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Research Article

Analysis of Safety Behavior of Prefabricated Building Workers' Hoisting Operation Based on Computer Vision

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Safety accidents occur frequently in the construction industry, and unsafe behavior of workers is one of the main reasons for the occurrence of safety accidents. In recent years, the rapid development of emerging technologies has provided effective support for the automatic identification of unsafe behaviors. In particular, computer vision technology does not require equipment to be attached to workers. It has little impact on its operation and can process a large amount of image data in a timely and fast manner. Therefore, it is more suitable for the construction site environment. This study starts from the hoisting operation on the construction site of prefabricated building projects and introduces relevant machine learning methods. Early warning analysis on the safety risk of the tower crane is carried out to complete the hoisting operation of prefabricated components. To suspend dangerous tasks in time according to the warning results, relevant measures are taken and potential risks are eliminated to prevent accidents.

1. Introduction

A prefabricated building is a building assembled on-site with prefabricated parts. Although the promotion of prefabricated buildings has achieved good results, it is moving forward with high progress. However, we have to realize that, at this stage, China's prefabricated buildings are still in the initial stage of development. There is still a big gap compared with developed countries and industrial powers in terms of technical support, market cultivation, supporting construction, and management model transformation [1, 2]. In particular, reflected in the overall level of assembly construction is not high, and there are many hidden dangers in construction safety and so on.

The prefabricated construction operation brings benefits such as cost reduction and efficiency increase, energy conservation, and environmental protection. This low-mature construction method increases the operational safety risks of on-site hoisting and parallel construction of prefabricated buildings [3, 4]. It is more likely to cause safety accidents on the construction site.

The hoisting operation on the prefabricated building construction site consists of two links: hoisting operation and installation operation. In the whole process, tower cranes or forklifts need to be used to change the spatial position of prefabricated components to complete the splicing and assembly of various components [5]. Different from conventional hoisting operations, in the construction process of prefabricated buildings: the hoisting operations of components account for more than half of the on-site engineering volume, with a long duration and high strength; the shape of the lifting object is irregular, and the single-piece mass is large [6, 7]. The assembly requires high operation accuracy, stable suspension, no shaking, and poor visibility. All of these make the on-site hoisting operation of prefabricated buildings become the source of high-frequency safety accidents.

In recent years, the development of new technologies, especially the development of wearable technology and computer vision technology, has made it possible to automatically identify the unsafe behavior of workers. The identification method based on wearable technology mainly obtains workers' position information or movement information by installing positioning labels, accelerometers, and other devices on workers [8]. After extracting the features, they are analyzed and trained to realize the recognition of workers' unsafe behavior. However, this method requires workers to wear additional equipment, which is cumbersome and inconvenient, has a certain impact on workers' normal operation, and may even cause new potential safety hazards [9].

The recognition method based on computer vision technology does not have the above limitations. It mainly collects workers' behavior images, extracts key features from them, analyzes and trains them, and realizes the recognition of workers' unsafe behaviors. In addition, the monitoring camera is widely used in the construction site, which also provides the basis for the application of computer vision technology. Therefore, the identification method based on computer vision technology is more suitable for the actual construction environment and provides effective support for the automatic identification of workers' unsafe behavior.

2. Relevant Overview and Theoretical Basis

2.1. Prefabricated Building

2.1.1. Definition of Prefabricated Building. Prefabricated building refers to the integration of prefabricated parts for the main parts of the building's structure, outer protection, equipment, and pipelines. Prefabricated buildings are mainly divided into prefabricated concrete buildings, steel structure buildings, wood structure buildings, and their composite structures [10]. Among them, prefabricated concrete buildings are most widely used in China, and they are also the research object of this study. The difference between prefabricated buildings and general cast-in-place buildings is shown in Figure 1.

2.1.2. Prefabricated Building Construction. The difference between prefabricated concrete building and traditional concrete building is that their construction is based on components. Therefore, the prefabricated building construction not only refers to the construction site in the traditional sense but also includes the component production of the factory, the logistics transportation after production, and the component assembly. Therefore, the prefabricated building construction referred to in this study is an extended definition based on the components necessary for its construction.

2.1.3. Prefabricated Hoisting Construction

(1) Composition of Prefabricated Hoisting Construction System. The prefabricated hoisting construction system is a relatively complex dynamic system. It mainly includes four basic elements: prefabricated components, hoisting machinery, hoisting environment, and employees [11]. In the actual hoisting construction process, these four basic factors serve the prefabricated hoisting construction system at the same time and influence and restrict each other in the service process.

