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RESEARCH ON TRANSPORTATION SAFETY OF PREFABRICATED BUILDING COMPONENTS BASED ON SPA-ABC

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ABSTRACT

Aiming at the safety problem of the transportation of prefabricated components in prefabricated buildings, set pair analysis (SPA) and Pareto analysis (ABC) are used to propose a transportation safety evaluation model for prefabricated components in prefabricated buildings based on SPA-ABC. Based on the existing research results, the risk factors in the three stages of transportation preparation, transportation work and storage work are sorted out, and the evaluation index system of transportation safety is established. Combining the status quo of transportation operations, SPA is used to determine the index weights. Based on the ABC theory, risk factors are divided into major risk factors (type A), secondary risk factors (type B) and general risk factors (type C), and recommendations are made based on the major risk factors. The results show that ten risk indicators such as transportation operators, transportation plans, and fixing measures for prefabricated components are type A risk factors, which are the focus of prefabricated construction transportation operations.

KEYWORDS

Prefabricated building, Transportation of prefabricated components, Safety evaluation system, Set pair analysis method (SPA), Pareto analysis method (ABC)

INTRODUCTION

Since the goal of “striving to make the proportion of prefabricated buildings exceed 30% in 10 years” was put forward in 2016 [1], clear arrangements for prefabricated construction work have been made across the country. This year has entered the "second half" of achieving this goal. China's support for prefabricated buildings has also been further increased. Yunnan, Sichuan, Anhui and other places have introduced a series of related policies and implementation measures to support the construction of prefabricated buildings [2]. At the same time, the requirements for all aspects of prefabricated buildings are getting higher and higher. In terms of engineering safety, although prefabricated buildings are safer than traditional cast-in-place buildings, safety accidents still occur from time to time, so prefabricated buildings have their own unique risks [3]. Prefabricated buildings have increased a large number of hoisting operations and transportation operations. The safety of hoisting operations "occupies a major position" in frequent accidents, and has always been an important object of people's attention. In contrast, transportation safety issues are often overlooked by people. However, the safety and efficiency of the transportation link is also an issue that cannot be ignored for the development of prefabricated building safety. Once there is a problem in this link, it will have a significant impact on the construction safety, quality and schedule of the entire project [4].

In recent years, scholars at home and abroad have also made a lot of in-depth explorations on the safety of prefabricated buildings. These studies mainly focus on two aspects, one is the safety study of the whole process of prefabricated buildings, and the other is the detailed study of safety during the hoisting phase of prefabricated buildings. In contrast, there are very few studies on the transportation safety of prefabricated building components. Wang et al. [5] used the importance-performance analysis method to study the risk factors affecting the development of prefabricated buildings in China. Factors such as unreasonable transportation conditions, insufficient coordination during transportation, and transportation tools were taken into consideration. Jin et al. [6] used Netica software to compile Bayesian network models and sensitivity analysis methods to analyze each type of risk factor to compare the degree of influence of these risk factors on the safety of prefabricated buildings. The results pointed out that the risk level of the transportation stage belonged to level 3, where the lack of fixing measures during the transportation of prefabricated components was the most influential risk factor. Duan et al. [7] used the structural equation model to study the main factors of the safety of prefabricated buildings. They believed that the on-site transportation, unloading and stacking of prefabricated structures were key issues affecting construction safety, but off-site transportation was not considered. Li et al. [8] simultaneously adopted the structural equation model and confirmatory factor analysis theory, and believed that the risks in the transportation and storage stages were greater than those in the production and installation stages, and the biggest safety problem in transportation stage was transportation vehicles. Liu et al. [9] used the analytic hierarchy process to analyze the factors affecting the quality of prefabricated buildings from four aspects: design, production, transportation and installation, and concluded that many unnecessary problems could be avoided by strictly implementing national operational standards in the transportation stage. Chang and Chang [10] analyzed the problems existing in the transportation stage of prefabricated components and put forward reasonable suggestions. Wang and You [11] studied the hoisting safety of prefabricated buildings based on the C-OWA operator, and combined the Pareto classification method to classify the factors in the transportation and hoisting stages of prefabricated components. The results showed that the disturbance of the lifting point and the contamination of the pre-buried materials at the lifting point caused by the transportation stage belonged to category C risk. When Wang and Yan [12] studied the construction safety of prefabricated buildings, they also considered the damage caused by transportation. In summary, domestic and foreign scholars have conducted relatively detailed studies on the main influencing factors, risk identification, and safety warnings of prefabricated building safety issues, which has greatly promoted the development of the prefabricated building industry in China. Most of the above studies take the transportation phase into consideration, which illustrates the importance of safety issues during the transportation phase. However, a complete transportation operation safety management system has not yet been formed, and specific risk factors are simply mentioned or ignored.

