Computer Fraud and Security
ISSN (online): 1873-7056

Research on the Construction of an Intelligent Safety Assurance System for Building Construction and Accident Prevention Strategies and Network Security Technology

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Abstract:
As society's technology evolves, especially with advancements in big data and artificial intelligence, management systems across various industries need continuous innovation.To effectively prevent accidents in the construction industry, this paper relies on current laws, regulations, and standards to deeply research strategies for building a safety assurance system. Through analyzing \"Supervision Penalty\" documents and accident investigation reports from the Ministry of Housing and Urban-Rural Development over the past three years, it has been determined that hidden dangers, inspections, training and education, systems, supervision, technical briefings, investment, and emergency rescue are the eight major factors leading to accidents. Based on these findings, we have constructed six sub-systems within the safety assurance framework, encompassing risk classification and control, hidden danger identification and treatment, safety inspections, safety education and training, systemic guarantees, oversight, and technological and financial support. These sub-systems collectively form the construction safety guarantee system. Verified through questionnaire surveys, this system receives an average rating of nearly 8 points, demonstrating its application value in reducing production safety risks. Finally, targeted prevention measures based on each sub-system are proposed for common injury types such as falls from height, struck-by incidents, machinery injuries, and collapses. This further highlights the system's characteristics of being straightforward, easy to operate, and highly effective in preventing accidents.

Keywords: construction enterprise, safety assurance system, accident prevention, questionnaire survey method, artificial intelligence, network security

INTRODUCTION

As societal modernization progresses, particularly with the rapid evolution of technological advancements like computer technology, management systems across various industries undergo continuous iteration and enhancement. Within the realm of construction, given the multitude of equipment and materials on construction sites, the intricate and specialized nature of construction processes, coupled with high personnel turnover and volatile working environments, safety production has emerged as a pivotal focal point for industry advancement[1]. Nevertheless, as the construction enterprises strive towards establishing standardized safety systems, they commonly face a myriad of challenges: weak safety management awareness, deficiencies in professional skills among personnel, and inadequate management structures that urgently necessitate rectification[2]. Presently, the state of safety management in construction arouses concerns: inadequacy in workers' safety knowledge and skills, absence of a comprehensive safety training system, some enterprises have safety management and supervision mechanisms that are superficial and lack substantial investment in safety costs. Simultaneously, prevalent issues concerning the quality of construction materials and vulnerability to adverse environmental conditions during construction processes further escalate safety risks[3]. Within tall building construction, issues become even more pronounced, encompassing unauthorized commencements by enterprises, lax on-site safety management, ineffective handling of major safety hazards, inadequacies in construction personnel safety education, and insufficient adherence to safety protocols, all substantially imperiling safety production at construction sites. Given this backdrop, to effectively address the prominent safety production challenges faced by construction enterprises, elevate safety management standards, and genuinely safeguard the lives of individuals, this study aims to delve deeply into and establish a scientific and rational construction safety assurance system, alongside exploring corresponding accident prevention strategies. Through this research endeavor, we aspire to offer substantial support to construction enterprises, propelling continuous enhancement and comprehensive upliftment of safety production within the industry.

Furthermore, with the rapid development of big data and artificial intelligence technologies today, the labor safety and security system is undergoing profound changes. The application of these technologies makes safety management more intelligent and precise, able to predict and prevent potential safety risks by analyzing a vast amount of construction data [4]. At the same time, intelligent monitoring systems can monitor construction sites in real-time, automatically identify unsafe behaviors, thereby reducing the probability of accidents. However, this also requires the labor safety and security system to keep pace with the times, update relevant regulations and technical standards, strengthen technical training for practitioners, and build a safety management system that adapts to new technologies.

Research on safety assurance systems in foreign countries dates back to an earlier period. A study conducted in 2002 on the German safety management system reveals that Germany implements a safety production inspection management system characterized by "national supervision, government oversight, owner responsibility, and employee adherence". In the occupational safety and health management system, Germany adopts a legislative, supervisory, and insurance integrated management model, employing economic regulatory measures to establish a management mechanism for safety production through prevention, rehabilitation, and compensation functions. The function of managing occupational injury insurance in Germany is carried out by a legally established professional occupational injury insurance association [5]. In 1970, the United States established the Occupational Safety and Health Administration (OSHA) to oversee occupational safety and health work nationwide. OSHA is tasked with formulating regulations and standards for construction safety, ensuring employees work in a safe environment, supervising the implementation of construction safety regulations, coordinating with other federal agencies and the construction industry, and providing support [6]. Since the enactment of the Occupational Safety and Health Act (OSHAct) in 1970, all regulations related to construction safety have been replaced by the OSHAct [7]. In 1974, the United Kingdom introduced the Health and Safety at Work Act, which explicitly states the employer's obligation to ensure that employees work in a healthy and safe environment. Since 1996, the UK Health and Safety Executive and other related departments have established collaborative relationships, allocating approximately £19 million annually for safety research endeavors [8].

Research on safety assurance systems in China started relatively late. Ding [9] focused more on the construction of large systems, starting from six modules: laws and regulations, government oversight, emergency response, evaluation systems, insurance, and information platforms. However, as time has progressed, many new laws and regulations have been introduced, and more advanced technologies have emerged, rendering this system somewhat antiquated. Hao [10] proposed a safety assurance system from grassroots institutions, including safety training and education systems, safety briefing systems, safety production inspection systems, safety production meeting systems, important period safety production duty systems, safety production accident reporting and investigation systems. However, this system only involves personnel related to safety work and does not encompass emergency response or accident investigation. The safety assurance system lacks comprehensiveness, focusing solely on institutional aspects. In the book Construction Safety Technology and Management, Yu [11] introduced a safety assurance system that comprises organization, institutions, technology, investment, and information systems. However, this system does not address the later-stage operation of the system, lacking a comprehensive approach.

