

Research on the Intelligent Safety Management Evaluation System for Construction Sites

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Abstract: In response to the problems such as insufficient intelligent application in on-site safety management under the context of intelligent construction, low efficiency of traditional management models, and the lack of a scientific system for safety management performance evaluation. Based on the theory of intelligent construction, this paper uses methods such as the Carnot model analysis, analytic hierarchy process, and fuzzy evaluation to deeply analyze the problems existing in the integration of intelligent construction technology and construction safety management. It establishes a corresponding performance assessment and evaluation model. It proposes improvement measures such as building hardware infrastructure, information platforms, data sharing, and intelligent decision-making. The practical results show that this method can effectively enhance the intelligence level of on-site safety management and reduce safety accidents.

1. Introduction

Currently, the application of intelligent construction technology in on-site safety management faces issues such as insufficient intelligence level, difficulties in integrating traditional management with new technologies, and the lack of a scientific performance evaluation system. These problems not only limit the improvement of construction efficiency and safety levels but also increase construction risks and management costs. Therefore, in-depth research on the intelligent transformation of on-site safety management in the context of intelligent construction has significant practical significance.

Domestic and foreign scholars have conducted a large number of studies in this field. For instance, Gamabatese J. A. [1] established a safety design database through computer technology to assist in risk identification during the design stage; Wang [2] integrated construction progress and safety management information using simulation technology; Park [3] et al. developed a safety visualization system based on BIM, AR and game technology; the University of Illinois in the United States developed safety monitoring and performance evaluation software, effectively preventing accidents. Domestic scholars such as Gao Nan [4] pointed out that the construction of smart construction sites requires improving the functions of the data platform and achieving information-based management; Chen Yitao [5] emphasized the need to enhance the application level of informatization in small construction enterprises; Wei Yu Ren [6] believes that a unified safety management informatization standard needs to be established. However, these studies still have shortcomings in practical applications, such as the lack of systematic intelligent construction technology standards and norms, insufficient deep integration of technology and management, and insufficient practicality of intelligent application platforms.

At present, the existing research still has deficiencies in the depth and breadth of the application of intelligent construction technology, especially in the aspect of performance evaluation models for on-site safety management. Based on this, this paper uses methods such as the Kano model analysis,

analytic hierarchy process and fuzzy evaluation method to construct a performance evaluation model for on-site safety management, studies the effective integration mechanism of intelligent construction technology and safety management, and aims to provide theoretical support for the intelligent transformation of construction enterprises, promote the development of construction safety management towards intelligence and efficiency, and has important practical significance.

2. Concept Definition

2.1 Intelligent Safety Management Performance in Construction Sites

In the context of the rapid development of intelligent construction, the connotation and extension of the safety management performance on construction sites have undergone significant changes. Intelligent construction not only brings about technological innovations but also prompts the transformation of safety management methods from traditional manual inspections and result-oriented approaches to an intelligent management model that emphasizes prevention, process and result balance. The definition of the safety management performance on construction sites needs to fully consider the driving effect of intelligent construction technology and its impact on the entire safety management process.

The safety management performance on construction sites refers to the degree and level of improving the safety management efficiency of construction sites through a series of management activities, reducing the occurrence of accidents and hazards, and ultimately achieving the safety management goals of construction sites. It covers aspects such as personnel management, equipment and materials, construction operations, management systems and effect feedback. In the context of intelligent construction, this definition further emphasizes the deep integration of technology and management, as well as the continuous optimization capabilities driven by data.

The application of intelligent construction technology has made the safety management performance on construction sites no longer dependent on traditional experience management and manual control. Through technologies such as the Internet of Things, big data, blockchain and artificial intelligence, various information on construction sites, such as personnel positioning, equipment operation status, and environmental safety monitoring, can be collected and analyzed in real time, thereby achieving the transformation from "post-event handling" to "pre-event prevention". For example, using intelligent sensors and the Internet of Things technology can monitor abnormal operating conditions of equipment in real time and issue early warnings to reduce safety accidents caused by equipment failures; with the help of big data analysis, potential risks in the construction process can be accurately identified and the construction plan can be optimized, improving the accuracy and timeliness of safety management.

