

Research on the application of smart construction sites in construction safety engineering

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Abstract. With the continuous acceleration of the digitalization process of the construction industry, the traditional safety management method that relies on manual inspection has gradually become lagging and limited. The emergence of smart construction site technology provides new solutions to this problem. Through tools such as the Internet of Things, BIM, big data and artificial intelligence, the construction site can realize real-time monitoring of personnel and equipment, and carry out intelligent analysis and early warning intervention on this basis, so as to promote the gradual transformation of safety management from "post-processing" to "pre-prevention and dynamic control". This paper focuses on the application practice of smart construction sites in personnel and equipment management. In terms of personnel management, measures such as real-name attendance, smart helmets and AI identification have made risk identification more timely and accurate; In terms of equipment management, intelligent monitoring and predictive maintenance of key facilities such as tower cranes, elevators and deep foundation pits effectively reduce the incidence of accidents. Research shows that smart construction sites are not only superimposed on technology, but also reflect the deep combination of safety concepts and digital management, providing a new path for building safety governance.

Keywords: smart construction site; building safety management; Internet of Things; BIM. Artificial intelligence.

1. Introduction

With the progress of the times, the continuous development of science and technology, the scale of the construction industry continues to expand, with the increasing scale and complexity of construction projects, due to the relevant construction and management technology is not fully mature, the safety hazards and management problems in the construction process are gradually emerging. As a high-risk workplace, construction sites may face various safety accidents such as slipping and falling, object strikes, and mechanical injuries, which will bring serious losses to people's lives and enterprise economy. Especially in small and medium-sized construction enterprises, safety risks are more prominent due to insufficient management capabilities and technology investment[1]. Therefore, how to use modern technology to improve the level of safety management has become a core topic of concern in academia and industry. Based on the technology of modern society, our country's current research in this area mainly focuses on the key technology composition and scenario-based application of smart construction site systems, such as personnel positioning, hazard warning, VR safety education, deep foundation pit and tower crane safety monitoring[2,3]. Some scholars have tried to verify its safety effectiveness and implementation difficulties by means of test benches and actual project cases[1]. This study aims to sort out the key technical paths and practice modes of smart construction site systems in construction safety management[2]. Analyze its suitability, feasibility and effectiveness in the project, and explore the constraints in its promotion.

2. Technology of smart construction sites

2.1. The concept of smart construction site

Smart construction sites are a new management model that has emerged with the informatization and digital transformation of the construction industry in recent years. It relies on advanced technologies such as virtual reality, intelligent sensing, and artificial intelligence[4], Embed these technologies into building components, construction machinery, safety equipment worn by workers, and access control facilities[5]. In practical projects, these technology carriers are interconnected to form an IoT system that covers the entire site and interacts with the Internet platform. In this way, managers can not only view the construction status in real time on the platform, but also carry out digital simulation and scheme optimization of the whole process of the project, so that intelligent management can be implemented in all aspects of construction. The design of the system focuses on improving the efficiency and flexibility of information interaction. It supports real-time data sharing between various engineering subsystems and personnel in different positions, making communication more direct and smoother. For example, when sensors detect potential safety hazards in high-altitude work areas, the system will immediately synchronize the information to on-site workers and safety management personnel to adjust the operation method in time. In addition to improving construction production efficiency, smart construction sites emphasize the initiative of construction safety management, and realize the closed-loop management mode of "pre-prevention, in-process control, and post-event traceability" through real-time monitoring, intelligent early warning, and data-driven analysis and decision-making.

However, traditional construction site safety management needs to rely on manual inspection, safety training and institutional constraints, although the incidence of accidents is reduced to a certain extent, but there are shortcomings such as high labor costs, lagging response and low identification rate of hidden dangers[6]. The emergence of smart construction sites has changed the way safety management is from experience-driven to data-driven, making safety management more accurate, efficient and traceable.

2.2. Technical system of smart construction sites

Smart construction sites are usually composed of four parts: perception layer, transmission layer, platform layer and application layer, each layer has specific functions:

Perception layer

BIM: In the early stage of project construction, the construction process is simulated through 3D visual models, potential risk points are identified, and safety program support is provided for subsequent construction.

IoT sensors: environmental temperature and humidity sensors, noise and dust monitors, displacement sensors, wearable positioning devices, etc. deployed at construction sites to collect real-time environmental data and personnel status. For example, when the foundation pit displacement exceeds the set threshold, the system will immediately push an alarm to remind relevant personnel to carry out reinforcement treatment.

Video surveillance and AI recognition: Automatically identify and record violations (such as not wearing seat belts while working at height) through high-definition cameras combined with computer vision algorithms.

Transport layer

It uses 4G/5G network, Wi-Fi and other communication methods to transmit the collected multi-source data to the cloud platform or data center in real time. The transport layer needs to ensure low latency, high stability, and data security to ensure that risk information is captured and communicated to managers as soon as possible.

