Zhou, Li, Deng, & Wu, 2009). Broadly defined, threatening events are events or a series of events that have the potential to cause injury, illness, or death. In foreign countries, threatening events are a concept that has been widely used in aviation, nuclear power, fire protection, the chemical industry, and other high-risk industries. The classic safety pyramid model and iceberg theory both suggest that the number of dangerous events is greater than the number of accidents, and these dangerous events essentially cover the base of the accident pyramid.

Ensuring safety is fundamental to the smooth progression of various tests and the commissioning of high-speed railways (Huang, 2021). Currently, domestic high-speed railway joint inspections and trials primarily employ a traditional accident-based safety management approach. This method, which relies on summarizing historical experiences and lessons, struggles to prevent similar accidents in the future due to its passive nature. In contrast, safety management for high-speed railway joint adjustments and trials is based on proactive hazard identification and risk analysis throughout the system's life cycle, as well as the development of risk control measures. This shifts the focus from reactive accident tracing and handling to proactive safety pre-control, which is a more advanced approach than traditional accident-based safety management. To a significant extent, this ensures the safety and effectiveness of high-speed railway joint tests (Ma, 2015). In recent years, increasing attention has been paid to the research on safety risk management. For example, based on the construction and operational status of the railway safety dual prevention mechanism, an operational evaluation system for the railway safety dual prevention mechanism has been developed, covering aspects such as basic management, security risk control, hidden danger investigation and management, and the construction and application of information systems (Yang, Xie, Luo, Liu, & Jiao, 2023). Furthermore, the general concept

of railway safety risk information classification has been studied and established, and risk information standardization items have been analyzed and presented based on the railway safety risk management process (Xi *et al.*, 2023).The safety management method based on hazardous event analysis focuses on the proactive discovery of problems, with greater emphasis on early detection and treatment of numerous hidden dangers and hazardous events at the base of the accident pyramid. It is a holistic approach to solving safety problems and a superior method for ensuring the safety of personnel and equipment during joint inspections and trials. Therefore, starting from the dual prevention mechanism, the management of threatened events is introduced. This is combined with the actual situation of safety management in China's high-speed railway joint inspections and trials. A causative model of threatened events for high-speed railway joint inspections and trials, based on three types of danger sources, is proposed to analyze the relationship between threatened event management and risk pre-control. Building on this foundation, the control strategy for threatened events in high-speed railway joint inspections and trials is further researched. This provides practical guidance for the safety management of high-speed railway joint testing, helps to enhance the efficiency and effectiveness of safety management, and is of significant theoretical and practical value for improving the safety management level of high-speed railway joint testing and reducing the risk of accidents.

2. Research on double prevention mechanism and threatening event

The linkage test is a critical phase bridging the construction and operation phases of high-speed rail, and its success directly determines whether the project can be completed on schedule and with high quality. It is an essential component in the construction process of high-speed rail. Therefore, during the linkage test of high-speed rail, it is crucial to proactively identify and eliminate safety risks, eliminate safety hazards, and advance the frontier of accident and fault prevention. This proactive approach is vital for ensuring railway safety during the linkage test period and after the line becomes operational, as well as for enhancing transportation efficiency. Traditional railway safety management strategies have included risk classification and control, as well as hazard identification and elimination. Although these strategies can identify and control potential safety risks to some extent, they require further strengthening and supplementation in the high-speed, high-technology, and high-risk environment of high-speed rail. Consequently, beyond the dual prevention mechanisms of risk classification and hazard identification and elimination, a third line of defense—hazard precursor event management—is proposed. This addition is intended to further enhance the ability to control and eliminate accidents, thereby improving the safety management system for the linkage test of high-speed rail. It ensures a more comprehensive and in-depth identification and response to hidden safety risks, with the goal of preventing accidents at their source.

2.1 Research on theory and basic concept of double prevention

Dual prevention mechanisms include two parts: hierarchical control of security risks and investigation and management of security risks. By learning from and absorbing the theoretical basis of accident prevention, the relationship between hazard sources, risks, hidden dangers, and accidents is clarified. Theoretical methods for identifying, classifying, and managing security risks are explored, and methods and processes for optimizing the investigation and management of security risks are also explored. To eliminate, reduce, or control related risks at the source, this approach reduces the likelihood of accidents and the severity of consequences (Liang, 2024).