Intelligent construction also emphasizes the synergy of data information. Through information sharing and collaborative work among different construction links and departments, traditional information silos are broken, making safety management more efficient and transparent. At the same time, in the context of intelligent construction, the evaluation of the safety management performance on construction sites also places greater emphasis on the continuous optimization of value. This means not only focusing on the current safety management achievements, but also paying attention to long-term sustainable development, including process reengineering, the establishment of new organizational forms, and full life cycle management.

The safety management performance on construction sites in the context of intelligent construction is not only an objective evaluation of construction site safety management activities, but also a comprehensive measurement of the intelligent level of construction site safety management. It requires construction site managers to fully utilize intelligent technologies to achieve comprehensive perception, real analysis, real-time control and continuous optimization of safety management, thereby improving the safety management level of construction sites, reducing the occurrence of accidents, and ensuring the safety of personnel and property on construction sites.

2.2 Intelligent Construction Theory

Intelligent construction theory is a new type of construction theory that integrates advanced information technology, artificial intelligence technology and traditional construction technology.

At the technical level, intelligent construction is based on digital, networked and intelligent technologies to achieve ubiquitous perception of the construction process, efficient transmission and accumulation of information, and systematic management. Through sensors and other devices, real-time monitoring of the engineering site is realized, and big data and cloud computing technologies are used to analyze and process massive data to provide scientific basis for construction decisions.

Intelligent construction drives the integration and intelligent decision-making of the entire engineering construction life cycle through digital chains. From the project's planning and design stage to construction, operation and maintenance, information is seamlessly connected and collaborative work is achieved, improving the quality, efficiency and sustainability of the project.

The functional goal of intelligent construction is to deliver intelligent engineering products that are people-oriented, green and sustainable, and to create a more comfortable, safe and environmentally friendly building environment to meet people's demands for high-quality life.

The application of intelligent construction in digital design: By applying software such as computer-aided design (CAD), designers can complete all aspects of architectural design on the computer, including architectural structure, material selection, construction techniques, etc. optimization design. At the same time, digital design can also conduct virtual simulation and optimization to improve design quality and efficiency.

Automated construction: Through the application of Internet of Things, sensors and other technologies, intelligent monitoring and management of the construction site are realized, improving construction safety and efficiency. For example, intelligent tower cranes, automated construction robots, etc., can greatly improve construction accuracy and efficiency.

Information-based management: Information-based management can realize real-time monitoring and adjustment of the construction project's progress, ensuring construction safety and quality. At the same time, information-based management can also realize real-time collection and analysis of construction operation data, improving the predictability and initiative of operation and maintenance.

The intelligent construction theory not only involves the application of technology, but also involves the process reengineering, mode innovation and industrial upgrading of the entire construction industry. With the continuous development and innovation of technology, intelligent construction will play an increasingly important role in the construction industry.

2.3 Safety management elements for construction sites

The Japanese scholar, Katsuhiko Nishida, proposed the 4M theory (4M stands for the first letters of Man, Machine, Media and Management), categorizing the factors leading to accidents into four types: human factors, equipment factors, operation factors, and management factors. Among them, human factors include the physiological and psychological reasons of project participants, as well as occupational reasons such as communication ability and interpersonal relationships; equipment factors include reasons such as the unsafe state of construction equipment; operation factors include reasons such as poor construction work environment and unreasonable operation methods; management factors include reasons such as safety education, training, supervision, and guidance.

The safety management elements of the construction site include both explicit elements such as personnel, materials and machinery, as well as implicit elements such as management systems and effect feedback, namely project personnel, equipment materials, construction work, management systems and effect feedback. Specifically, the safety management of the construction site covers all aspects of the construction process.