In addition, the continuity of prefabricated hoisting construction operation makes the risk factors contained in each element in the process of continuous dynamic evolution. Therefore, to prevent and control the occurrence of hoisting safety accidents, it is necessary to deeply study and master the specific risk factors and their interaction strengths contained in each production element in the hoisting construction system of prefabricated components. On the contrary, the prefabricated hoisting construction system is safe and reliable only if the harmonious coexistence of various elements within the system is ensured.

(2) Construction Characteristics of Prefabricated Hoisting. The safety management in the hoisting construction of prefabricated buildings is difficult, which is related to the current situation that the development of prefabricated buildings in China is not quite mature. The relevant technical standards are not complete, and the management concept also stays at the traditional level of safety management [12]. Faced with the frequent safety management bottleneck of hoisting accidents in various industries, the safety management of component hoisting of prefabricated buildings has received much attention.

The hoisting construction of prefabricated buildings has the following characteristics: ① the components themselves have high potential energy and large volume. Once an accident occurs, the consequences will be serious; ② hoisting operation is a combined movement of hoisting machinery, hoisting tools, and prefabricated components. There are many and scattered dangerous points, which makes it difficult to control; ③ the hoisting machinery runs across the operation site with load and is higher than other equipment, facilities, and people; ④ hoisting is a group operation, which requires the cooperation of signal workers, tower crane drivers, installers, and other people, and most of them are exposed to danger, so there is a strong demand for dynamic control; and ⑤ the operation conditions are complex and there are many uncertain factors.

2.2. Definition and Characteristics of Unsafe Behavior of Workers

2.2.1. Definition of Unsafe Behavior. The research object of this study is defined as the unsafe behavior of workers on the construction site. The unsafe behavior of construction workers at the construction site is defined as the behavior of construction workers that violates relevant safety regulations, which directly causes or may directly cause safety accidents.

The research object of this study is behaviors that directly cause or may directly cause safety accidents due to violations of relevant safety regulations, including conscious unsafe behaviors and unconscious unsafe behaviors. Conscious unsafe behavior refers to the influence of construction workers for some motivation, psychological needs, or other factors. He still made the act on the premise that he knew

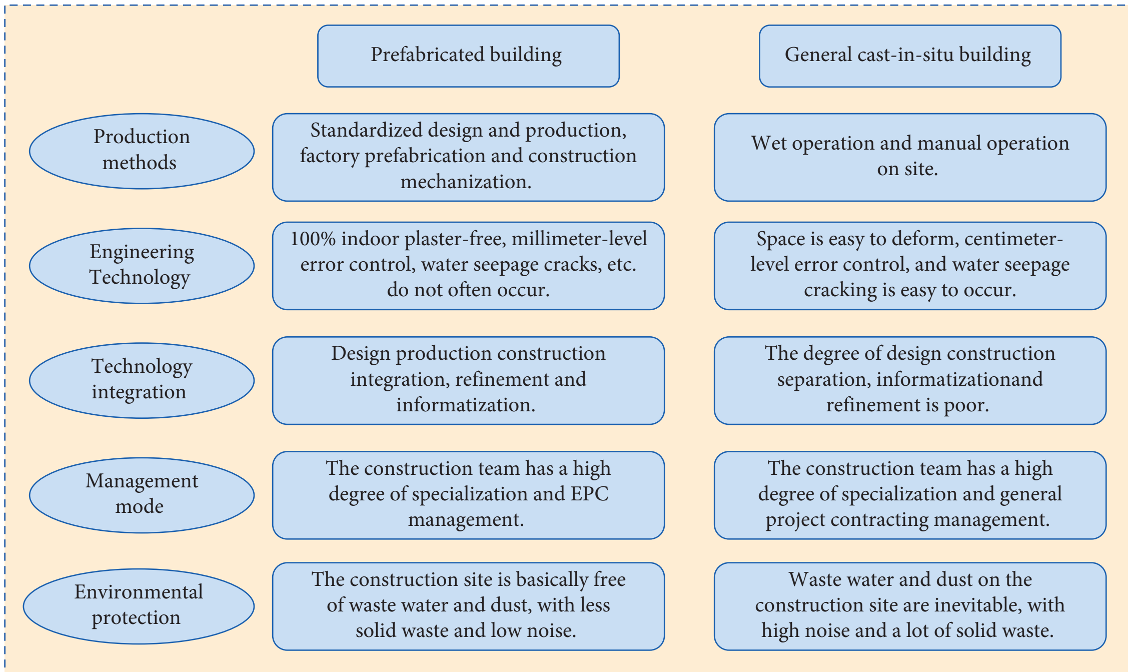

Figure 1: Comparison of prefabricated buildings and cast-in-place buildings.