Risk points are the basis for risk management and control, and refer to the facilities, sites, and areas associated with risk, as well as the operational processes associated with risk

implemented at specific facilities, sites, and areas, or a combination of the above. Secondly, the hazard source is the key and core concept of constructing the dual prevention mechanism, and it is also the core of the safety management of high-speed railways. According to the Occupational Health and Safety Management System standards, a hazard is defined as a source that may cause injury and health damage, property damage, or other losses. Hazards can be divided into source hazards and state hazards. The root hazard refers to the objective existence of dangerous substances or energy carriers that may cause personal injury or health damage under existing conditions. State hazards refer to the potential danger state of the source hazard under certain conditions, and their essence is the virtual "harm + injury mode". For the specific environment of high-speed railway combined tests, hazards refer to the starting point, current state, or operational behavior of unsafe factors that may trigger safety accidents, mainly including equipment defects, operational errors, management omissions, and the results of their interaction, which is the basis for risk assessment and control measures of high-speed railway combined tests.

The concept of potential accidents is derived from the in-depth understanding and application of production safety regulations. According to the "Interim Provisions on the Investigation and Treatment of Potential Accidents" implemented in 2008 (Order No. 16 of the State Administration of Work Safety).It refers to the violation of production safety laws, regulations, rules, standards, procedures, and provisions of the production safety management system by the production and business unit, or to other factors in the production and business activities that may lead to the occurrence of dangerous conditions in objects, unsafe behavior by people, and management defects. potential accidents during high-speed railway joint tests (referred to as potential accidents) can be defined. If the relevant laws, regulations, rules, standards, and procedures of production safety are violated, or other factors lead to the dangerous state of equipment, unsafe behaviors of personnel, and defects at the management levels during the test activities that may cause accidents, mainly including but not limited to defects in track facilities, operator errors, and insufficient dispatch systems, these are potential risk points. It is necessary to prevent security incidents through careful investigation and strict management.

2.2 Research on the internal relationship of dual prevention mechanism

(1) Risk points and hazard sources

For high-speed rail systems, the risk point is mainly manifested in three key aspects: operational activities, track and vehicle equipment, and facilities, and key parts of stations and lines. The risk point is the carrier of the risk source, and it is necessary to clarify how the risk source is attached to the risk point. As an objective and realistic hazard source, a risk point may contain multiple such hazard sources. For example, for the signal system under test, signal failure may become a potential source of danger due to an electrical failure. In addition, damage to the track circuit may also pose a danger due to its potential impact on train operation. Therefore, there is an inclusive relationship between risk points and fundamental risk sources, and risk points and sources are inevitably present in the routine operation activities of railway transport, especially during the joint adjustment and joint test stage before opening.

(2) Danger source and accident hidden danger

In the field of railway safety, there is a close internal logical relationship between the hidden dangers of accidents, the sources of hazards, and state hazards. As an objective and realistic factor, the risk control strategy is mainly reflected by technical means, operational behaviors, and management systems. If these control measures fail, they may evolve into a hidden

danger of an accident (Haas & Yorio, 2016). For example, in a high-speed train, if the brake system fails, it signifies the failure of technical measures, leading to an unsafe state of the train and forming a hidden danger of an accident. If the driver does not perform safe operations according to the regulations, it reflects the failure of behavioral measures and demonstrates unsafe behavior of people, which also constitutes a hidden danger of an accident. If the train is not regularly maintained and inspected, this reveals the inadequacy of management measures, exposes defects in the management, and is also a hidden danger of an accident.

State hazards are usually the potential consequences caused by accident hazards, which directly trigger these potential states and form a direct causal chain (Xu, 2018; Fu & Zhang, 2018). For example, for high-speed trains, derailment, collision, or equipment failure that may occur is a potential risk state, which may be caused by accident hazards such as brake system failures, operational errors, or track problems, and there is a direct causal link with these accident hazards. Therefore, railway safety management requires a comprehensive consideration of technical, operational, and management measures to prevent and control accident hazards and ensure the safety of the entire system.