Project personnel element: includes unified personnel management, qualification management, personnel trajectory management, etc. Equipment materials element: includes construction electricity and machinery management, machinery usage management, equipment and material storage and inspection, etc. Construction work element: includes civilized construction edge protection management, special construction work monitoring and early warning, work environment safety

monitoring and early warning, etc. Management system element: includes safety education management, safety technical measures management, safety inspection and remote monitoring, etc. Effect feedback element: includes accident prevention effect, safety management performance feedback, and improvement of safety management performance.

2.4 The method for establishing a performance indicator framework for on-site construction safety management

The performance indicator framework for on-site construction safety management fully embodies the characteristics of intelligent construction. By reasonably applying the relevant theories of intelligent construction and innovatively applying the related technologies, the framework innovates and applies intelligent construction technologies. Intelligent construction is a comprehensive term for theories, methods, processes, and technologies that integrate sensing technology, communication technology, data technology, construction technology, and project management, and perceive, analyze, control, and optimize the safety, quality, environmental protection, progress, and cost of the constructed objects and construction activities. It is a method for promoting safe, high-quality, green, and efficient construction.

The construction industry in China has gone through a primary stage dominated by manual work, a mechanization stage, an information and networking stage, an intelligent construction stage, and has achieved a stage where the advanced management concepts and application of intelligent construction technologies are fully integrated throughout the process of perception, analysis, decision-making, and optimization. With the further maturity and development of intelligent construction technologies, smart construction is driven by innovation and technology-oriented. The characteristics of the era mainly focus on technological innovation-driven, data information collaboration, and continuous value optimization. The intelligent construction characteristics guiding the determination and evaluation of on-site construction safety performance indicators are oriented towards the above three aspects.

To construct a scientific and reasonable performance indicator framework for on-site construction safety management, first, based on the intelligent construction closed-loop control theory, ensure that the indicator framework can reflect the logic of comprehensive perception, real analysis, real-time control, and continuous optimization. Secondly, combined with the 4M theory (people, machines, materials, methods), the indicator system is divided into five dimensions: project personnel, equipment materials, construction operations, management systems, and effect feedback. Each dimension has specific secondary indicator items. During the construction process, the application scenarios and advantages of intelligent construction technologies, such as using big data technology to collect and analyze safety management information and using IoT technology to realize real-time monitoring of equipment and the environment, are fully considered to ensure that the indicator framework can effectively integrate intelligent construction technologies. Through literature analysis and expert interviews, the quality assessment and analysis of the indicator system were conducted to ensure its scientificity and rationality. The final formed indicator framework not only covers the key elements of on-site construction safety management but also reflects the characteristics and requirements of intelligent construction and provides a solid foundation for subsequent performance assessment and evaluation.

2.5 The assessment and evaluation methods for the safety management performance of construction sites

In the context of intelligent construction, the assessment and evaluation methods for the safety management performance of construction sites mainly include performance assessment and comprehensive evaluation methods. Based on overall evaluation control and specific indicator contents, key performance indicator items are established, and the analytic hierarchy process and fuzzy comprehensive evaluation method are adopted. The analytic hierarchy process is used to design the indicator hierarchy structure model, and the weights of each indicator are calculated through expert scoring and consistency testing to provide a scientific basis for the evaluation. The fuzzy comprehensive evaluation method constructs the evaluation comment set, membership matrix,

weight matrix and score matrix, and conducts a comprehensive assessment and scoring of the safety management performance of construction sites, which is particularly suitable for handling complex evaluation problems with fuzziness and uncertainty. Finally, the effectiveness of this assessment and evaluation model was verified through practical cases, and targeted improvement suggestions were proposed based on the assessment results to optimize management strategies and enhance safety performance.