that his behavior violated relevant safety regulations and there were safety risks. Unconscious unsafe behavior refers to the unsafe behavior of construction workers without knowing that their behavior violates relevant safety regulations.

2.2.2. Characteristics of Unsafe Behavior. The construction site operations are carried out in a complex coupled system of man, machine, and environment. Under the operation of this complex coupled system, the unsafe behavior of construction workers is common. The unsafe behavior of construction workers on the construction site has its own uniqueness, which mainly includes the following two aspects.

(1) The characteristics of construction safety production are different.

① Construction is complex and dynamic. Dangerous sources have great uncertainty in construction site operations. Compared with the traditional manufacturing industry, most of the manufacturing industry produces fixed products in fixed plants, so its production process, influencing factors, and existing hazard sources are relatively stable [13]. Many complex variable factors, such as long construction period, many open-air operations, complex construction processes, and multiple cross operations may have an impact on the working environment of the construction site, resulting in the unsafe behavior of construction workers.

② There are too many safety codes, standards, and operating procedures in the construction field that is complex and scattered. Therefore, construction workers cannot understand and memorize various terms and relevant safety knowledge, thus inducing unconscious unsafe behavior.

③ The level of mechanization of construction and production of construction projects is low, and the construction and production environment is poor. Most of the operations on the construction site can easily lead to fatigue and distraction of construction workers, which can easily lead to unconscious operation errors.

(2) The main body of unsafe behavior of construction workers is different.

① Construction workers at the construction site have high mobility, low cultural and professional level, and less experience in receiving professional skill training. Unintentional and unsafe behaviors are due to lack of relevant safety regulations and professional skills, such as incorrect operation of construction machinery, equipment, and instruments such as cranes.

② Most construction workers have a low degree of compliance with safety operation procedures, which leads to conscious unsafe behaviors such as taking risks and violating regulations.

③ The habitual unsafe behavior of construction workers is very common. The unsafe behavior of construction workers stems partly from conscious risk-taking and violations and partly from unconscious habitual unsafe behavior [2, 14]. This habitual unsafe behavior is the subconscious result of the long-term habit of construction workers. For example, construction workers often do not wear safety helmets when entering the construction site.

2.2.3. Classification of Unsafe Behaviors. During the construction process, the personnel on the construction site must abide by various standards, specifications, rules, and various safety management regulations. According to the operating procedures, domestic and foreign literature, and the experience of experts on the construction site, the unsafe behaviors of workers are mainly divided into the following three categories:

(1) Personal protection equipment (PPE) is not used or not used correctly. For example, the on-site high-altitude workers do not wear safety belts as required; workers do not wear safety helmets when entering the construction site; and workers do not use dust masks and noise protective equipment as required [15]. It is worth noting that the use of PPE can protect construction workers from or reduce safety accidents and occupational hazards during operation on the construction site and has a direct protective effect on human body. Common PPE includes ① safety helmet and other head protective articles; ② eye protective equipment such as protective glasses; ③ fall protection devices such as safety belt, safety rope, and safety net; and ④ hand protectors such as protective gloves.

(2) Close to hazardous areas. Being close to the dangerous area means that the workers on the construction site are within the scope of risks and potential safety hazards. That is, the workers on the construction site stay in unsafe places or carry out construction operations.

(3) Safety procedures were not followed. Failure to follow safety procedures includes two types of unsafe behaviors: ① workers on the construction site do not operate machinery in accordance with standardized, standard, and correct operation procedures; ② construction workers make unsafe actions unconsciously during construction operations.

Table 1 lists the unsafe behaviors of some workers on the construction site. These unsafe behaviors are chronic diseases that cause safety accidents on the construction site. Some scholars have used computer vision and deep learning methods to automatically recognize that construction workers are not wearing helmets or safety belts during work. These research methods can accurately identify a certain unsafe behavior of workers from a specific construction scene, identify a variety of unsafe behaviors in pictures, and promote the development of automatic and continuous identification of unsafe behavior of construction site workers.