Safety is a state where individuals are free from unacceptable risks [12]; the construction safety assurance system refers to the use of legal and institutional means by the government and relevant social entities to gather and mobilize social forces. This aims to ensure that individuals engaged in construction product production activities remain unharmed during the production process. In cases of injury, casualties, or unforeseen circumstances during production, individuals can receive economic assistance and relevant services from the government and society to guarantee their basic livelihood [13]. As time progresses and technology advances, the traditional construction safety assurance system urgently requires updating and integration to address challenges within the current system, such as overlapping responsibilities and difficult decisions between safety and interests. This study aims to construct a succinct, easy-to-operate, and timely effective construction safety assurance new system by conducting in-depth analysis of laws and regulations, integrating enterprise safety practices, strengthening government oversight, and optimizing accident investigation and emergency response mechanisms.

ANALYSIS OF THE CONSTRUCTION SAFETY SITUATION

From 2014 to 2022, based on the total number of safety incidents in housing and municipal construction announced by the Ministry of Housing and Urban-Rural Development, the overall trend of construction safety incidents in China has been on the rise since 2015-2019. By 2019, the number of incidents had risen to 772, with 904 fatalities. Comparing the incident and fatality numbers in 2019 to those in 2015, there was an increase of 74.66% and 63.17%, respectively. However, from 2019 to 2022, there has been a general downward trend in both the number of incidents and fatalities. In 2022, construction enterprises reported 550 production safety incidents, resulting in 624 fatalities. Compared to 2019, the total number of incidents decreased by 223, and the number of fatalities decreased by 280, representing a reduction of 28.85% and 30.97%, respectively. In 2022, compared to 2019, the high incidence of COVID-19 in December 2019 posed increased risks of accidents, while in 2022 it was in a period of COVID-19 transition. From 2015 to 2020, the number of significant safety incidents in housing and municipal construction remained relatively stable at around 22 incidents, with fatalities fluctuating around 90. The period from 2020 to 2022 saw a noticeable decrease in both the number of significant safety incidents and fatalities, by 52.17% and 47.31%, respectively. Overall, the safety situation in housing and municipal engineering in China is severe, and efforts to enhance safety practices in construction enterprises are crucial. Detailed data can be found in Figure 1 and Figure 2.

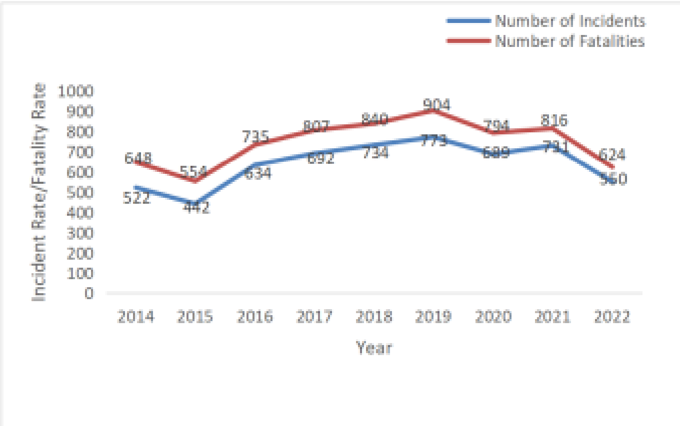

Figure 1. Statistical chart of total number of housing and municipal incidents from 2014 to 2022

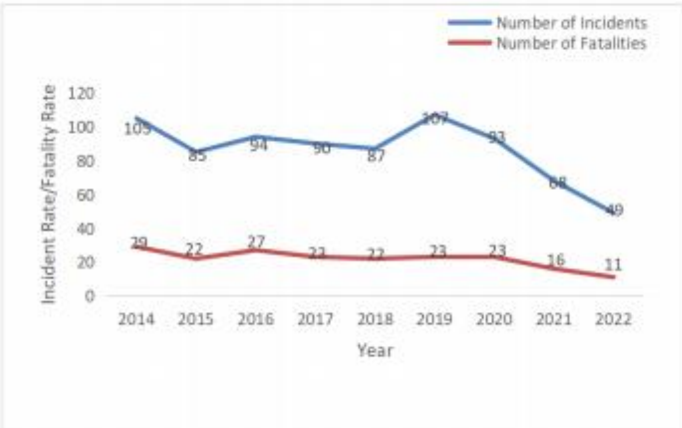

Figure 2. Statistical chart of significant safety incidents in housing and municipal construction from 2014 to 2022

This chapter analyzes and organizes the causes of production safety incidents in the construction industry from the perspectives of punishment and accident investigation reports, laying the groundwork for the establishment of a robust construction safety assurance system. Simultaneously, it reviews the current status of laws and regulations in the construction industry to adequately prepare for the enhancement of the construction safety assurance system.

Analysis of Issues in the Construction Industry from a Punitive Perspective

Over the past three years, the Ministry of Housing and Urban-Rural Development has issued a total of 112 documents under the label of "J.D.F.Z.". Among them, penalties targeting project managers account for 29.16%, penalties against project chief supervisors account for 43.75%, penalties against actual construction general contracting units account for 8.33%, penalties against engineering project leaders account for 4.16%, and other penalties makeup 14.58%. The reasons for these punitive actions are as follows:

(1) High frequencies of penalties against project managers stem from failures to meticulously implement hazard identification and technical briefing protocols, neglect to enforce safety measures for falls, failure to promptly detect temporary electrical setups, in addition to insufficient hazard inspections, lax implementation of safety education, inadequate inspections of subcontractor compliance with specialized construction plans, and inadequate supervision of on-site safety conditions.

(2) Penalties against project chief supervisors are often due to negligence in fulfilling their duties, overlooking instances of substandard steel reinforcement, failing to promptly identify subcontractors lacking qualifications for contracting and installation, lack of stringent oversight in managing specialized tasks, inadequate supervision of machinery maintenance records, unauthorized project commencements, lack of thorough hazard corrections, instances of proxy signing for off-duty tasks, delayed enforcement of subcontractor hazard corrections, absence of on-site construction supervision, lax oversight of temporary electrical setups, verbal notification of hazards without issuing written directives or assigning personnel for monitoring and rectification.