The paper intends to start from the safety problems existing in the transportation of prefabricated buildings and construct a system of risk factors in the transportation stage. The set pair analysis method (SPA) is used to determine the weight of each indicator, and the Pareto analysis method (ABC) is used to determine the risk factor category. Finally, the authors take a project in Wuhan as an example to prove the feasibility and practicability of this method, and proposed targeted measures for Type A risk factors. The specific process is shown in Figure 1. It is expected to provide reference suggestions for the safety management of prefabricated buildings, especially the safety management of transportation operations.

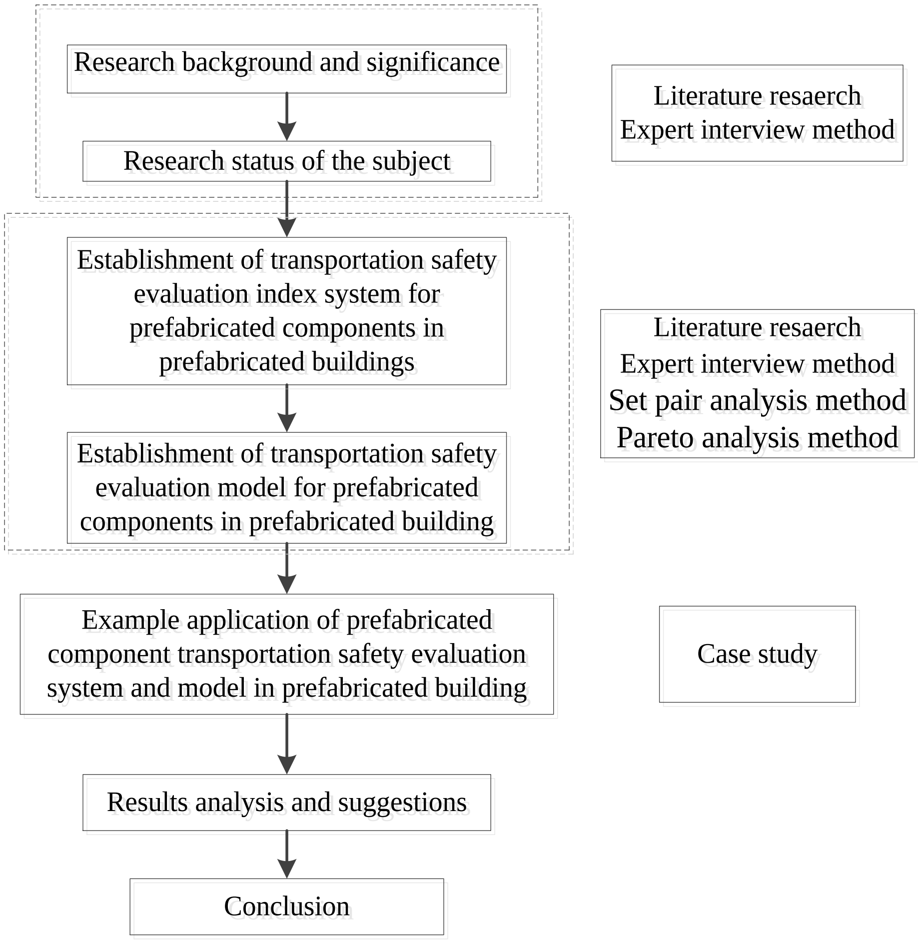

Fig.1 - Transportation safety evaluation process of prefabricated components in prefabricated buildings