2.3. Behavior-Based Safety Theory. Behavior-based safety (BBS) is a set of theories and methods for accident prevention from the perspective of behavioral science. It was first proposed in 1979 by British scholars Gene Earnest and Jim Palmer under the name of BBS. In the late 1970s, BBS was introduced into China. After more than 40 years of theoretical research and exploration, BBS is considered to be a very valuable research method to prevent safety accidents, improve safety performance, curb unsafe behavior, and encourage and consolidate safety behavior.

BBS focuses on individual behavior. It is a combination of psychology, sociology, organizational behavior, and ergonomics on the basis of behavior science. By establishing the difference between unsafe behavior and safe behavior, people's unsafe behavior at the production and operation site is identified, monitored, corrected, analyzed, and counted [5, 16]. It is a scientific and progressive management method to continuously solidify habits by adopting the cycle mode to carry out the process of "observation-correction-re-observation-re-correction" and gradually avoid or eliminate people's unsafe behaviors.

BBS research focuses on how to reduce unsafe behaviors of individuals, focusing on people's "unsafe behaviors." Compared with traditional safety management methods, BBS has two main differences: (1) BBS emphasizes observing workers' behavior, while traditional safety management methods examine unpredictable factors, such as workers' safety awareness. (2) BBS advocates encouraging behaviors of normative workers, while traditional safety management methods focus on punishing workers who engage in unsafe behavior.

3. Application and Common Methods of Computer Vision

3.1. Application of Computer Vision in Construction Engineering. In construction engineering, several applications of computer vision are related to the monitoring of construction sites and can be used for productivity and safety management. Image processing algorithms including object detection, object classification, and object tracking are available. Object detection algorithms identify objects of study by detecting their color, shape, or other characteristics. Object classification algorithms classify objects using intelligent classifiers or discriminative functions.

In the existing literature of computer vision in the construction industry, some of them are used to simply detect and track the entities on the scene and recognize the activities and gestures of the entities [17]. With the development of research, more and more scholars apply computer vision to the management activities of construction site.

One of the main applications of computer vision in construction sites is productive detection and recognition. Primarily by detecting and tracking entities on the construction site, it assists managers in calculating productivity, including construction equipment and workers. Luo et al. used computer vision technology to identify the activities of workers installing steel bars on construction sites, which can be used for labor activity assessment. Using photogrammetry and video analysis techniques to create time series of point clouds, Bügler et al. generate statistics of construction activity that estimate productivity on a time scale, assessing productivity levels in underground construction earthwork excavations. Chen et al. proposed a framework for activity and productivity evaluation of multiple excavation

Table 1: Unsafe behaviors of workers on construction site.

Unsafe behavior category	Description of unsafe behavior
Improper use of personal safety equipment	Not wearing safety helmet Not wearing seat belt as required Do not use dust masks and anti-noise protective gear as required
Close to hazardous area	Workers approaching construction machinery within the working radius During crane operation, workers stay under the jib When the crane is working, the object to be lifted passes directly above the person
Safety procedures not followed	The main and auxiliary hooks of the crane work at the same time Crane pulling heavy objects or hoisting buried objects

equipment. Other scholars use computer vision technology to detect and track materials and temporary resources on construction sites.

Another important application of computer vision technology is the detection and tracking of safety in construction sites, which can be divided into unsafe behaviors and unsafe conditions. Worker unsafe behaviors include improperly wearing personal protective equipment (PPE), entering hazardous areas, and failing to follow safety procedures. For PPE-related research, Fang et al. used a deep learning approach to detect workers' PPE. Fang et al. used the same model to detect workers' safety helmets. The difference is that most studies detect safety helmets in a closer distance. This study can detect whether workers wear safety helmets in a further monitoring scene. For the research related to entering dangerous areas, Fang et al. combined computer vision with mask R–CNN. This knowledge is used to identify the unsafe behavior of individuals supported by structures and then determine the relationship between these objects.

Through the above review, it is not difficult to see that computer vision technology has realized the detection and tracking of building entities in construction projects. The computer vision applications used are image classification, target detection, and pose estimation. The above application research will be used as a technical reference for the safety behavior analysis of assembly construction workers in hoisting operation based on computer vision in this study.