In the establishment of safety management performance indicator items for construction sites, referring to the key performance indicator method, performance assessment indicators are divided into three categories: developmental indicators, improvement indicators, and monitoring indicators. For each performance indicator item, two parts are set: overall evaluation control and specific indicator contents. For example, the performance evaluation indicator item of "operator qualification management, construction unit qualification management" has the overall evaluation control principle: the qualification management of the construction site is effective, and there are no incidents of unlicensed operation or mismatched qualifications; its specific indicator items include using intelligent construction technologies such as big data and blockchain to identify, determine and analyze the qualifications of relevant personnel and units, etc.

3. Construction site safety management performance framework

3.1 The characteristics of intelligent on-site construction safety management performance

The specific manifestations of technological innovation-driven development include: the application of intelligent technologies, the integration of intelligent devices, and the innovation of intelligent technologies. The application of intelligent technologies refers to the use of intelligent construction technologies such as artificial intelligence, big data, and cloud computing to solve safety management problems; the integration of intelligent technologies refers to the organic combination of various technologies in accordance with the concepts and processes of on-site safety management to achieve superimposed empowerment; the innovation of intelligent technologies refers to the enhancement of efficiency and effectiveness in specific on-site safety management and safety production process flows in accordance with intelligent construction technology. Information integration refers to the collection and generation of various data in management activities based on certain standards and forms; information management and collaboration refer to the storage, transmission, and invocation of collected data on a unified platform; information decision-making refers to the pre-processing and analysis of relevant data through analysis programs; information platforms and environments refer to the fundamental investment in management assets. The specific manifestations of continuous value optimization include: process reengineering, new organizational forms, standardization construction, full life-cycle management, and green construction, etc.

In the context of intelligent construction, the characteristics of the performance of on-site safety management in this context mainly lie in technological innovation-driven development, data information collaboration, and continuous value optimization. Technological innovation-driven development emphasizes the application, integration, and innovation of intelligent technologies, such as the application of artificial intelligence, big data, and cloud computing in on-site safety management, which can effectively enhance the efficiency and accuracy of safety management. Data information collaboration focuses on information integration, management, collaboration, decision-making, platforms, and environments, ensuring the standardized collection, storage, transmission, and analysis of various data on-site safety management, providing strong support for safety management. Continuous value optimization is reflected in process reengineering, new organizational forms, standardization construction, full life-cycle management, and green construction, etc., through intelligent construction technology, it can optimize the management process on-site, improve management efficiency and benefits, and achieve sustainable development. These characteristics together constitute the core connotation of the performance of on-site safety management in the context of intelligent construction, providing a theoretical basis for the construction of a scientific and reasonable safety performance evaluation system.

3.2 Combining on-site construction safety management performance with intelligent construction technology

In the context of intelligent construction, the integration of on-site safety management performance with intelligent construction technologies is the key path to enhancing management efficiency. Intelligent construction technologies, including big data, the Internet of Things, cloud computing, blockchain, artificial intelligence, building information modeling (BIM), geographic information system (GIS), unmanned aerial vehicles (UAVs), robots, and virtual reality (VR), have formed a systematic application framework through deep integration with safety management elements.

From the perspective of application scenarios, in the personnel management field, intelligent safety helmets and facial recognition technology are utilized to achieve trajectory tracking and access control; in equipment and material management, sensors and blockchain technology are relied upon to complete status monitoring and warehouse traceability; in monitoring and control management, measures such as unmanned aerial vehicle inspection and BIM model early warning are comprehensively adopted to identify potential risks. In intelligent terminal management, tools like mobile applications are used to assist in safety inspections and data recording.

In the mechanism of combining technology and management, the intelligent construction closed-loop control theory centered on perception, analysis, control, and optimization is the core. For example, big data and the Internet of Things technology focus on real-time perception of the on-site environment and equipment status, cloud computing and AI technology are used to analyze risk data and generate warning strategies, unmanned aerial vehicle and robot technologies achieve remote control and the substitution of dangerous operations, and VR and BIM technologies help optimize management processes and conduct training simulations. This integration not only promotes the transformation of safety management from passive response to proactive prevention, but also builds a performance improvement model driven by technological innovation through data information collaboration and continuous value optimization, providing intelligent and refined solutions for on-site safety management.