TRANSPORTATION SAFETY MODEL OF PREFABRICATED BUILDING COMPONENTS BASED ON SPA-ABC THEORY

Determination of indicator weight

The SPA proposed by Zhao Keqin is a mathematical method that comprehensively considers and studies the certainty and uncertainty of the system [13]. It combines set theory with dialectics of nature. The basic idea is: when studying a problem, use the degree of connection to express the certainty and uncertainty of a research object, and consider the two and their transformation as a system for comprehensive research [14]. Compared with the analytic hierarchy process, the use of set pair analysis to determine the index weight is easier to distinguish and comprehensively evaluate [15].

Its connection degree expression is as follows:

$$\begin{cases} \mu = a + bi + cj, \left(i \in [-1,1],\ j = -1 \right) \\ a + b + c = 1 \end{cases} \tag{1}$$

Where a, b, and c represent the degree of identity, degree of difference, and degree of opposition, respectively; i and j represent the coefficient of uncertainty and the degree of opposition, respectively. By affecting the value of c, j affects the size of a; the values of i and j are also affected

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by a, b, and c [16]. In short, these few parameters are a whole. They influence and restrict each other to form a complex system.

This model transforms the uncertainty of related issues into specific mathematical theories. At the same time consider the certainty and uncertainty of the system. This makes the determined index weights more objective and authentic. The following will list the specific steps of applying the set pair analysis method to determine the index weight: This section should describe in detail the study material, procedures and methods used.

(1) The construction of the judgment matrix

Suppose there are r related professionals, and the evaluation index set is:

$$X = \{X_K\}, k = (1,2,3\cdots n) \quad (2)$$

Then, using the 9-scale method, professionals are invited to compare each indicator pair by pair and evaluate its importance. So as to get the elements of the judgment matrix and construct the corresponding judgment matrix $M_{kl}^{(r)}$..

$$M_{kl}^{(r)} = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{pmatrix} \quad (3)$$

Where r represents the judgment matrix obtained by the rth expert. And exist $x_{ij} = 1/x_{ji}$.

(2) Determination of connection degree model

When evaluating various indicators, there is no situation in which different experts have diametrically opposite evaluation opinions on two indicators. That is, there is no expert who thinks x_1 is extremely important than x_2, while another expert thinks that x_2 is extremely important than x_1. Generally speaking, the situation of similar opinions but differences is more in line with the actual situation. Therefore, it is considered that j=0, and the same-different model is adopted: μ=a+bi.

The connection degree model determined by the matrix form of the above-mentioned similarity and difference model:

$$\mu_{ij} = A_{ij} + iB_{ij}$$
$$= \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} + i \begin{pmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{pmatrix} \quad (4)$$

$$a_{ij} = \begin{cases} \min\{x_{ij}^{(r)}\}, x_{ij}^{(r)} \geq 1 \\ \max\{x_{ij}^{(r)}\}, x_{ij}^{(r)} \leq 1 \end{cases} \quad (5)$$

$$b_{ij} = f(x) = \begin{cases} \left|\max\{x_{ij}^{(r)}\} - \min\{x_{ij}^{(r)}\}\right|, x_{ij}^{(r)} \geq 1 \\ -\left|\max\{x_{ij}^{(r)}\} - \min\{x_{ij}^{(r)}\}\right|, x_{ij}^{(r)} \leq 1 \end{cases} \quad (6)$$

$$(r = 1,2,3\cdots n; i = 1,2,3\cdots n; j = 1,2,3\cdots n)$$

In formula (4), A_{ij} represents the identity matrix; B_{ij} represents the difference matrix.