3.2. Common Method

3.2.1. Convolutional Neural Network. The combination of the development of deep learning methods and computer vision technology enables computers to better understand what they see, thus promoting the development of the field of computer vision. Compared with traditional machine learning methods, the biggest feature of deep learning is that it can automatically learn the features suitable for the task and has stronger ability of feature learning and feature expression. Among them, the most widely used deep learning method is a convolutional neural network (CNN).

The deep learning method based on CNN has been widely used in the field of computer vision since it was proposed, for example, image classification, object detection, image semantic segmentation, pose estimation, and face recognition, and it achieved good results. Common deep convolution neural network models include AlexNet, VGGNet, GoogleNet, and ResNet. The application and development of CNN provide theoretical and technical support for the identification of workers' unsafe behavior in construction site [18].

3.2.2. Recurrent Neural Network. A recurrent neural network (RNN) is a neural network with short-term memory ability. It can not only process the current input information but also store the output information of the previous layers, forming a network structure with loop. RNN has been widely used in the field of natural language processing and has made great breakthroughs in machine translation, machine reading, text classification, and other tasks.

RNN can be regarded as the expansion of neural network in time series. Theoretically, it can deal with sequences of any length. RNN is very intuitive in design, and the shared parameters in each time step make it not easy to fall into overfitting, so it is very suitable for sequence modeling. In response to the long-term dependence problem of RNN, the Sepp long-term short-term memory (LSTM) introduces input gate, output gate, and forgetting gate on the basis of RNN to selectively forget or remember the information in neurons, so that RNN can model longer time series. Chung et al. proposed gated recurrent unit, which combines the forgetting gate of LSTM with the input gate and greatly improves the operation speed without losing the accuracy of the model.

3.2.3. Support Vector Machines. A support vector machine (SVM) can identify arbitrary samples by reconciling the learning accuracy of the model and the ability of error-free according to the limited sample data information. That is to find the optimal compromise between model complexity and learning ability and then obtain the best generalization ability, which is widely used in function fitting, regression analysis, and so on. Because it can quickly solve the disadvantages of small samples, high-dimensional nonlinearity, and local minima, it has become a new research hotspot after neural networks.

SVM is a novel small sample learning method with solid theoretical foundation. Different from the existing statistical methods, SVM does not involve probability measure and the law of large numbers. In terms of computational complexity, because the final decision function only depends on the support vector, not all samples, there is no need to worry about the "dimension disaster" to a certain extent, and it is easy to grasp the key samples and has good robustness. However, the selection of kernel function and the determination of function parameters have an impact on the output results, which need to be improved in combination with practical application such as least-squares vector machine and correlation vector machine, and using particle swarm optimization or grid search method to determine function parameters.

4. Safety Behavior Analysis and Measures of Prefabricated Building Hoisting

4.1. Safety Behavior Analysis of Prefabricated Building Hoisting

4.1.1. Hoisting Operation Procedure and Safety Measures. The hoisting operation at the construction site of prefabricated buildings consists of two parts: hoisting operation and installation operation. The whole process requires tower crane or forklift to change the spatial position of prefabricated components, so as to complete the splicing and assembly of various components [19]. After the hoisting operation is completed accurately and qualified according to the technical scheme of construction organization design, the next step of component node connection can be carried out. The basic operation procedures, key points, and measures of safe construction are described as follows:

(1) Basic Procedures of Hoisting Operation: during the basic process of hoisting prefabricated components, the connection between the component and the tower crane cannot be separated until the temporary support of the component hoisted in place is fixed well.

Among them, "component lifting and installation" and "component adjustment, correction, and temporary fixation" are often the unstable links that are most likely to cause accidents and last for a long time in the construction process. Due to the quality, shape, size, and other factors of the hanging object, there are a lot of uncertain factors in many processes in the two links, such as poor visual range, high shaking frequency, long duration, and large strength strain of the connection point. To fully and accurately identify the risk factors existing in the hoisting operation as much as possible, it is necessary to understand each process of these two links.

(2) Safety Measures for Hoisting Operation.

Regarding the safety measures for the construction of prefabricated buildings, the safety measures for related hoisting operations are shown in Table 2.

Based on the summary of the operation characteristics of tower crane and the analysis of the hoisting operation procedures and key points and measures of safe construction on the construction site of prefabricated building, compared with the traditional cast-in-place process construction, the characteristics of prefabricated concrete construction engineering in construction safety protection are as follows: ① frequent lifting operation; ② the lifting capacity is greatly increased; ③ a large number of formwork erection operations become temporary support; and ④ reduced work on external scaffolds. Therefore, when identifying the hazard sources of hoisting operation, it is necessary to analyze and establish the identification list of hazard sources of prefabricated building hoisting operation and determine the safety influencing factors in combination with the above four characteristics.