2.3 Study on the relationship between double prevention mechanism and threatening event

In the field of safety science, threatening events, as a special form of safety accidents, refer to small loss incidents that fail to develop into complete accidents due to the failure of safety protection measures or barrier functions, because the contact energy does not reach the critical value for an accident or lacks the necessary trigger factors. Although such incidents may be insignificant in terms of material losses, the characteristics demonstrated by accident symptoms provide valuable early warning signals for accident prevention (Bella & Eloff, 2016). The occurrence of threatening events is often the result of the existence of hidden dangers and is triggered by specific conditions. There is a direct causal chain between threatening events and the potential consequences of accidents. Once the energy level involved in threatening events accumulates to the critical value for an accident, or the corresponding trigger factors are satisfied, the original small loss incident may quickly escalate into a serious safety accident (Li, Dong, Pi, & Lou, 2021; Zhao, Miyahara, Mizuno, Ito, & Han, 2021). Therefore, in-depth study of threatening events based on the dual prevention mechanism is helpful to reveal the underlying patterns of accidents and provide a scientific basis for the formulation of preventive measures.

Hazard sources are the root causes of the occurrence of hazardous events, and if these sources are not properly controlled, they may evolve into hidden dangers. When hidden dangers are not eliminated in time, unsafe behavior under unsafe production conditions can lead to unsafe events, which may then induce hazardous events or accidents (Larouzee & Coze, 2020). The essence of a hazard source is an unrealized combination of "harm + injury mode," which may evolve into realistic risk factors leading to accident consequences under specific conditions. Threatening events can be regarded as the intermediate links in the transformation from a virtual state to a real dangerous state; they represent the specific manifestation of the virtual dangerous state under certain conditions, and their essence is the realized combination of "harm + injury mode." Therefore, from this perspective, state hazard sources evolve into actual hazardous events through the triggering of accident hidden dangers, revealing the potential developmental path of accidents and providing a key entry point for the implementation of the dual prevention mechanism. Through the identification, evaluation, and control of threatening events, the evolution process from danger sources to accident consequences can be effectively blocked, preventing and reducing the occurrence of safety accidents at the source, as shown in Figure 1. The expansion of the research perspective by introducing the double prevention mechanism into threatening events reflects

the deepening and expansion of traditional safety management concepts and marks the development of high-speed railway safety risk management towards a more refined and systematic direction. Through the implementation of the triple prevention mechanism, more effective safety risk control can be achieved in the joint tests of high-speed railways, providing solid theoretical and technical support for ensuring high-speed railway operational safety.

3. Analysis of hazardous event of high speed railway joint adjustment and trial

3.1 The definition and classification of high speed railway combined trial hazard event

Railway threatening events refer to events or phenomena that have the characteristics of railway accident symptoms and may lead to loss or injury. Due to successful defense or insufficient conditions for causing the accident, no loss or injury occurs or only minor loss or injury occurs. In the definition, "successful defense" refers to the timely adoption of control measures or the successful operation of individual protective equipment, and "insufficient conditions leading to accidents" are the key conditions that could lead to accidents. The comparison table of the characteristics of railway threatening events and railway accidents is shown in Table 1. Railway hazardous events include no loss, casualties, and minor accidents with minor loss or personal injury. The deviation of railway threatening events from standard safety states is small; if they are controlled in time, it is easier to reach standard safety states. On the contrary, if the occurrence of railway hazardous events is not paid attention to and allowed to develop, they may gradually trend toward a worsening trajectory, and the safety benchmark recedes further and further.

As a subset of railway warning events, the classification of the high-speed railway warning event can be divided into various types according to the object of action, the degree of influence, and the mechanism of action. According to the different affected objects after the occurrence of the event, high-speed railway combined trial warning events are divided into combined trial warning events, non-warning events of the combined trial, and personal warning events. The classification of warning events for high-speed railway joint commissions and trials is shown in Figure 2.

3.2 The model of risk event causation of high speed railway

The accident causation theory is a mechanism and model of accidents extracted from the analysis of the essential causes of a large number of typical accidents, which can reflect the laws of accident occurrence (Roberto, Cinzia, & Barbara, 2000; Xue, 2010; Ebrahimi, Sattari, Lefsrud, & Macciotta, 2021). In recent years, many scholars both domestically and