In formula (5): exists $x_{ij} = 1/x_{ji}$, therefore, $\max\{x_{ij}^{(r)}\} = 1/\min\{x_{ij}^{(r)}\}$, and $a_{ij} = 1/a_{ji}$

(3) Consistency treatment of identity matrix

Compared with the analytic hierarchy process, using the compatibility matrix method for consistency processing can simplify the calculation process. It does not require a consistency check to obtain a matrix that meets the consistency requirements. Compatibility matrix $D = (d_{ij})_{n\times n}$.

$$d_{ij} = \sqrt[n]{\Pi_{m=1}^{n} a_{im} \times a_{mj}} \tag{7}$$

Where $d_{ij} = 1/d_{ji}, d_{ij} = d_{im} \times d_{mj}, d_{ii} = 1$

(4) Calculation of index weight

$$\omega_i = c_i \Big/ \left(\sum_{p=1}^{n} c_p\right) \tag{8}$$

$$c_p = \sqrt[n]{\Pi_{j=1}^{n} d_{ij}} \tag{9}$$

ABC method risk classification

ABC classification method (Pareto analysis method), or primary and secondary factor analysis method. As the name suggests, it focuses on distinguishing the primary and secondary, seizing the key influencing factors among many factors, and implementing corresponding measures [17]. According to the Pareto principle, this method holds that most of the harvest comes from the few efforts, and most of the output comes from the few inputs. Similarly, the majority of risks come from the minority of reasons, as long as the cumulative majority of risks are found, the main cause of the minority can be obtained [18]. The advantage of the ABC classification is that it simplifies our workflow and reduces our workload [19]. Because we can identify the major risk factors, we can focus on those risk factors instead of focusing on all the risk factors all the time. Therefore, the analysis objects are divided into three types: A, B, and C. Corresponding to major risk factors, secondary risk factors, and general risk factors. Among them, the cumulative weight value of A risk is less than 60%, the B risk is between 60% and 90%, and the C risk is between 90% and 100%.

CONSTRUCTION OF RISK FACTOR SYSTEM FOR PREFABRICATED BUILDING COMPONENT TRANSPORTATION OPERATIONS

Prefabricated building is a type of building in which some of its prefabricated components are manufactured in a designated plant according to the demand plan, transported to the construction site by special transportation vehicles, and assembled on site using some connection technology. At present, the prefabricated building components generally prefabricated in the factory include prefabricated beams, walls and floor slabs and other main components; prefabricated stairs, bay windows or kitchens and toilets and other special-shaped components. Most of these main building components are cast-in-place in traditional buildings, but are prefabricated in prefabricated buildings. Therefore, a lot of transportation work is inevitably required. Coupled with the characteristics of large weight, large volume, and irregular shape of the prefabricate components, this has caused difficulties in transportation operations. This article is based on the characteristics of prefabricated building transportation operations and existing research results, combined with the traditional five aspects of building safety influencing factors "people, materials, machines, management and environment". Analyze the risk factors of transportation operation of prefabricated construction from three stages of transportation preparation, transportation operation and storage work.

Transportation preparation

Transportation preparation is very important for subsequent transportation operations, and whether it is fully prepared directly affects the entire transportation process. The main risks at this stage are: (1) Inadequate training for transport operators, lack of safety awareness, and negligence of labor protection measures; (2) Insufficient capabilities of transport management personnel, poor organization and coordination capabilities, lack of sufficient management knowledge and Corresponding professional knowledge; (3) Lack of emergency plans or incomplete emergency plans, and no field drills on the plans formulated, and unskilled; (4) Inadequate attention to transportation operations, resulting in rough and incomplete transportation plans.