(3) Common infractions leading to penalties against actual construction general contracting units include irregular project undertakings, substituting management for active oversight, inadequate implementation of safety protocols, organizational chaos, insufficient safety personnel, premature use of unapproved machinery, lack of post-inspection for elevated platform operations, absence of specialized emergency drills, insufficient emergency response equipment, disregarding construction requirements and safety standards, and inadequate management of subcontractors.

(4) Project leaders often face penalties due to deficient safety protocols, ineffectual safety training and technical briefings that lack substance, lack of dedicated safety supervision for high-risk activities, and premature use of machinery without proper validation.

Upon scrutinizing the reasons behind punitive actions outlined in the "J.D.F.Z." documents, it becomes apparent that several key themes recurrently surface with notable frequency. In particular, inadequacy, deemed as a deficiency in a specific aspect, and non-compliance, denoting equipment or facilities falling below standards, are grouped together due to their related nature concerning insufficient aspects of operations. The prevalent occurrences of these themes are highlighted in Table 1 below:

Table 1. Frequency of key search terms in the "J.D.F.Z." documents

SN	Search Term	Quantity	Percentage of Total (%)
1	Hazards	35	31.25%
2	Inspections	28	25.00%
3	Supervision	21	18.75%
4	Regulations	19	16.96%
5	Training	12	10.71%
6	Deficiencies or Non-compliance	11	9.82%
7	Emergency Response	5	4.46%

Based on the higher occurrences of these distinct keywords, the reasons for punitive measures can be classified into seven primary aspects, which encompass:

(1) Inadequate hazard assessments, such as ineffective rectification of safety hazards and lackluster hazard inspections.

(2) Insufficient safety inspections, including failures to promptly detect temporary electrical setups.

(3) Laxity in supervision and management, exemplified by neglectful oversight leading to instances of substandard steel reinforcement.

(4) Shortcomings in the implementation of regulations, as seen in failures to diligently enforce hazard identification and technical briefing protocols.

(5) Deficiencies in safety training and education, evidenced by lapses in the implementation of three-tier safety education.

(6) Insufficiencies in resource allocation, demonstrated by deploying non-compliant machinery.

(7) Inadequacies in emergency response readiness, highlighted by the absence of emergency drills.

Examination of Safety Issues in the Construction Industry from the Perspective of Accident Investigation Reports

By analyzing accident investigation reports obtained from the "J.D.F.Z." documents over the past three years, this study aims to extract accident causes and safety issues prevalent within related enterprises for further examination. A total of 78 accident investigation report titles were identified, with 30 reports actually obtained. Through a detailed analysis of the causes and safety issues within these 30 accident investigation reports, it was observed that certain words occurred frequently in both the reasons for accidents and the identified safety problems. This is outlined specifically in Table 2 below.

The research revealed search terms with frequencies exceeding 40%, including hazards, training, inspections, regulations, technical briefings, supervision, and lack of allocation. This underscores the importance of focusing on these key aspects in the establishment of a robust occupational safety and health management system. (The term "lack of allocation" refers to a deficiency in assigned safety personnel or protective equipment, which is considered a facet of insufficient investment in this context.)

Table 2. Frequency of search terms in "Accident Investigation Reports"

SN	Search Term	Quantity	Percentage of Total (%)
1	Hazards	24	80.00%
2	Training	21	70.00%
3	Inspections	18	60.00%
4	Regulations	16	53.33%
5	Technical Briefings	15	50.00%
6	Supervision	13	43.33%
7	Lack of Allocation	12	40.00%

CONSTRUCTION OF THE LABOR SAFETY SYSTEM IN THE CONSTRUCTION INDUSTRY

The comprehensive construction of a labor safety protection system in the construction industry, as derived from the aforementioned analysis, necessitates the integration of several key elements. These include hazards, inspections, training, regulations, supervision, technical briefings, and investment. (Given the relatively low probability of emergency response issues, it has been excluded from the sub-systems.) Moreover, the Safety Production Law explicitly states that safety work should prioritize human-centric approaches, adhere to the principles of safety first, prevention as the primary focus, and overall governance to proactively prevent and manage significant safety risks at their source. It mandates that managing industries must ensure safety, business operations must prioritize safety, and production management must prioritize safety. This involves reinforcing the primary responsibility of production entities and government regulatory duties, establishing mechanisms emphasizing the accountability of production entities, the involvement of employees, government oversight, industry self-discipline, and societal supervision. This study emphasizes the construction of the labor safety protection system in the construction industry across six key aspects: risk grading and hazard investigation and management, safety inspections, safety education and training, regulations, supervision, technical briefings, and investment. Notably, within the system architecture, "technical briefings" and "investment" have been integrated into one sub-system, known as the Technical Briefings and Investment Assurance System. Please refer to Figure 3 for a visual representation of the labor safety protection system.