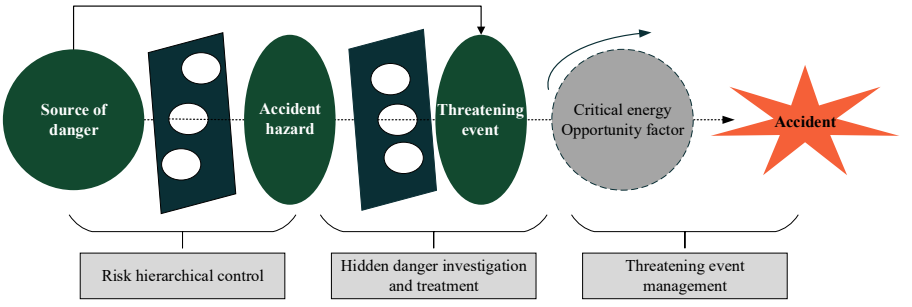


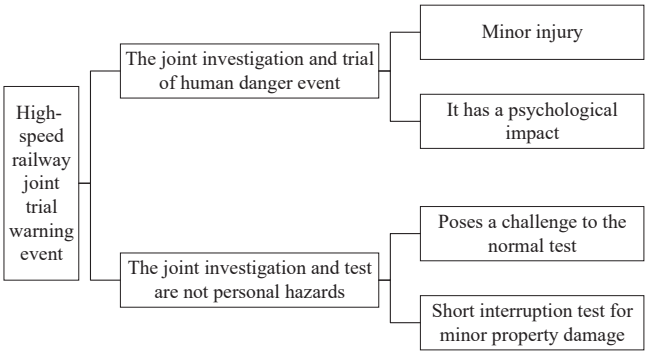
Figure 1.
Schematic diagram of triple prevention mechanism based on double prevention mechanism and threatening event management

Source(s): Authors' own work

	Railroad danger event	Railway accident
Extent of damage	The degree of loss is small or no loss, focusing on the psychological impact	The degree of loss is large. Focus on economic losses and casualties
Probability of occurrence	The probability of occurrence is large, which is convenient for statistical analysis	The small probability of occurrence is not conducive to statistical analysis
Manageability design goals	There are difficulties in the specific self-management of railway grass-roots departments, such as identification and up-withdrawal	Managers include superior departments, government supervision departments, foreign experts, etc., and concentrate multiple forces for post-hoc analysis and management
Influence degree	It has little impact on society and individual psychology	It has great influence on society and individual psychology
Feedback action	The event information contains the successful countermeasures of defense, which facilitates the search for direct and effective control countermeasures	After the analysis, the management and control measures are found. The accident information cannot reflect the specific match
Safety correction strength	Deviation from the standard safety state is small, easy to correct the deviation	The degree of deviation from the standard safety state is large, which is not conducive to correcting the deviation

Source(s): Authors' own work

Table 1. Comparison table of characteristics of railway threatened events and railway accidents



Source(s): Authors' own work

Figure 2. Classification of hazardous events for high-speed railway joint commissioning and trial

internationally have studied this theory. Tian Shuicheng *et al.* for instance, classified hazard sources, proposed the theory of three types of hazard sources, systematically analyzed and classified the failure paths within the model, proposed the principle of "three hands" for accident prevention, and established a model for accident prevention failure mechanisms based on these three types of hazard sources (Tian, Li, & Wang, 2006). The theory of three types of hazard sources emphasizes that poor organizational and management factors are the root causes of accidents, which is particularly applicable to the railway industry. Therefore, this paper introduces the theory of three types of hazards, expands upon it based on Reason's "Swiss cheese" accident causation model, and establishes a simple causation model for the combined and pilot hazard events in high-speed railways.

Reason studies the accident causation theory based on organizational management factors and believes that accidents are usually not caused by isolated factors but are the result of a series of system vulnerabilities or defects acting together, and attributes accident

causes to defense failures, which are divided into potential and explicit failures. The Swiss cheese model provides a visual explanation of the formation mechanism of complex system accidents, as shown in Figure 3. The holes in the model represent the holes or defects in the defense system, and the positions and sizes of these holes can change. When the holes align, the holes or defects in the defense system form an opportunistic accident trajectory, and the danger passes through this "trajectory," resulting in an accident. These layers are stacked like layers of perforated cheese, hence the name Swiss cheese model (Reason, 1990). The theory divides the development process of accidents into three stages: the organizational factors stage, the workplace factors stage, and the unsafe behavior stage. Organizational factors include decision-making, management, and audits; workplace factors include inadequate training, lack of communication, and poor operating procedures. The organizational accident process tracing model is shown in Figure 4.

The Swiss cheese model identifies the hazard as the source of the accident but does not detail the various stages the hazard may evolve through after passing through the holes or defects in the defense layers. If the management of the hazard is not in place and control fails, the hazard may further evolve into a hidden danger, increasing the likelihood of an accident. When a hidden danger occurs, if it is not eliminated promptly under unsafe production conditions, it can lead to unsafe events. When an unsafe event occurs, if it is properly managed, it will not result in loss or injury, or will only result in minor loss or injury. If not managed properly, it can lead to significant loss or injury, culminating in an accident. Based on the above views and as depicted in Figure 5, the causal model for high-speed railway combined operation and trial danger events is established, as shown in Figure 4.