4.1.2. Problems in Safety Management of Hoisting Operation. Due to the limited supply and uneven quality of prefabricated components at this stage, the low technical level of workers on the construction site, and the lack of tools, instruments, and equipment matching with the construction process of prefabricated buildings, the risk level of prefabricated construction system is high, and the potential safety hazards cannot be ignored [20]. The problems existing in the safety management of hoisting operation in prefabricated building construction mainly include the following aspects:

(1) The safety production management system of all parties involved in construction safety management is not perfect.

① It is difficult to control the procurement, ordering, supply, and quality of components, limited control of on-site progress, quality and safety production, and limited investment in safety measures.

② The management capabilities of technology and general subcontracting mode need to be improved, and the responsibilities and capabilities of the existing security officers need to be changed accordingly.

③ The ability of in-depth design of prefabricated components is lacking, the proportion of consideration of construction safety in the design process has changed, and the design mode and drawing process are not suitable for the characteristics of prefabricated construction.

④ The supervision content, method, and control means are different from those of the traditional cast-in-place process.

(2) The safety production management guarantee system is absent.

① The safety production management of prefabricated buildings cannot directly copy the current safety technical standards and specifications based on traditional construction and production operations.

② The financial security measures are backward, and the safety and civilized construction fee items in the existing measure fees cannot meet the actual requirements of mechanization and modularization required for the construction of prefabricated buildings.

Table 2: Safety measures for hoisting operation.

Measure content	Factors involved
The hoisting personnel of prefabricated components shall wear safety shoes, safety helmets, and safety belts, and the safety hook shall be fixed in the designated safety area	Personnel and materials
During the hoisting process, hook removal and other climbing operations should use qualified ladders, tools, and accessories. Anti-slip measures should be taken, and it is strictly forbidden to throw up and down	Personnel and materials
During the hoisting process, the suspended workplace shall be provided with protective railings or other temporary and reliable protective measures	Materials and management system
Before the commencement of hoisting operation, the operation area shall be enclosed, a warning line shall be set and special personnel shall be assigned to take care of it. Safety signs shall be arranged to prevent personnel irrelevant to installation from entering	Personnel and management system
During hoisting, it is strictly forbidden for personnel to stay below the operating radius. Relevant operators can only approach when the component is lowered to within 1m from the ground	Technology and management system
When hoisting edge components, operators should wear lifelines, and temporary protection should be done during edge operation	Personnel, materials, and management system
The operation should be stopped when there are safety hazards or unqualified safety inspection items during the hoisting process	Management system

③ The current safety supervision model cannot be fully controlled. The operation of prefabricated construction projects includes the production, transportation, and hoisting of components. The space is parallel and multidimensional. The entire production system is cross-regional and cross-industry, and it is easy to find regulatory loopholes.

④ There is a lack of mature and professional prefabricated construction project management team and construction operation team, and the supporting management system, education and training, assessment standards, and other systems are not perfect.

(3) The standard system is not perfect.

Safety management standards applicable to prefabricated building construction operations have not been formed, and the management systems, operating procedures and standards of all parties, and the scope of responsibilities and rights of management departments are unclear. The current safety construction standards and regulations in the industry are difficult to directly guide the safe and civilized operation of the assembly site, and there is no ready reference for the settings of safety enclosures, three treasures and four ports, and scaffolding.

The above three aspects lead to a large number of factors affecting the safety of operators, materials, equipment, and mechanical appliances in the hoisting operation of prefabricated building construction. It should be considered in the early warning analysis of prefabricated building hoisting operation, and combined with the actual demand, the influence degree and control mode of each point are analyzed, to achieve the accurate, scientific, and objective early warning goals.

4.1.3. Hazard Identification of Hoisting Operation. At present, the total amount of hoisting and assembly work is regarded as the most dangerous factor in the whole construction process. It is also regarded as the weakest point of safety control in the whole construction process. At the same time, there are also safety risks in the links such as on-site layout and component stacking and transportation, which precede the hoisting operation, resulting in the frequent occurrence of hoisting accidents. Therefore, when identifying the hazard sources of hoisting operation, these presequence links should be considered and determined in combination with the actual needs.