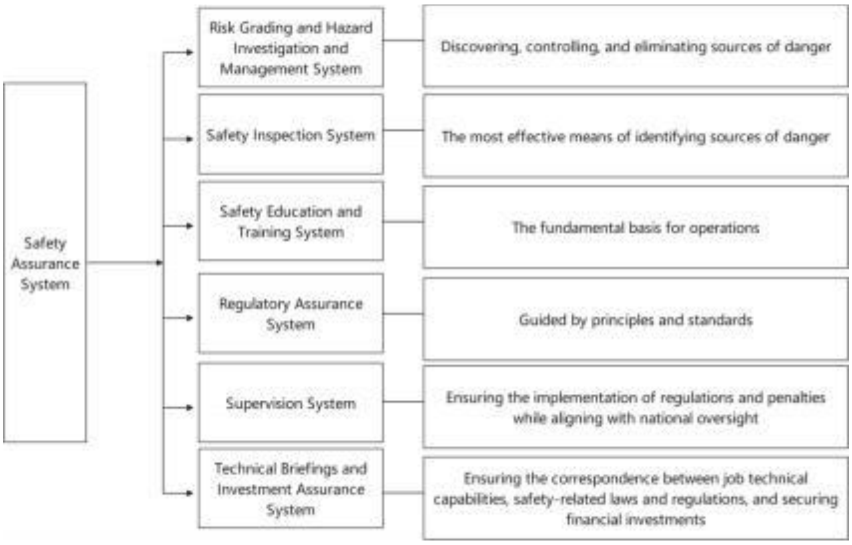

Figure 3. Comprehensive diagram of occupational safety assurance system

Risk Grading and Hazard Investigation and Management System

In 2016, General Secretary Xi Jinping clearly pointed out in the meeting of the Standing Committee of the Political Bureau of the Communist Party of China the necessity of adopting a dual preventive mechanism of risk grading and control, as well as hazard investigation and management in industries prone to major accidents. This approach was formally incorporated into the new Work Safety Law in 2021 [14]. Within the Risk Grading and Hazard Investigation and Management System, it is required to comprehensively identify risks in the construction process related to the environment, equipment and facilities, and work aspects. Moreover, there is a mandate to categorize identified risks for subsequent management to create a database of construction risks. Also, it necessitates the development of risk control forms for different levels of risks and the clear assignment of responsibilities for hazard investigation at various levels. The establishment of a safety performance assessment mechanism is crucial for promoting safety management. By setting up a safety archive system, the management of hazard investigation and control can be effectively transferred online, allowing for better monitoring and control of the status of hazard investigation and management. Identified risks can be utilized during safety training and education sessions. This holistic approach achieves a closed-loop hazard investigation and management process with full participation from all levels, fostering a culture of safety from the ground up.

Risk Assessment typically employs the "Job Condition Hazard Assessment Method". For identified different types and levels of hazards, control measures are implemented through the 3E approach (Engineering, Education, Enforcement) to reduce or eliminate risks. By utilizing techniques such as technical modifications, personnel status control, risk notification, standardized operations, and safety inspections, risks are managed to prevent their transformation into hazards, ensuring their controllability.

In high-risk areas or processes (such as deep excavation construction, crane installation and dismantling, scaffold erection or lifting, hot work operations, temporary electrical usage), long-term hazard investigation and management work is conducted. For each risk point, safety hazard investigation checklists are tailored according to safety laws, regulations, and standards. Based on defined responsibilities, the project contractor hands over the safety hazard investigation and management work to the project leader, project supervisor, and subcontractors to lead the efforts in various construction zones. The security department is tasked with overseeing the hazard investigation and management process, providing necessary safety technical support. Depending on the severity of safety hazards and the difficulty of rectification, hazard grading standards are established to categorize and delegate hazard rectification responsibilities to different entities autonomously [15].

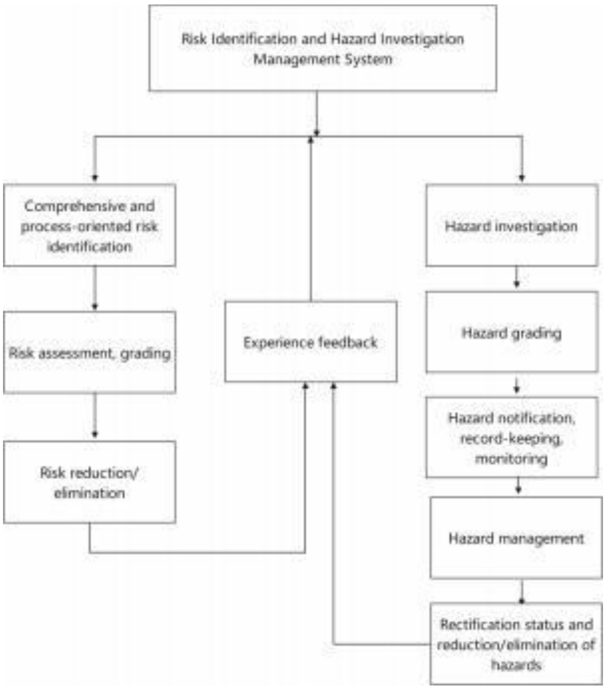

Figure 4. Risk identification and hazard investigation system

Methods commonly used in the process of identifying hazards include the Safety Checklist Method, the Job Condition Hazard Assessment Method, and the Experience Analysis Method. However, each of these methods has its own advantages and limitations. For instance, the Experience Analysis Method is easy to implement but is strongly influenced by subjectivity. The commonly employed methods in the hazard identification process are the Safety Checklist Method, the Job Condition Hazard Assessment Method, and the Experience Analysis Method. These methods each have their own limitations; for example, while the Experience Analysis Method is relatively easy to implement, it is heavily influenced by subjectivity. It is essential to conduct on-site supervision of major hazardous operations in construction, promptly rectifying any identified accident hazards. Authorities have the power to halt construction in the event of significant issues, publicly announce and notify, and carry out regular monitoring, evaluation, and control of major hazardous operations, including periodic inspections. Furthermore, the development of emergency plans is mandated, ensuring that employees are informed of emergency procedures. The specific risk identification and hazard investigation system can be visualized in Figure 4.

Safety Inspection System

The requirements for safety inspections are explicitly outlined in laws and regulations such as the "Workplace Safety Law" and the "Special Equipment Safety Law". The proposed safety inspection system adheres to the principles of "hierarchical responsibility, integration of line and surface, emphasis on key points, coordinated management". Drawing inspiration from a military barracks construction project, where safety management personnel conducted site inspections, overcame formalism, and issued rectification receipts for identified safety hazards, a practice of weekly summations of safety issues with clear incentives and penalties was implemented. In this project, safety inspections were categorized into eight key areas: safety management, site cleanliness, external scaffolding, "three treasures" and "four mouths" protection, electrical installations, material hoists, tower cranes, and construction machinery [16]. Building upon the strengths observed in safety inspections at the military barracks project, a fusion and enhancement process was initiated to develop a robust Safety Inspection System.