In the model, the three types of hazard sources influence and interact with each other to form the root cause of the hazard events. The first type of hazard source consists of the material conditions that lead to the occurrence of threatening events, and its existence determines the possibility of their occurrence. However, in the process of joint adjustment and testing, the first type of hazard source is always inevitable. To avoid the occurrence of dangerous events, it is unrealistic to eliminate the existence of the first type of hazard source; this can only be achieved by controlling the second and third types of hazard sources. The second type of hazard source is the trigger condition for the combination of hazardous events, and its existence increases the likelihood of such events, while the third type of hazard source is the root cause of the first two types, especially the second type. The third type of hazard source, such as management defects, can lead to the generation of physical obstacles or

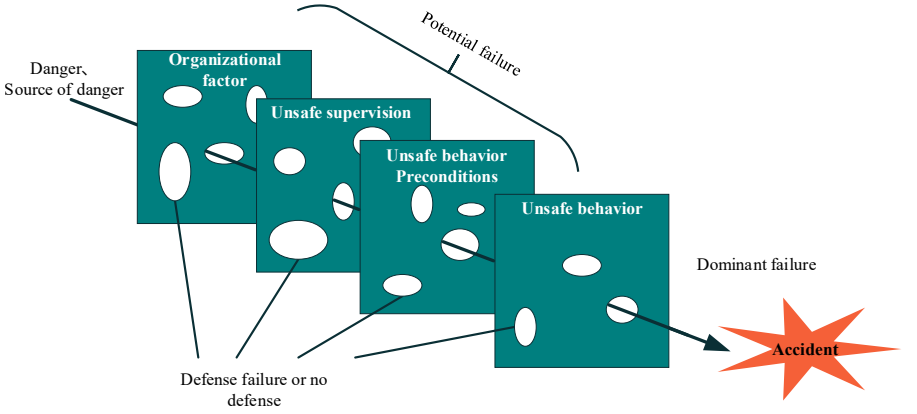


Figure 3.
Swiss cheese model

Source(s): Authors' own work

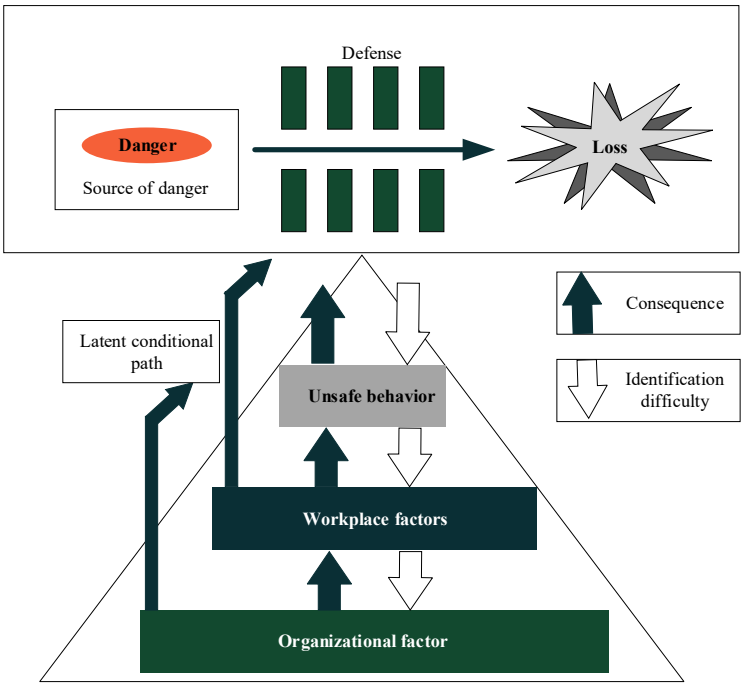


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Figure 4.
Organize accident process backtracking model