Platform layer

It consists of a cloud computing platform and a big data analysis engine for data storage, processing, and analysis. Combined with AI algorithms, pattern recognition and risk prediction of historical accidents and real-time monitoring data are displayed to managers through a visual interface.

Application layer

Mainly for safety management personnel, project managers and construction personnel, it provides safety inspection management, personnel attendance positioning, environmental monitoring, equipment management, hazard early warning and other functions. It supports mobile and PC access, so that managers can grasp the on-site security status anytime and anywhere.

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2.3. Technical system of smart construction sites

In actual construction, the smart construction site is not a set of static management tools, but like a continuous circulation system, following the process of "collection, transmission, analysis, decision-making, execution, and feedback". It first collects information such as temperature, dust concentration, and personnel location on site through various sensors and equipment, and then transmits it to the platform for analysis based on a stable network. The results of the analysis are translated into management decisions, such as adjusting the order of operations, pausing a construction project, or issuing safety alerts, which are immediately implemented on site. The effect after implementation will be re-recorded and evaluated by the system, and the next strategy will be adjusted accordingly. This cycle keeps safety management in dynamic optimization, rather than waiting for accidents to occur before remediating.

Data collection

Sensors (figure 1), cameras and positioning terminals are deployed at the construction site to collect personnel, machinery, environment and other data in real time. As shown in Figure 2, workers' helmets have built-in positioning chips that can record position and activity trajectories, and identify physical abnormalities in combination with heart rate monitoring.



Fig. 1 Sensor display screen



Fig. 2 Smart helmet

Data transfer

Use high-speed networks such as 5G to transmit data to the cloud platform in real time. For example, the data of sensors in some high-risk equipment can be transmitted to the platform in real time to provide a basis for safety decision-making. In order to ensure this real-time, construction sites usually use Wi-Fi and wired transmission as backups, and deploy relay equipment in areas with obvious signal attenuation, such as tunnels and basements, to ensure that all kinds of monitoring data can be stably transmitted back to the cloud platform in different construction environments.

Data analysis and risk identification

The platform uses algorithms to match the collected data with BIM models to identify high-risk areas and violations. For example, in the monitoring of aerial work, the system will continue to compare the location information of workers with the safety requirements of the operation, and once it detects that a person has entered the aerial work area and is not wearing a seat belt, it will immediately generate early warning information and notify relevant personnel through multiple channels such as mobile terminals and sound and light alarms.

Early warning and disposal

The system notifies on-site personnel and safety management personnel through text messages, APP push, sound and light alarms, etc., and requires immediate measures. If necessary, the relevant machinery and equipment can be automatically shut down to prevent the accident from expanding.

Continuous improvement

Through the system circulation of smart construction sites, historical accident data, early warning records and management experience are deposited into the database, and safety strategies and construction processes are continuously optimized.

Smart construction sites combine information technology such as Internet of Things, BIM, and big data with construction safety management, so that safety management can gradually shift to real-time monitoring and prevention. With the help of sensors and intelligent analysis platforms, managers can detect potential risks earlier in the construction process and adjust construction plans or operation methods in a timely manner based on the analysis results, thereby reducing the probability of accidents. The operation of the system not only relies on data collection and analysis, but also includes information transmission, on-site execution, and subsequent improvement, forming a dynamic cycle of management process. In practical applications, as shown in Figure 3 this model improves the transparency and efficiency of security information.



Fig. 3 Smart construction site operation technology

3. Application of Smart Construction Site System

3.1. Application status of smart construction sites

With the rapid development of informatization and intelligent technology, smart construction sites have gradually become an important driving force for the digital transformation of the construction industry. By integrating advanced technologies such as BIM, IoT, big data, and artificial intelligence, smart construction sites are constantly changing the traditional safety management model of construction sites. In the past, the method of relying on manual inspection and empirical judgment has gradually been replaced by real-time monitoring, intelligent analysis and automatic early warning. This transformation not only makes safety management more accurate and efficient, but also makes the construction site truly digital [3,7]. In the specific practice of safety management, the value of smart construction sites is mainly concentrated in two aspects: personnel safety management and equipment safety management.

3.2. Smart construction site personnel safety management

There are many people and miscellaneous types of work on the construction site, which is the most likely link for safety risks to be concentrated. Traditional management often relies on manual supervision, which inevitably has regulatory loopholes and slow handling of accidents. However, the introduction of smart construction sites has taken personnel management to a whole new level.

Real-name system and attendance system

In smart construction sites, personnel entering and exiting usually rely on real-name management systems. The construction site ensures that the information of each worker entering the site is true and traceable through face recognition, fingerprint recognition, ID card swiping, etc. This model not only improves the standardization of on-site personnel management, but also provides data support for the traceability of subsequent safety responsibilities[8]. In addition, the real-name system combined with the attendance system can grasp the distribution of personnel on the construction site in real time, and in the event of an emergency, it can quickly verify the location of personnel and start the emergency plan.