3.3 The content of the safety management performance framework for construction sites

The constructed safety management performance framework for construction sites, based on intelligent construction, integrates three aspects: technological innovation-driven, data information collaboration, and continuous value optimization, to form a systematic management system covering all elements. The framework includes first-level indicators such as project personnel, equipment materials, construction operations, management systems, and effect feedback, and has secondary indicators such as unified personnel management, qualification management, construction power supply and machinery management. Among them, personnel management focuses on intelligent identity recognition, trajectory monitoring, and dynamic qualification review, using big data and blockchain technology to integrate personnel information and verify qualifications; equipment and material management uses IoT sensors and BIM technology to conduct full lifecycle status monitoring and electronic archive management of construction machinery and storage materials;

The construction operation link combines unmanned aerial vehicle inspection, VR simulation, and environmental sensors to achieve real-time monitoring and early warning of civilized construction, special operations, and working environment; the management system level relies on cloud computing and intelligent terminals to optimize safety education and training, technical measure implementation, and remote inspection processes; effect feedback uses blockchain and intelligent decision-making systems to achieve intelligent closed-loop management of accident prevention, performance analysis, and improvement suggestions. The indicator system deeply couples intelligent construction technology with safety management elements, with the core of the "perception, analysis, control, and optimization" closed-loop mechanism. It not only focuses on the intelligent control of personnel and equipment and other explicit elements, but also emphasizes the digital upgrade of system processes and performance feedback, providing an operational management system for the intelligent transformation of construction enterprise safety management.

3.4 Application of Safety Management Technology in Construction Sites

Equipment operation monitoring and real-time warning: By utilizing IoT sensors, cloud computing and big data platforms, various operation parameters and information data of the equipment are collected. These data are then organized, cleaned, analyzed, and utilized. Once the monitoring data exceeds the standard limit, the construction safety monitoring system will provide an over-limit alarm. The alarm will be given in the form of sound and light or through mobile devices, warning the on-site operation subjects. The equipment operation status will be transmitted to the safety center managers through the mobile communication network. At the same time, the alarm and violation data will be classified and statistically analyzed. When the equipment fails, it can trace and restore its historical working status to assist in accident analysis.

Intelligent identity recognition and personnel trajectory management: Implement fingerprint recognition or facial recognition for operators. After passing the verification, they can use specific mechanical equipment. The records of each operator's operation behavior will also be synchronized and saved for later analysis and handling. To prevent unqualified personnel from entering specific areas of the construction site, access control systems or electronic fences will be deployed at the entrances and key areas, high-risk areas, and deployed dynamically on the system. Combined with intelligent recognition technology, personnel will be controlled for passage, preventing unauthorized personnel, non-specific shift personnel, non-specific workers, or non-specific time periods from entering.

Safety inspection handheld terminal: The safety inspection handheld terminal is used to assist in safety inspection work. The working process is that the inspection personnel discover safety hazards in the construction site during the inspection, including unsafe behaviors of people, unsafe states of mechanical equipment, and unsafe places. Then, these hazards are photographed and uploaded. The category, level, and designated person/responsible unit for rectification of the hazards will be selected. After receiving the notification, the person/responsible unit will handle the hazards. They can directly feedback through the platform if the hazards are still not handled within the specified time. The system will automatically remind the safety personnel responsible for the inspection if the hazard is not handled, and then intervene in this hazard handling event until it is completed. Violations and non-compliant safety places can be recorded in real time, which is conducive to assigning responsibilities and timely rectification.

Safety information database: Establish various information resource libraries such as safety knowledge database, safety regulations database, safety technical measures database, and safety emergency response database. On the one hand, safety managers can query relevant information from the safety information database and retrieve inspection standards and references in real time, reducing the requirements for the professional skills of safety managers and improving the quality and effectiveness of safety inspection work. When construction site personnel perform high-risk operations, they can retrieve the standard construction procedures for reference in real time, understand the emergency response procedures and operation processes in advance, and define, generate, update, and adjust personalized data information resources based on the actual situation of the construction site to achieve customized management.