Combined with the theory of the causes of safety accidents and the characteristics of prefabricated building construction, reference is made to relevant building construction safety technical standards, research literature, and accident case analysis reports [21]. According to the safety table inspection method, all the risk factors that may lead to safety accidents in the four aspects of on-site stacking, lifting, installation, and high-altitude work are collected and summarized, and a list is listed. Combined with the hazard source control objectives, the hazard sources are identified in each link that may cause hoisting accidents.

Compared with the safety risks faced by the tower crane lifting operation in the traditional cast-in-situ process, the key construction processes, key points and measures of safe construction, and the current situation of safety management of hoisting operation of prefabricated buildings are analyzed, to complete the hazard identification of hoisting operation of prefabricated buildings. Based on this, a comprehensive list of hazard sources for prefabricated building hoisting operation is obtained, from which the safety early warning index system of prefabricated building hoisting operation can be analyzed and determined.

4.2. Suggestions for Safety of Hoisting Operation. According to the safety early warning analysis of the hoisting operation process of the above prefabricated building project engineering cases, combined with the safety management characteristics of prefabricated building construction, the following countermeasures and suggestions are put forward to help improve the safety level of hoisting operations.

(1) During the hoisting operation, the tower crane driver needs to pay attention for a long time, and measures shall be taken to ensure the operation state of the driver. For example, a high frequency of communication and dialogue is kept, to avoid fatigue, sleepiness, inattention, and other situations of the driver. At the same time, the impact of high-temperature operation in summer on the tower crane driver should be considered, the operation time should be adjusted, the drinking water supply should be increased, and the cooling and heatstroke relief supplies and drugs should be distributed to reduce the probability of heatstroke and heat radiation disease.

(2) The prefabricated components have heavy weight and long suspension duration, which is easy to cause the performance fatigue of tower crane long arm trolley, steel wire rope, sling hook, and other metal parts. Then, cracks, shrinkage, and deformation occur, resulting in instability of tower crane structure and falling of lifting objects, resulting in safety accidents. Therefore, redundant connections should be arranged between the tower crane and the spreader and between the spreader and the lifting object to ensure the safety in case of cable breakage.

(3) The finished products of components shall be protected before delivery, especially the positions of embedded parts, bolt sockets, etc. The auxiliary operation time in the process of component installation is reduced and the continuity of operation lapping is improved. In addition, it is also necessary to increase the investment in technology and scientific research to realize the dynamic simulation of operation links such as component hoisting, wet operation at nodes, and erection of temporary support system as soon as possible. Potential safety hazards in advance are discovered and eliminated.

(4) As a key operation link, the presence and role of relevant personnel shall be ensured during hoisting operation, and the absence of supervision by the supervision unit in construction and production shall not occur frequently. The comprehensive cooperation of safety self-management and multiparty supervision is ensured, the unsafe behavior of people and the unsafe state of objects are discovered timely, and it is dealt and solved as soon as possible according to the special scheme and emergency plan for hoisting operation. At the same time, it is also necessary to prepare emergency plans in advance for various emergencies according to the actual situation and do a good job in relevant safety education and training, as well as the preview of the plan.

(5) The property rights and other information of all parties involved in the project are collected and sorted, for example, adjacent buildings, subways, basements, hydropower and natural gas pipelines, and the probability of eliminating adverse factors caused by temporary local load changes caused by the stacking of prefabricated components. The requirements of high-intensity load of air conditioner and high-temperature exposure operation on power and heat dissipation system shall also be considered, and the power safety and tower crane body maintenance shall be strengthened.

5. Conclusion

The method for identifying unsafe behavior of workers constructed in this study has both theoretical and practical values. First, the identification method constructed in this study is top-down, systematic, and universal. The fragmented scenarios are aggregated for overall consideration, not limited to specific unsafe behaviors or application scenarios. Second, the behavioral data obtained in this study can support long-term digital security management. The unsafe behaviors and dangerous areas that need to be managed at a certain stage are identified, and corresponding resources are allocated to improve the level of safety management. Furthermore, this research provides the possibility for the utilization of a large amount of video data on-site and improves the level of informatization on the construction site. Finally, the method is applied in the actual construction site. That is, the identification of unsafe behaviors of workers can effectively support construction site early warning and reduce the occurrence of safety accidents.

Data Availability

The dataset can be accessed upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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