Personnel positioning and real-time monitoring

Through IoT technology, smart helmets or other wearable devices worn by workers can achieve real-time positioning. The management platform can dynamically grasp the specific location of each worker on the construction site and identify the distribution of personnel in high-risk work areas. For

example, in deep foundation pits or high-rise operation areas, the system can provide early warning to incoming personnel to prevent irrelevant personnel from mistakenly entering the danger zone[9]. At the same time, the trajectory data of personnel work can also provide a reliable basis for post-accident investigation.

Intelligent detection and behavior recognition

Smart construction sites use video surveillance and AI recognition technology to detect workers' operating behavior in real time. For example, when violations such as not wearing a seat belt or a safety helmet are found when working at height, the system will immediately alarm and push it to the management terminal[7]. This mode of "behavior recognition and automatic warning" is more immediate and accurate than traditional manual supervision. Some projects also combine the voice broadcast function to remind illegal workers on the spot, improving the timeliness of education and control.

Health protection and personnel management

Smart construction sites not only pay attention to the safe operation of construction personnel, but also pay attention to their physical health. For example, some smart helmets are equipped with heart rate and body temperature sensors, which can monitor vital signs in real time. If there is an abnormal situation such as heat stroke or excessive fatigue, the system will immediately push an early warning[10]. In addition, workers' skills training, admission education and other information can also be linked with the platform to achieve an integrated closed loop from training, assessment to daily management.

3.3. Safety management of equipment

Compared with personnel management, the safety risks of construction equipment are often more direct and destructive. Whether it is tower cranes, elevators, or support equipment for deep foundation pits, once a problem occurs, the consequences are extremely serious. The advantage of smart construction sites is that they carry out real-time monitoring and remote data analysis of equipment, which significantly improves the intelligent level of equipment management.

Intelligent detection of tower cranes

Tower cranes are the most typical high-risk equipment on the construction site. Nowadays, tower cranes are generally equipped with wind speed sensors, torque sensors and inclinometers to collect operating data in real time. In the event of an abnormal situation such as overload, excessive wind speed or deflection, the system will immediately alarm and even automatically trigger shutdown protection[11]. In a high-rise residential project, the data of the tower crane wind speed sensor can be synchronized to the platform in less than a second, and the project manager decisively stopped the hoisting to avoid possible accidents.

Intelligent detection of elevators and deep foundation pits

Construction elevators are also often included in the monitoring scope of smart construction sites because they undertake a large number of vertical transportation tasks. The system can monitor the load, operating speed and access control status of the elevator in real time, and immediately warn if overload or illegal operation is detected[7]. In high-risk areas such as deep foundation pits and slopes, data is continuously collected through displacement sensors and inclinometers, and when the monitoring value is close to the early warning threshold, the platform will automatically trigger the emergency mechanism to remind the management to take measures in advance.

Full life cycle management of equipment

Smart construction sites not only pay attention to the operation safety of equipment, but also pay attention to the management of the whole life cycle of equipment. Through big data technology, the system can comprehensively analyze the operation logs, maintenance records and service life of the equipment, predict potential faults in advance and schedule maintenance in advance[9]. This

"predictive maintenance" model not only improves the reliability of equipment operation, but also reduces the risk of safety accidents caused by equipment failure.

Remote monitoring and management of equipment

Video surveillance also plays an important role in the equipment management of smart construction sites. Taking the elevator as an example, the high-definition camera combined with AI algorithms can not only help the driver eliminate blind spots, but also prevent the collision of hanging objects. At the same time, many systems support remote access, and project managers can check the operation of equipment in real time through mobile phones or computers even if they are not on site, and remotely issue instructions when necessary, improving management flexibility and emergency response capabilities.

4. Summary

The construction of smart construction sites is not just a stack of technology, but a deep combination of management concepts and digital tools. With the increase in the scale and complexity of construction projects, the traditional safety management methods that rely on manual inspections and institutional constraints have gradually become limited. The emergence of smart construction sites has enabled safety management to shift to a new model of "real-time monitoring, intelligent analysis, and active intervention". From the real-name system of personnel, positioning monitoring to the whole life cycle management of equipment, smart construction sites are transforming the original fragmented and lagging management methods into a set of systematic and traceable closed-loop mechanisms. In terms of personnel safety, smart helmets, positioning devices, and AI video recognition effectively improve the speed of perceiving violations and emergencies, allowing managers to make more accurate judgments through data instead of relying on experience and intuition. At the same time, vital sign monitoring also includes the health of workers in the scope of safety management, reflecting the concept of "people-oriented". In terms of equipment safety, high-risk equipment realizes real-time early warning and predictive maintenance through sensors and big data platforms, which not only reduces the accident rate, but also improves construction efficiency.

Overall, smart construction sites provide an effective new path for construction safety management. It not only improves the timeliness and scientific nature of risk prevention and control, but also accumulates practical experience for the digital transformation of the industry. In the future, with the further maturity of artificial intelligence and big data technology, smart construction sites will show greater potential and value in the field of construction safety.

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