4. Evaluation of Safety Management Performance Indicators in Construction Sites

4.1 Construction site safety management index construction and assessment ideas

Based on legal norms and relevant literature, combined with expert interview opinions, a performance indicator system and assessment system for on-site safety management were constructed. The establishment steps of the assessment system include: indicator dimension division, indicator scope, indicator item composition, indicator evaluation content, content assessment and feedback adjustment, etc., forming a closed-loop design. Referring to the traditional engineering management concepts of "people, machines, materials, methods, and environment" and the 4M theory, primary indicators such as project personnel, equipment materials, construction operations, management systems, and effect feedback were extracted. There are 15 secondary indicators, such as

unified personnel management, qualification management, etc., taking into account the evaluation orientations of intelligent construction evolution, such as intelligence and sustainability.

Indicator design focuses on the integration of intelligent construction characteristics. At the technological innovation-driven level, attention is paid to the application and integration level of intelligent technologies. At the data information collaboration level, the evaluation of information integration and decision-making ability is examined. At the value continuous optimization level, emphasis is placed on process reshaping and full life cycle management. Each indicator adopts a combination of "overall evaluation control items + specific indicator items": the overall control items focus on the bottom-line effect of safety management, such as whether an accident occurs, and are quantitatively evaluated based on data ledgers; the specific indicator items rely on intelligent construction technologies, such as big data, BIM, etc., to assess the degree of intelligent realization of the safety management process, and are qualitatively analyzed through expert scoring. This approach ensures the scientificity and systematicness of the indicator system and highlights the technical characteristics and improvement paths of safety management in the context of intelligent construction.

4.2 Establishment of safety management performance indicators for construction sites

The safety performance index system for construction sites constructed under the background of intelligent construction is based on both traditional engineering management concepts and intelligent construction theories, forming a "dual-dimensional + three-oriented" index design framework. In terms of the division of index dimensions, based on the traditional management concepts of "people, machines, materials, methods, and environment" and the 4M theory, five primary index dimensions of project personnel, equipment materials, construction operations, management systems, and effect feedback are extracted, with 15 secondary indicators under each dimension. Among them, the project personnel dimension includes 3 indicators such as unified personnel management and qualification management, the equipment materials dimension covers 3 indicators such as construction power supply and machinery management, the construction operation dimension includes 3 indicators such as civilized construction and edge protection management, the management system dimension includes 3 indicators such as safety education and training management, and the effect feedback dimension includes 3 indicators such as accident prevention effect.

The evaluation orientation of the index system closely revolves around the three major characteristics of intelligent construction: the technological innovation-driven aspect focuses on the application and integration level of intelligent technologies, such as the application of BIM technology in construction scheme simulation; the data information collaboration aspect emphasizes the integration of information and decision-making ability, such as the real-time collection of on-site data by IoT sensors; the value continuous optimization aspect pays attention to process reconfiguration and full life cycle management, such as the realization of traceability of safety performance data through blockchain technology. Each index adopts a "comprehensive evaluation control item + specific indicator item" composite structure: the overall control item sets the safety management bottom-line requirements, such as "no occurrence of personnel death and serious injury incidents", and is evaluated quantitatively based on data ledgers; the specific indicator items focus on the application of intelligent construction technologies, such as "using big data technology to dynamically verify personnel qualifications", and achieve qualitative assessment through expert scoring. This index system not only covers the intelligent control of explicit elements such as personnel trajectory management and equipment status monitoring, but also includes the digital upgrade of implicit processes such as safety technical measure management, providing an operational index framework for the scientific assessment of safety performance in the context of intelligent construction.