Safety inspection responsibilities are allocated across various organizational tiers as follows: Leadership Level: Leaders oversee ideological aspects and are tasked with visiting construction sites to instill a "safety-first" mindset during inspections. They serve as role models, championing safety while providing support for other managerial tiers. These inspections are typically conducted biannually. Enterprise Level: Here, management inspections are led by senior executives with the participation of department heads. The focus lies on scrutinizing the implementation and adherence to upper-level directives, the progress of safety initiatives at grassroots levels, the assessment of job roles, any instances of negligence or misconduct, and the overall achievement of set targets. These examinations occur quarterly. Grassroots Unit Level: Project leaders orchestrate these inspections with the involvement of project supervisors, management personnel, and team leaders. The primary aim is to monitor the rectification of identified hazards and ensure the effective implementation of risk control measures to promptly address any shortcomings. Monthly evaluations are the norm. Team Level Inspection: Led by team supervisors with safety officers intow, these assessments center on identifying and rectifying violations. Duties include pre-shift safety checks to confirm personnel qualifications, technical and physical conditions, and emotional states. In-shift patrols focus on monitoring equipment operations and swiftly addressing any violations, while post-shift checks aim to eradicate any lingering safety hazards like power sources, hot work areas, and protection mechanisms. Position Level Inspection: This level entails self-inspections by employees. Pre-shift inspections encompass verifying environmental safety, tool integrity, and the reliability of safety measures, while in-shift checks focus on detecting any violations committed by personnel [17].

Throughout the safety inspection process, it is important to emphasize professionalism, conduct inspections during crucial periods, focus on critical areas, quantitatively analyze and compile inspection results, publicly disclose identified issues, integrate inspection outcomes into safety performance assessments for all units, and establish video surveillance systems for critical areas and key equipment. For a comprehensive understanding of the safety inspection system, please refer to Figure 5.

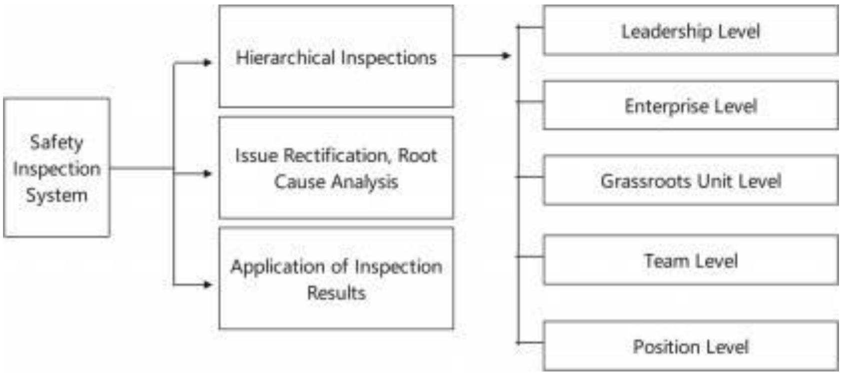

Figure 5. Safety inspection system

Safety Education and Training System

Figure 6. Safety education and training system

The purpose of safety education and training is to enhance employees' safety competence, knowledge, and skills, making safety management easier and preventing production safety accidents. Within the safety education and training system, different levels and types of employees require distinct training content, encompassing safety education and training objectives, plans, content, records, and continuous learning modules [18]. This includes annual safety training for main leaders at various levels within the enterprise, project managers, project management personnel, managerial staff at different project levels, and technical personnel. It also involves training for special engineering operation personnel, pre-job training for resuming work, job transfer, and position change, as well as three-tier education for new employees. Construction companies should organize various types of safety production education according to a schedule, regularly inspect and assess implementation and actual outcomes, and ensure the proper storage of safety education and training records and certificates. They should actively establish channels for demand communication characterized by "individual proposals, department consolidation, enterprise platform, and professional implementation", resource integration characterized by "enterprise focus, individual supplementation, and knowledge sharing", and career development integrated with "training, evaluation, competition, and reward and punishment" through customized safety training [19]. Online training through WeChat mini-programs makes training more convenient and efficient [20]. Please refer to Figure 6 for the detailed system.

Regulatory Assurance System

Establishing the regulatory assurance system

The Regulatory Assurance System plays a pivotal role in formulating and refining safety-related regulations, as depicted in Figure 7. When crafting the safety production responsibility system within an enterprise, it is essential to adhere to the guidelines outlined in the Regulations on the Establishment of Safety Production Management Structure and the Appointment of Full-time Safety Production Managers for Construction Enterprises and the Regulations on the Management of Construction Projects. These regulations delineate the specific safety responsibilities of key personnel such as project managers, general contractors, subcontractors, chief engineers, safety officers, team leaders, foremen, and workers. The Regulatory Assurance System encompasses the development of regulations, their effective implementation, and the establishment of fundamental regulations, as outlined in Figure 8.