Transport operations

(a) Integral transport frame

(b) A type transport frame

Fig.2 - Type of transport frame

(a) Fixing measures and pads

(b) No fixing measures

Fig.3 - Suitable and unsuitable fixing measures

Various details in transportation have always been the focus of attention. The key to whether the transportation work is completed smoothly and safely lies in whether these details can be done. The main risk factors at this stage are: (1) Failure to select suitable transport vehicles according to the specifications, shapes, weights, etc. of the prefabricated components; (2) The selection of loading and unloading equipment is inappropriate or cannot meet the requirements for carrying capacity; (3) The transport frame designed or manufactured cannot meet the stress requirements of the corresponding components; Under normal circumstances, the transport frame used to transport the components is shown in Figure 2. (4) The prefabricated component fixing measures are not considered adequately, and measures such as protection and shock absorption are not adopted; This is shown in Figure 3. (5) In order to reduce transportation costs, blindly pursue short transportation routes, resulting in unreasonable route planning. Or not survey the route on the spot to verify whether the special location of the road can meet the transportation requirements. For example, the radius of gyration of the road and the bearing capacity of the bridge; (6) The crack resistance of the most unfavorable section of the component has not been checked to understand the force form of the unfavorable section of the precast component; (7) The construction site is uneven; (8) In terms of social environment, if the transportation route passes through urban arterial roads and other busy roads, it is easy to cause traffic congestion, which will cause huge safety hazards to urban traffic and people; (9) Weather conditions during transportation will affect transportation work, such as strong winds, heavy rain, heavy snow, etc.

Storage work

Since the storage work is directly related to the loading and unloading work in the transportation phase, it is also taken into consideration. If the storage work is perfunctory, one is to cause damage to the components, which will affect the safety of the follow-up work. Second, the components tilt or collapse when they are stacked, which will inevitably cause safety hazards to nearby workers. The main influencing factors at this stage are (1) The stacking location is not specified or the stacking location is not planned in the appropriate order, resulting in the secondary handling of the components. Furthermore, the stacking site is uneven and the drainage measures are not adequate; (2) Failure to adopt appropriate stacking methods according to the shape and force form of the components, causing damage to the components; (3) Insufficient protection measures when stacking components . Figure 4 shows an example of the above three factors

(a) Storage space clutter

(b) Prefabricated stairs placed vertically without fixed measures

(c) Unsuitable pad position

Fig.4 - Misbehavior in the storage work

Tab. 1 - Risk factors for transportation operations in prefabricated building

Target layer	Criterion layer	Index layer
Safety Evaluation of Prefabricated Building Transportation	Transportation preparation A_1	transportation operators A_{11}
		transportation management personnel A_{12}
		emergency plans A_{13}
		transportation plans A_{14}
	Transportation operation A_2	transportation vehicles A_{21}
		loading and unloading equipment A_{22}
		transportation racks A_{23}
		prefabricated component fixing measures A_{24}
		transportation routes A_{25}
		checking component strength, construction site A_{26}
		construction site A_{27}
		social environment A_{28}
		natural environment A_{29}
	Storage work A_3	stacking location A_{31}
		stacking method A_{32}
		stacking component protection measures A_{33}

From the above analysis, we can know the risk factors of each stage of the transportation operation of prefabricated components. Transportation preparation stage: transportation operators, transportation management personnel, emergency plans, transportation plans. Transportation operation stage: transportation vehicles, loading and unloading equipment, transportation racks, prefabricated component fixing measures, transportation routes, checking component strength, construction site, social environment, and natural environment. Storage work stage: stacking location, stacking method, stacking component protection measures. Based on this, the risk factor system of transportation operations is presented in Table 1.

Tab 2 - Indicator weight

Criterion layer	Indicator	Index layer	Indicator	Relative weight	Comprehensive weight
Transportation preparation A1	0.4089	A11	0.4570	0.1523	0.0623
		A12	0.1611	0.0537	0.0220
		A13	0.0995	0.0332	0.0148
		A14	0.2824	0.0941	0.0420
Transportation operation A2	0.4464	A21	0.1164	0.0388	0.0173
		A22	0.0948	0.0316	0.0141
		A23	0.1211	0.0404	0.0180
		A24	0.1584	0.0528	0.0236
		A25	0.1387	0.0462	0.0206
		A26	0.1305	0.0435	0.0194
		A27	0.0710	0.0237	0.0106
		A28	0.0798	0.0266	0.0119
		A29	0.0893	0.0298	0.0133
Storage work A3	0.1447	A31	0.2453	0.0818	0.0118
		A32	0.4093	0.1364	0.0197
		A33	0.3454	0.1151	0.0167