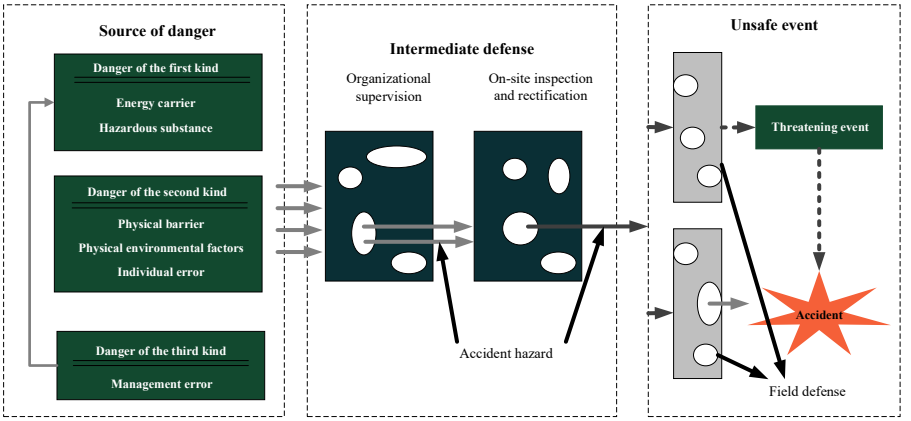

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Figure 5.
The model of risk event causation of high speed railway

untimely elimination, resulting in unsafe behavior. Therefore, it is necessary to strengthen the control of the third type of hazard source to fundamentally avoid the occurrence of danger events during joint investigation and trial.

Intermediate defense refers to the layers of defense before the occurrence of unsafe events caused by hazard sources. The intermediate defense in this model includes organizational

supervision and on-site inspection, in which organizational supervision refers to the management and decision-making of managers and the operation of ordinary employees, while on-site inspection refers to the inspection of three types of hazard sources at the location where dangerous events occur. Due to the loopholes in the intermediate defense, the existence state of the hazard sources is transformed into a hidden danger of an accident, which further leads to the occurrence of unsafe events during joint investigations and tests.

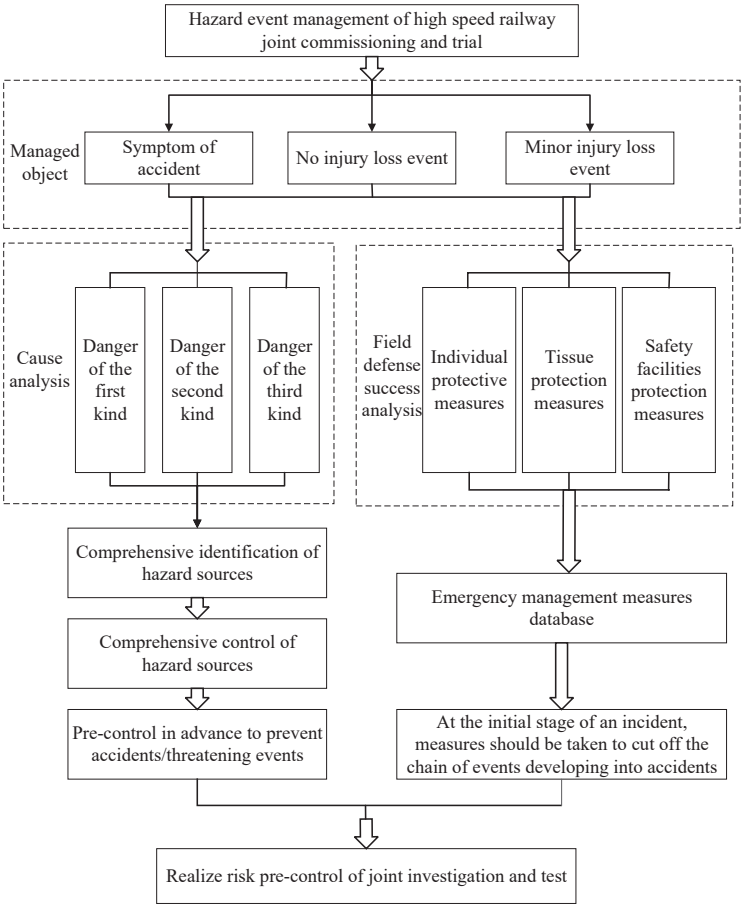
In the event of an incident of unsafety, the defensive measures taken are called on-site defenses. The success of on-site defense determines whether the unsafe event is a warning event or an accident. One of the components of managing joint investigation and trial danger events is to collect successful on-site defense measures and feed them back to the workers at the construction or test site to enhance their emergency response abilities.