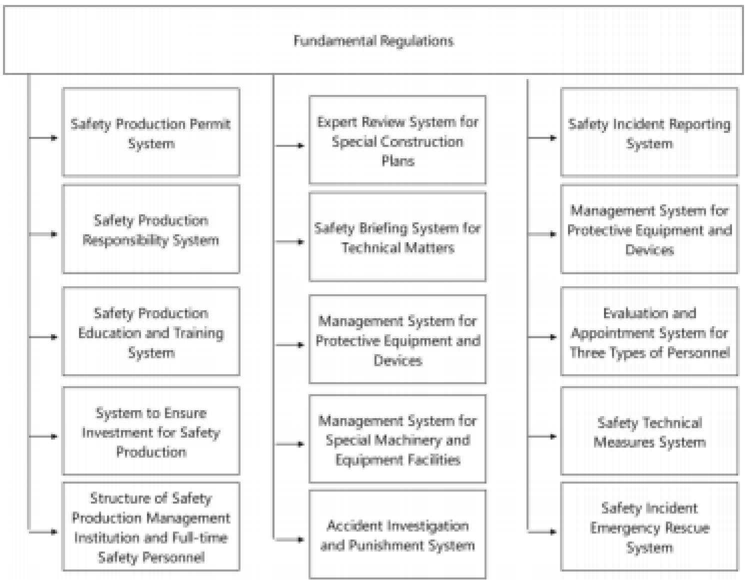

Figure 7. Fundamental regulations

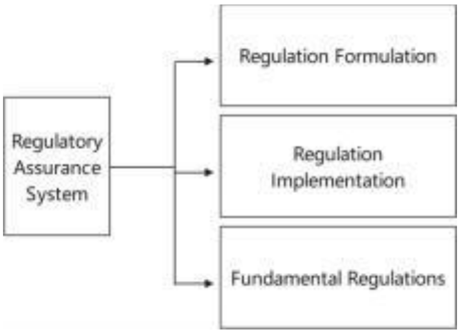

Figure 8. Regulatory assurance system

Current status of legal regulations and standards in the construction industry

The compilation of relevant laws, regulations, standards, technical specifications, and industry policies in the construction sector provides a solid foundation for other systems, enabling all personnel within enterprises to access, reference, and learn from them, with a mandate for continuous updates.

The information obtained from the official website of the Ministry of Housing and Urban-Rural Development, as of March 25, 2023, reveals that there are currently 134 regulations and 138 administrative normative documents in existence. The current regulations encompass a wide range of areas such as construction project quality inspection, administrative licensing, penalty procedures, acceptance management, design document review, safety management, bidding and tendering, crane management, qualification management of engineering supervision enterprises, subcontract management, industry standard management, and more. The existing administrative normative documents cover standards for determining major safety risks in production, regulations on the occupational qualifications of supervisory engineers, management methods for general contracting of projects, penalties for individuals within construction enterprises responsible for safety accidents, measures for identifying and addressing illegal acts in construction contracting, and more.

Since 2019, the Real Estate Market Supervision Department has issued a total of 44 documents, primarily focusing on the registration and deregistration of real estate appraisers and announcements regarding the first-tier qualifications of real estate enterprises. The Building Market Supervision Department has issued 615 documents, mainly comprising lists of initial registration of supervisory engineers and survey and design registration engineers, among others. The Engineering Quality and Safety Supervision Department has released 51 documents addressing issues related to the quality and safety of residential and municipal engineering projects, such as the Construction Project Inspection Management Measures and the Guiding Opinions on Strengthening Tunnel Engineering Safety Management. The Urban Management Supervision Bureau has issued 457 documents, predominantly involving the revocation of first-tier general contracting qualifications obtained through deception, revocation of certificates for illegal use of cost engineers (credential fraud), and imposing corresponding penalties, such as suspension and rectification, on construction enterprises following incidents of production safety accidents as per investigation reports.

According to the information available on the website of the Ministry of Emergency Management regarding legal regulations and standards, there are a total of 71 laws and regulations, including eight related to the construction industry. These laws and regulations encompass various aspects such as the Law on Production Safety, the Regulations on Safety Production Management of Construction Projects, the Regulations on the Prevention and Treatment of Pneumoconiosis, the Regulations on Emergency Response to Production Safety Accidents, and more. There are also 63 regulations, with 15 related to the construction industry, addressing matters concerning administrative law enforcement personnel, evaluation and testing institutions, emergency plans, confined spaces, outsourcing, specialized operators, safety production training, hazard investigation, and accident penalties. Furthermore, there are a total of 913 standard texts covering areas such as flame-retardant products, emergency plans and drills, prevention and control of occupational hazards, training and assessment of emergency management personnel for safety production, design of occupational disease prevention facilities for construction projects, evaluation of enterprise safety culture construction, operational safety standards, fall protection, and more.

Supervision System

Composition of the safety supervision system

While the safety supervision system does not supplant a systematic safety management approach, its core responsibility lies in ensuring the implementation of pertinent safety protocols within enterprises. It entails penalizing individuals responsible for inadequate or absent compliance, investigating and consolidating feedback on unrestrained areas, ultimately ensuring a meticulous enforcement of safety measures. This enterprise oversight system harmonizes with the national industry surveillance apparatus, overseeing and conducting internal inspections within the enterprise. The supervisory body within the enterprise, led by the principal, includes members such as the head of project management, safety management director, project leaders, union representatives, survey and design units, engineering supervisory entities, subcontractors, supply personnel, among others. The establishment of an integrated intelligent safety oversight system [21] combines online and offline modalities. Specific requirements include: participation in digitized monitoring of construction personnel, their credentials, and job responsibilities; supervision of projects from obtaining construction permits to completion and various documentation processes; establishment of integrity assessment systems related to enterprises and individuals; utilization of digital tools to oversee and manage engineering quality and safety procedures, as well as the daily operations of quality inspection units; digitized supervision and management of the daily activities of supervisory units; comprehensive understanding of on-site progress and control of project timelines through the application of IoT technology; and comprehensive information supervision ranging from the formulation, review, and execution of specialized construction plans to safety briefings, safety measures, initiation of work, post-operation inspections, and the overall process of information-based regulation. Moreover, subcontractor safety oversight follows a "1+4" safety monitoring protocol, as detailed in Figure 9.

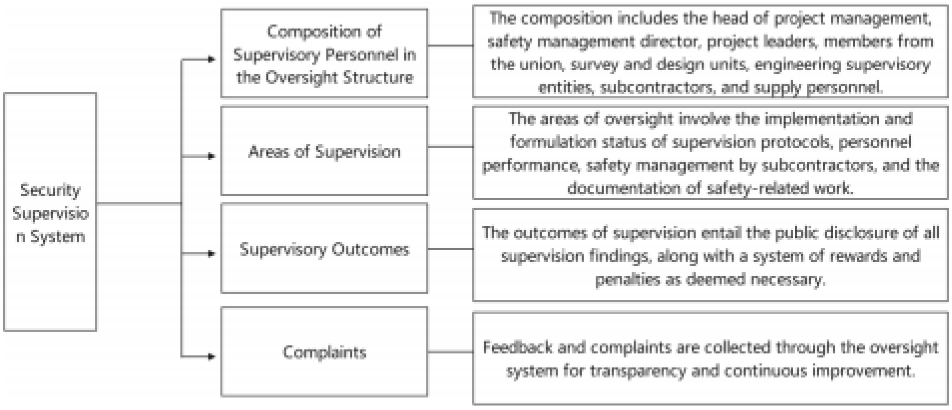

Figure 9. Safety supervision system

Current state of the national safety supervision system

The primary regulatory body in the construction industry is the Ministry of Housing and Urban-Rural Development. Both the safety production supervision departments and the construction administrative authorities bear the responsibility of overseeing safety measures within the construction industry (refer to Figures 3-8). Entities affiliated with the State Council that are involved in safety production within the construction industry are illustrated in Figure 10.