CASE ANALYSIS OF TRANSPORTATION SAFETY MODEL OF PREFABRICATED BUILDING BASED ON SPA-ABC THEORY

The following will analyze the transportation safety model of prefabricated buildings based on the SPA-ABC theory, taking the transportation of prefabricated building components of an affordable housing project in Wuhan as an example. The beams, slabs, roof trusses, stairs and other components of the project are all prefabricated. The 16 risk indicators (Table 1) in the three stages of transportation preparation, transportation and storage of this project are selected to construct the evaluation index system of this project.

Determine the index weight

Based on the SPA method, 3 experts and scholars and 2 relevant managers are invited to compare each index in Table 1 with each other to obtain a judgment matrix. Because in the process of evaluating the importance of indicators, it is easy to be affected by subjective factors. So this research will adopt an anonymous method and make full use of the professional knowledge and work experience of experts. Let experts make independent judgments and minimize the influence of unnecessary factors. According to the above-mentioned SPA method to determine the weight, the weight value of each indicator of the project and the weight value of these three stages (A_1, A_2, A_3) can be obtained as shown in Table 2. Among them, since the evaluation results of experts are not much different, *i* can be taken as 0.5[20].

Risk factor classification

According to the weights determined above, normalize the weights and calculate the cumulative weights. Based on the ABC analysis method, the risk factors are classified. The risk indicators of Type A, Type B and Type C are respectively determined as shown in Table 3 and Figure 5.

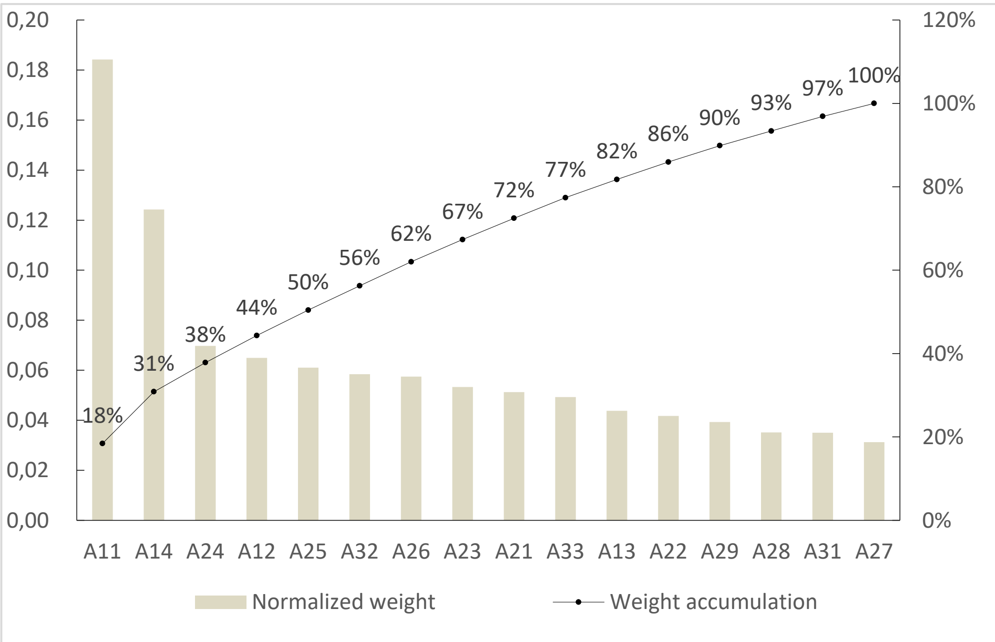

Fig.5 - Pareto chart

According to the above data, there are six indicators for Type A risk factors: transportation operators A_{11}, transportation plans A_{14}, fixing prefabricated components A_{24}, transportation management personnel A_{12}, transportation routes A_{25}, and stacking methods of components A_{32}. These indicators are the "critical few" of the factors that affect the transportation safety of prefabricated components of prefabricated buildings. In future work, these risk factors should be regarded as the main objects of concern. And corresponding measures should be taken to prevent them. There are seven type B indicators and three type C indicators, which are the "general majority" of the factors affecting the safety of transportation operations. Although the importance of these factors is after Type A risk factors, they cannot be ignored.