3.3 Research on the relationship between the management of premonitorable event and the safety risk of high-speed railway

Through the analysis of accident signs, non-injury incidents, and minor injury incidents, the management of warning events for high-speed railways aims to identify direct causes, indirect causes, root causes, and the effectiveness of on-site defense. Considering accident causes and on-site treatment countermeasures, measures are implemented to interrupt the progression from accident signs to accidents. Or, when an accident is unavoidable, implement the successful on-site defense measures analyzed in previous joint investigation and trial danger event cases to mitigate the accident's impact. Clarifying the specific relationship between the management of threatening events and the risk pre-control of high-speed railways and integrating the management of threatening events into risk pre-control management can maximize the role of threatening event management and significantly enhance the comprehensiveness and scientific rigor of safety management for high-speed railway combined investigations and trials. Figure 6 illustrates the specific relationship and function of the management of high-speed railway combined investigation and trial in risk pre-control management.

The risk pre-control management system for high-speed railway joint adjustments and trials emphasizes hazard identification and risk assessment as the basis, risk pre-control as the core, and unsafe behavior control as the focus. It strives to reduce and maintain risks at an acceptable level by taking effective measures to eliminate, reduce, dilute, and isolate hazard sources. The risk pre-control and management process for high-speed railways is a systematic and programmatic approach to achieve control over risk sources related to "man, machine, environment, and pipe." The process includes five steps: hazard identification, risk assessment, risk management standards, management measures, hazard monitoring, and hazard early warning. Among them, risk assessment involves evaluating and estimating the likelihood, severity, and risk level of hazardous events and is central to safety analysis (Bai, Wang, & Guo, 2011).

In the process of risk pre-control management for high-speed railways, the management of threatening events is integrated into risk pre-control management. In the stage of hazard source identification, the three types of threat sources are entered into the general database for risk pre-control hazard source identification to assist in expanding the database. In the stage of risk assessment, these danger events can directly reflect the risk level of the hazard. In the stage of risk management standards and measures, threatening events can be used as a benchmark in risk management, such as using them as a benchmark to control hazard sources. In the process of hazard monitoring, monitoring dangerous events can indicate the status of the hazard source, making the monitoring more intuitive. In the danger source early warning stage, after a warning event occurs during high-speed railway joint adjustments and trials, the relevant hazard sources should be identified and rectified.



Source(s): Authors' own work

Figure 6.
The relationship between the management of warning events and the pre-control of risk in high-speed railway

Through the above analysis, it is evident that the management of high-speed railway combined trial danger events is a component of risk pre-control management. The analysis of event causes, the identification of the three types of danger sources, and the successful on-site defense measures can provide the foundation and support for risk pre-control. This approach can offer new methods and perspectives for the risk pre-control management of existing high-speed railways, further enhancing the risk pre-control capabilities during combined trials, and advancing towards the goals of "zero accidents" and "zero injuries".

4. Research on the control strategy of hazardous event for high-speed railway combined operation and trial

4.1 The purpose and content of the management of the high speed railway combined trial danger event

The combined tests of high-speed railways have characteristics such as a prominent contradiction between time and test tasks, difficulty in construction safety management, a

wide scope of equipment safety, and heavy public security management. Compared with combined test accidents, combined test danger events are effective tools for acquiring risk pre-control experience at a slight cost because they do not cause actual casualties or losses. The main purpose of applying the management of danger events to the daily safety management of high-speed railways is to broaden the safety knowledge and enhance the safety awareness of the test units and personnel. It is easy to obtain sufficient data for statistical analysis and follow-up research. It provides the basis for the safety input and risk assessment indices of joint investigations and tests.

The main body of railway safety production is people, and people's knowledge and experience are very important for improving the level of railway safety production. The management of high-speed railway combined hazardous events is an effective measure to deepen participants' understanding of hazards and hazardous events and to improve their safety level by reporting, analyzing, and providing feedback on the relevant information of hazardous events by employees or safety inspectors. The main components of the management of high-speed railway combined hazardous events include the basic information of combined hazardous events, the causes of their occurrence, the analysis and treatment of these events, the rectification of danger sources and risk pre-control, and information feedback and training education.

4.2 Research on the control process of the high speed railway combined test hazard event

According to the objective and content of the management of the high speed railway combined investigation and trial danger event, the control of the high speed railway combined investigation and trial danger event is divided into five core links: identification, reporting, analysis, rectification and feedback.