Under the Ministry of Housing and Urban-Rural Development, there exists the Engineering Quality Supervision Department. This department comprises sections such as the Supervision and Coordination Division, Engineering Technology Division, Engineering Quality Supervision Division, Construction Safety Supervision Division, overseeing and managing the safety measures and engineering quality of construction enterprises. The National Engineering Quality and Safety Supervision Information Platform offer query services for various information, including enterprise safety production permits, safety production assessments, inspection agencies and personnel for construction drawings, and information regarding specialized operators.

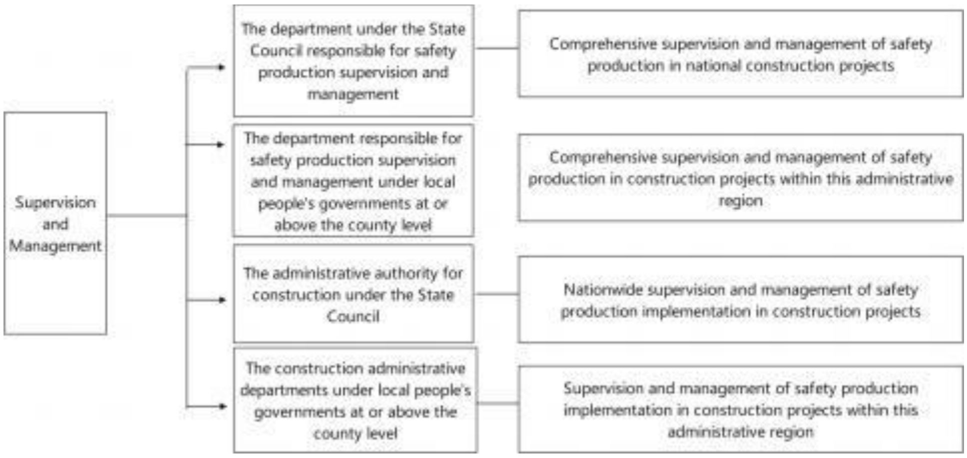

Figure 10. Chart of supervisory and management departments for safety work in the construction industry

Departments under the State Council related to safety work are depicted in Figure 11.

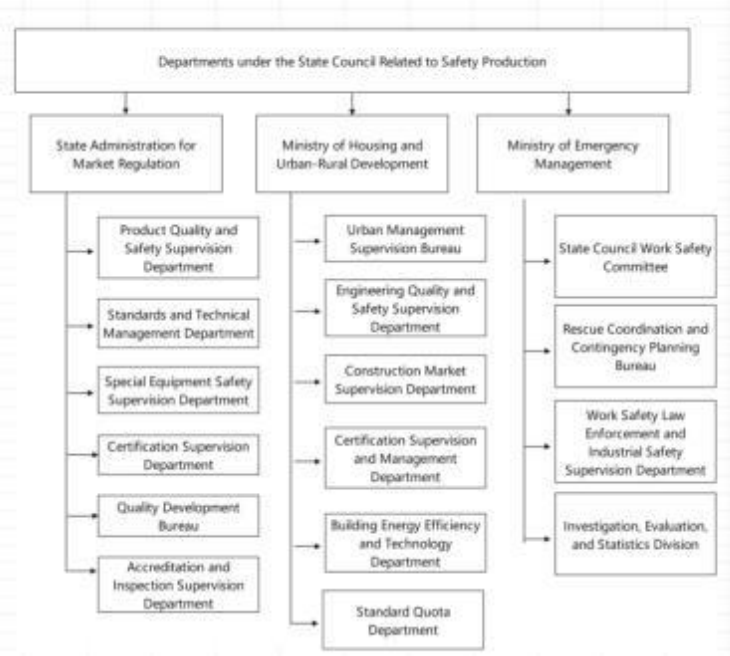

Figure 11. Departments under the state council related to safety work

Technical Assurance and Investment Guarantee System

The technical assurance is responsible for ensuring the technical proficiency of personnel involved in the survey, design, and construction of construction projects in enterprises, ensuring that individual skills align with job requirements. There should be specialized guidance for the implementation of new technologies, equipment, and methods used in project construction. Compliance with relevant safety technical laws, regulations, and standards in China is essential (refer to Figure 12). The technical assurance system encompasses technical training and assessments for various personnel, formation of mentorship programs within the industry, and conducting relevant technical training for personnel. Additionally, it includes the establishment of construction organization designs, special safety construction plans, and safety briefing systems.

The Code for Quality Management of Engineering Construction Enterprises GB/T50430-2017 clearly outlines the methods, content, and basis of safety technology briefings. The most common methods for safety technology briefings include briefing meetings, verbal briefings, written briefings, demonstration briefings, and job-specific briefings. Consideration should also be given to integrating safety technology briefings for various construction processes within tunnels onto a unified virtual platform. This platform provides a scenario-based, professionally immersive environment for construction personnel to autonomously and actively engage in learning safety technology briefings. Engineering and safety personnel need to conduct thorough inspections at construction sites, comprehend blueprints, construction plans, and the layout and coordination of construction procedures before developing practical and targeted safety technology briefings [22].

In terms of investment guarantee, capital assurance forms the foundation, including personnel assurance, equipment and facilities assurance, and material assurance. Ensuring that individuals in each position have the necessary technical expertise, that purchased or leased equipment meets standards, and allocating funds for equipment testing and maintenance processes are crucial aspects. Quality assurance is also paramount for materials procured.