4.3 Overall quality assessment and analysis of the safety management performance indicators system for construction sites

For the initially formed safety management performance indicator system, it is necessary to evaluate its rationality and require a scientific assessment and analysis of the overall quality of safety

performance. By using a questionnaire method, experts with on-site safety management experience were invited to offer suggestions for the indicator system. It was decided to adopt the Kano model as the tool for evaluating and analyzing the indicator system. During the interview process, the on-site safety management performance assessment indicator system was modified based on the expert opinions, and the characteristics of each indicator item under the combination of intelligent construction technology and safety management were clarified, and the positive and negative indicators that had a significant impact on safety management performance were selected.

The Kano model was used to conduct an overall quality assessment of the indicator system, and through questionnaire surveys and statistical analysis, the attributes and priorities of the indicators were clarified. Firstly, a Kano questionnaire with 15 indicator items was designed. Each indicator was divided into positive and negative questions. 20 industry experts and practitioners were invited to rate, and after the questionnaires were collected, the attributes of the indicators were statistically analyzed according to the classification standards of the Kano model (attractive attributes, expected attributes, necessary attributes, etc.). The results showed that the combined proportion of attractive and expected attributes indicators accounted for 63%, reflecting a high degree of satisfaction of the indicator system with the requirements of intelligent construction. However, the proportion of necessary attributes was only 4.67%, indicating that some basic indicators still need to be improved. Through the better-worse coefficient analysis, the priority of requirements was quantified, and the degree of satisfaction change when users have or lack certain functions was calculated to guide product development decisions.

The "increased satisfaction coefficient" and "decreased dissatisfaction coefficient" were calculated. It was found that indicators such as B2 qualification management and B1 personnel unified management ranked in the top five of both the satisfaction and dissatisfaction coefficients, requiring special attention. In addition, 25.67% of the indistinguishable attribute indicators in the indicator system reflected a lack of innovation, and 5% of the negative attribute indicators (such as B6, B9) indicated that contradictions such as the application of intelligent technology and privacy protection needed to be optimized. Finally, the frequency distribution method was used to determine the categories of indicator attributes, providing data support for the optimization of the indicator system and clarifying that the attractive attribute indicators (such as B7, B8) need to be prioritized for resource investment, and the indistinguishable attribute indicators can be gradually adjusted.

5. Example of Performance Evaluation for Safety Management at Construction Sites

5.1 Basic information of the assessment case

Taking a commercial center construction project as an example, a performance assessment model was constructed and an empirical analysis was carried out to verify the practicability of the safety management performance indicator system in the context of intelligent construction. This project includes one 33-story hotel and office building, two 27-story office buildings and a commercial center. The installation project covers pipeline laying, electrical systems, etc. In the construction management, BIM technology, cloud computing, and IoT sensors were introduced as intelligent means to achieve real-name management of personnel, equipment status monitoring, and real-time environmental warning functions. For instance, BIM technology was used for construction briefing and simulation control, IoT sensors were used to monitor the status of steel platform lifting equipment, VR technology was used for safety training, and intelligent terminals were used to implement hazard inspection and rectification tracking.

The project integrates multi-dimensional intelligent technologies in safety management: personnel management relies on the DingTalk system to achieve real-name data collection and analysis, and tracks trajectories through intelligent safety helmets and positioning technology; equipment management implements real-time monitoring and image recording of the operating status of hoisting machinery for lifting operations; environmental management deploys monitoring devices in areas with dust and noise sensitivity, and configures intelligent sensing devices for the temporary power system to achieve overload alarm. In the management process, safety managers report hazards

through mobile phone APPs, use BIM models to simulate construction power supply schemes, implement simulation monitoring of dangerous operation areas such as deep foundations and high formwork, and form a closed-loop management of "perception, analysis, control, and optimization".

5.2 Safety performance assessment results and improvement strategies

The overall score of this case is 72.50. The performance assessment level of the on-site safety management of the project is relatively average, and there is still considerable room for improvement in some performance assessment indicators.