(1) Identification refers to the identification of the occurrence of hazardous events, which is the basis of the management of hazardous events in high-speed railway joint investigations and trials. To ensure the effectiveness and authenticity of the management of hazardous events, it is necessary to fully identify whether the unsafe events that have occurred are hazardous events of the high-speed railway combined trials. The main methods for identifying hazardous events include checklists, Safety Observation and communication (STOP), Hazard and Operability Studies (HAZOP), Event Tree Analysis (ETA), and Fault Tree Analysis (FTA) (Wang, 2012). For the joint tests of high-speed railways, due to the large number of units involved, the training workload for ordinary staff is substantial, and checklists are a convenient and easy-to-master method. For safety managers, tools such as Event Trees and Fault Tree Analyses, Hazard and Operability Studies can be used for identification and analysis.

(2) The reporting process. Reporting refers to the communication of events experienced or known by the high-speed railway joint investigation and trial, as well as by the warning event unit or safety inspection personnel. Reporting is the most important and challenging process to complete accurately in the management process of high-speed railway joint commissioning and trial hazard events, and the quality and quantity of reporting are crucial to the implementation of subsequent processes. The report should ensure the accuracy of information and the comprehensiveness of the description. For this reason, the report should be carried out promptly after the occurrence of the hazardous event to avoid forgetting the event details over time.

(3) The analysis part. The analysis process includes screening, classification, grading, cause analysis, and event responsibility analysis. The personnel responsible for the management of threatening events should first conduct a preliminary analysis of the

reported event to determine whether it belongs to the joint investigation and trial threatening events. To ensure the accuracy of the information, they should seek confirmation from the parties involved in the event. Based on the category and level of the event, it is classified and processed accordingly, its priority is determined, and it is decided whether further reporting is necessary. Cause analysis starts from the hazard source and analyzes the three types of danger sources that produced the incident, which facilitates the formulation of targeted rectification measures. Additionally, the analysis should focus on root cause analysis to identify loopholes or defects in security management. When assessing incident responsibility, responsibilities should be differentiated based on the incident's impact and frequency, and a special investigation team should be established to investigate, analyze, and address high-risk joint investigation and trial threatening events.

(4) Rectification process. In view of the defects or loopholes in hazard management, risk pre-control, and other aspects reflected in the joint coordination and trial danger events, formulate rectification measures and rectify them within a time limit. Formulate a special audit system, and arrange special auditors to review the rectification situation. When the safety management defects or loopholes reflected in the high-speed railway joint adjustments and trial danger events are significant, the joint adjustment and trial command organization should convene a special rectification meeting to supervise the rectification, evaluate and review the rectification situation, and even conduct long-term tracking inspections and assessments. Rectification measures are generally divided into three types: corrective measures, preventive measures, and enhancement measures. For high and medium-risk threatening events, corrective and preventive measures should be formulated; for low-risk threatening events, corrective actions should be taken.

(5) Feedback session. It mainly refers to the form of education and training to feed back the information of high-speed railway joint adjustment and trial warning events to the test units and relevant personnel, and to formulate measures to prevent such incidents from recurring. For general hazardous events, the participating units can use their daily regular meeting time to provide feedback and education to employees, and for more significant or major hazardous events, the joint investigation and test command organization should arrange a special study meeting to give comprehensive feedback to the safety management personnel and project leaders of the participating units. By enhancing the research and assessment of safety risks during the joint investigation and test, the relevant units strengthen their dynamic understanding of danger sources and the development and refinement of control measures. They assign responsibility for managing safety risks and implementing risk control measures to specific roles and individuals, and build a safety risk control system for the duration of the joint investigation and test.

5. Conclusion

The safety management of high-speed railways is a systematic project, and it is an essential component in ensuring railway safety. Based on the dual prevention mechanism, the management of threatened events is introduced as the third line of defense. This paper integrates the concept of threatened events into the safety management of high-speed railway combined trials, analyzing the definition, classification, and cause model of these events. It studies the control strategy for warning events in high-speed railway combined trials, which is of great significance for ensuring the safety of these trials and preventing the

occurrence of safety accidents.In the application of the management plan for high-speed railway combined operation and trial danger events, two key issues need to be addressed in practice: First, effective measures to enhance the willingness of voluntary reporting of combined operation and trial danger events should be researched; second, a perfect and reasonable management information system for high-speed railway combined investigation and trial danger events should be designed. Due to the limitations of research depth, further studies will be conducted in the future.

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