MEASURES FOR PREVENTING CONSTRUCTION SITE ACCIDENTS

Table 3. Measures for falls from heights and struck by objects

SN	Approaches Proposed	Measures Proposed for Falls from Heights	Measures Proposed for Struck by Objects:
1	Risk Grading and Hazard Investigation and Management System	Identify potential hazards in fall protection devices such as scaffolding, edges, horizontal openings, shafts, crane mechanisms, pile frames, unloading platforms, and mobile workstations.	Conduct risk assessments for object strikes across different sites and processes to control potential risks.
2	Safety Inspection System	Conduct inspections at the team and positional levels using predefined safety checklists to identify and mitigate fall risks.	(1) Perform self-checks and mutual inspections at the positional level using designated safety checklists. (2) Evaluate the integrity of guardrails and safety nets, ensure workers wear safety helmets, and regulate the orderly stacking of items on platforms.
3	Safety Education and Training System	Provide personnel at all levels with training on fall prevention measures and educate them on high-risk areas for falls.	Provide workers with training on preventing object strikes, instruct them on correct safety helmet usage. Do not randomly stack items, whether building materials or construction equipment.
4	Regulatory Assurance System	(1) Strictly adhere to China's High-altitude Operation Safety Technical Regulations. (2) Establish protocols for the purchase, testing, and replacement of safety protection equipment and facilities.	Enforce regulations for orderly construction practices.
5	Supervision System	Ensure project supervisors and leaders regularly review inspection records, conduct on-site inspections, verify the authenticity of inspection records, and assess the condition of fall protection facilities.	Supervise self-checks and mutual inspections at the positional level to ensure compliance.
6	Technical and Investment Assurance System	(1) Provide technical training for personnel engaged in high-altitude work (2) Procure certified protective equipment, ensuring regular inspections, replacements, and maintenance.	(1) Supply workers with certified safety helmets, conduct regular inspections, replacements. (2) Establish safety signage, conduct pre-job briefings.

According to data on production safety accidents in the construction industry released by the Ministry of Housing and Urban-Rural Development, the most common types of accidents in the construction industry are falls from heights, struck by objects, mechanical injuries, and collapse accidents [23]. By establishing six sub-systems of the construction safety assurance system outlined in this study and referencing relevant literature [24, 25], measures to reduce the occurrences of falls from heights, struck by objects, mechanical injuries, and collapses are proposed.

Refer to Table 3 and Table 4 for specifics.

Table 4. Measures for collapse and mechanical injuries

SN	Approaches Proposed	Measures Proposed for Mechanical Injuries	Measures Proposed for Collapses
1	Risk Grading and Hazard Investigation and Management System	(1) Conduct regular safety hazard inspections on lifting machinery and other mechanical equipment. (2) Develop safety checklists for operations involving mixers, lifting machinery, hoists, rebar cutting machines, etc., prepared by professionals.	(1) Implement graded control measures in areas of foundation pit construction prone to soil collapses. (2) Conduct graded control and hazard identification during scaffolding construction processes.
2	Safety Inspection System	(1) During operations, positional levels should follow the established safety checklists and inspect systematically. (2) Before commencing work, ensure comprehensive understanding of the work environment, roads, overhead wires, buildings, and component weights and distributions.	Ensure strict quality inspection of structural components, allowing only approved components to be used on-site, categorize and stack components by specification, and apply waterproofing and moisture-proof treatments during storage.
3	Safety Education and Training System	(1) Provide specialized safety training for specific operation personnel. (2) Collect accident cases involving mixers, lifting machinery, hoists, rebar cutting machines to explain protection points and critical areas during training sessions.	Enhance safety education and training for workers, adhering strictly to operational procedures.
4	Regulatory Assurance System	(1) Strictly adhere to the Regulations on the Safe Use of Construction Machinery. (2) Enforce a certification system for specialized machinery and equipment management protocols.	(1) Organize the development of specialized construction plans for earth excavation, drainage reduction, and foundation pit support. (2) Adhere strictly to industry standards and regulations governing scaffold design, construction, dismantling, and safety management.
5	Supervision System	Supervise the implementation of various regulations by project leaders.	(1) Supervise workers to prevent rough construction practices, avoid unauthorized alterations to construction plans. (2) Oversee the implementation of various protocols.
6	Technical and Investment Assurance System	Purchase or lease qualified mechanical equipment, conduct maintenance, testing, and upkeep during usage, and provide specialized construction plans, safety briefings, and emergency plans for the installation and removal of lifting machinery.	(1) Engage external survey and design units as well as safety consulting agencies, verifying their qualifications. (2) Improve the technical competency of staff.

CONCLUSIONS

(1) By analyzing the reasons for accidents in the construction industry based on penalty documents issued by the Ministry of Housing and Urban-Rural Development over the past three years and investigations from accident reports, the top 8 contributing factors to accidents were identified as hazards, inspections, training, regulations, supervision, technological briefings, investments, and emergency response.

(2) The labor safety assurance system constructed through investigative research consists of six sub-systems , namely risk grading and control, hazard identification and management system; safety inspection system; safety education and training system; regulatory assurance system; supervision system; and technical and investment assurance system.

(3) Categorizing accident types in the construction industry, the top four incidents were falls from height, struck by objects, mechanical injuries, and collapses. We proposed measures to mitigate these types of injuries by referencing relevant literature and aligning with the labor safety assurance system presented in this study.

The primary focus of this research lies in the establishment of a labor safety assurance system, while research on the individual sub-systems remains relatively scarce. Future studies should delve deeper into this area for a more comprehensive understanding. Due to time constraints and other factors, the practical application of this system in construction enterprises was not feasible; however, future implementations and further research can enhance its practicality and depth.

ACKNOWLEDGEMENTS:

This work was supported by the China University of Labor Relations' Academic Innovation Team Support Program (Team for 'Education and Labor Market' research, 2024CX06).

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