The performance indicators obtained through the survey scoring are consistent with the actual situation of on-site safety management of the case project. Through the scoring, the shortcomings and weak points of the safety management work of the case project can be identified, and further improvement and enhancement are needed.

For the problems identified in the analysis of the assessment and evaluation process of the case project, a correlation analysis is conducted according to the involved links of construction enterprise on-site safety management to find out the factors that have a significant impact on it, such as personnel, resources, and systems. And according to the project-based management model, systematic improvement and optimization measures are formulated. Combined with the content of the performance indicator system for on-site safety management in the intelligent construction context constructed in this article, the response and improvement measures are sorted out in order of priority, and the path and measures for the evolution of on-site safety management towards intelligent construction are formulated.

The first priority is to improve the indicators that have problems and constraints in the current application. For example, indicators such as B8 special construction operation monitoring and early warning with a relatively low score and B9 operation environment safety monitoring and early warning are determined as priority improvements.

The second priority is important but not urgent. It is a precautionary type. It has not been widely applied, but has a significant impact on the intelligent transformation of on-site safety management. Indicator B12 safety inspection and remote monitoring is determined as the second priority for improvement.

The third priority is unimportant. It is a finishing touch type. The indicator weight is low. According to the actual situation, the realization guarantee degree is considered. Indicator B13 accident prevention effect is determined as the third priority for improvement.

5.3 Evaluation results application and countermeasures

Based on the assessment results, improvement measures are formulated for the project according to priority:

The configuration of software and hardware technical infrastructure, including information collection systems, intelligent decision-making analysis systems, mobile communication network infrastructure, and intelligent terminals. IoT sensors conduct real-time safety monitoring of the construction environment and record the information in real time. Cloud computing, BIM technology, and big data technology are used to optimize and simulate the project construction safety plan; a safety knowledge database is established and scientific classification, reasonable and customized management of hazard sources can be carried out based on the actual project situation. Monitoring and inspection are conducted using unmanned aircraft and video surveillance; if possible, robots are used to replace manual labor, and special operation construction with high safety risks is also included. Ensure that the video monitoring information collection points cover the key areas of the construction site; access the construction site safety system using intelligent terminals, mobile APPs, input, query and download various safety index data; adopt intelligent voice broadcasting, intelligent terminals, mobile APP alarms and hazard alerts.

Long-term improvement strategies include: configuring information collection systems and intelligent decision-making platforms, establishing a safety management integrated information database, achieving cross-project data sharing through cloud computing and big data technology, and ultimately forming a systematic safety management system of "hardware infrastructure, information

platform, data sharing, intelligent decision-making". This example verifies the effectiveness of the indicator system and provides a quantifiable and phased improvement path for construction enterprises to transform towards intelligent construction.

6. Conclusion

Technological innovation-driven approach emphasizes the application, integration and innovation of intelligent technologies, such as artificial intelligence, big data, cloud computing and other technologies being applied in on-site safety management. This can effectively enhance the efficiency and accuracy of safety management.

With the core of the "perception, analysis, control, optimization" closed-loop mechanism, it not only focuses on the intelligent control of explicit elements such as personnel and equipment, but also emphasizes the digital upgrade of system processes and performance feedback.

Based on legal norms and relevant literature, combined with expert interview opinions, an intelligent on-site safety management performance index system and assessment system were constructed, forming a systematic framework covering all elements.

A performance assessment evaluation model integrating the Analytic Hierarchy Process and Fuzzy Evaluation Method was designed. We can through the Kano Model analyze the attribute of indicators, using the Analytic Hierarchy Process to calculate the weight of indicators, and combining the Fuzzy Comprehensive Evaluation Method to construct the assessment process, an operational method system for quantifying safety management performance was provided;

The actual case application verified the effectiveness of the index system and evaluation model. Based on the assessment results, improvement measures were formulated according to priority, clarifying the intelligent transformation paths for important and urgent matters such as special operation monitoring and environmental warning, providing a reference for the transformation of construction enterprise safety management to intelligent construction.

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