ANALYSIS AND RECOMMENDATIONS

In the above case analysis, six main risk factors are derived. Among them, the transportation plan, transportation operators and transportation management personnel belong to the transportation preparation stage; the prefabricated component fixing measures and transportation routes belong to the transportation operation stage; the stacking method of the components belongs to the storage stage. The following will focus on the six factors in these three stages and put forward corresponding suggestions.

(1) Transportation preparation stage

When designing a transportation plan, the transporter needs to comprehensively analyze the types, quantities, and arrival time of the required components according to the needs of the construction party to ensure the smooth and safe completion of the transportation tasks.

For transportation operators, the most important thing is to cultivate their safety awareness. Therefore, strengthening training assessment and supervision is essential. During the training, some typical accident cases should be displayed frequently or experts should be invited to explain on the spot. During the assessment, the actual operation assessment should be combined with the theoretical assessment. Considering the cultural level of the general operating staff, the method of face-to-face inquiry can be adopted. Labor insurance products must be distributed to operators in a timely manner, and they must also be supervised whether they are used correctly at work.

In terms of management personnel, problems in safety management in construction projects have always been the main cause of human and material safety accidents. Therefore, managers should also regularly conduct regular and irregular training, learn management knowledge and corresponding transportation expertise, cultivate their organization and coordination capabilities, and enhance their sense of responsibility.

(2) Transportation operation stage

When the transportation components are fixed by lashing to prevent the components from moving, the contact points should be provided with protective measures such as pads. At the same time, in order to reduce the damage of components due to road bumps during transportation, some shock absorption measures can be taken. For example, a shock-absorbing shelving frame is set, a hydraulic method is used on the transport vehicle, or an air spring is set on the bottom of the transport vehicle. Before leaving the factory, these fixing measures should be further checked.

The transportation route should be planned with full consideration of the size and weight of the transportation vehicle. After selecting an optimal route, site surveys should be conducted on the route, especially bridges, culverts, etc. At the same time, plan an alternative route to prevent emergencies.

(3) Storage work stage

Different types of components adopt different storage methods. Transverse members can be stacked on hardened ground or steel frame. However, spacers should be arranged between the components, especially flexible gaskets should be inserted at the rigid resting point to prevent rigid contact between the components. And the number of layers should not exceed 6 layers. Vertical components can be used with special stacking racks to ensure stable storage and avoid "slip and fall" accidents. Prefabricated stairs, balconies and other components can be laid flat.

CONCLUSION

Compared with traditional buildings, prefabricated buildings have significant advantages in terms of safety. In recent years, the construction industry at home and abroad has developed rapidly. Although there has been a lot of research on its safety, there is a lack of research on the safety of transportation operations. Based on the SPA-ABC theory, this paper establishes a transportation safety model for prefabricated components of prefabricated buildings, and verifies the feasibility of this model through practical application.

(1) This model develops a prefabricated component transportation operation safety evaluation system based on the characteristics of prefabricated building transportation operations and existing research results.

(2) This article introduces the set pair analysis method, combined with the compatibility matrix method to determine the connection degree model of the relevant problem index weight. Comprehensive consideration of the identity and difference, certainty and uncertainty of experts' knowledge, so as to further reduce the influence of experts' subjective arbitrariness.

(3) Classify each risk factor through ABC analysis method. According to the results of the Pareto chart, it can be seen that the main risk factors (type A) of the "critical minority" include six factors such as transportation operators, transportation plans, and prefabricated component fixing measures. In addition, corresponding measures are implemented for the main risk factors. In this way, companies can use limited resources to obtain the greatest return on the safety management of transportation operations. The method is simple but not lacking in practicability.

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