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ANALYSIS OF VEHICLE SPEED CONTROL IN HIGHWAY TUNNEL SECTIONS

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China's mountainous highway tunnels are prone to accidents, and the main types of accidents are tailgating and wall crashes. On the basis of analyzing the distribution pattern of highway traffic accidents, we deeply investigate the impacts of people, vehicles, roads, and the environment, and put forward an analytical method for the causes of tunnel accidents by using the method of Principal Component Analysis, and put forward a method of setting up speed-control based traffic signs based on the characteristics of the drivers, and establish a strategy of setting up traffic signs in tunnels to perfect the overall safety protection technology of the dense section of tunnel of mountainous highway of China and to enhance the safety of tunnel road sections, which is of theoretical value and practical significance, and provides a technological support for the safe operation of the highway of mountainous areas of China.

Keywords: highways, traffic safety, accident causes, speed control

1. Introduction

China is a large mountainous country in the world, with a mountainous area accounting for two thirds of the national territory. Due to the influence of the geographical and environmental conditions of mountainous areas and the limitations of the terrain, the route line is complex, and there are a large number of tunnel sections in the highway route. As of 2019, the number of highway tunnels in China was 19,067, and the total length of tunnels reached 18,966,600 meters. In some sections, the number of tunnels is high and the distance between tunnels and tunnels is short, and even tunnels and tunnels are directly connected, forming a dense tunnel section. As the throat of highway traffic, tunnel sections are not only prone to accidents, but also difficult to deal with traffic accidents in tunnels, which can easily lead to mass deaths and injuries. In addition, the closed nature of the highway tunnel caused by the complexity of the driving environment, to the traffic safety management work has brought a certain degree of difficulty. Scholars have found that the proportion of accidents in tunnels is significantly higher than that in normal road sections, and the proportion of serious and serious accidents is higher, and the accidents usually lead to secondary accidents or chain accidents, and many tunnels have become highway traffic accidents and control areas.

Scholars at home and abroad have studied tunnel operation safety from various aspects such as driver behavior, tunnel safety evaluation and so on. Kerstin Lemke1.a)i.1 studied tunnel safety and proposed a safety analysis method to evaluate the average accident rate and accident cost rate of different tunnel sections in Germany. Caliendo et al.1.a)i.2 analyzed the serious accidents occurring in Italian highway tunnels by using stochastic parametric regression model, and improved the accuracy of the model by considering the time correlation. Domenichini et al.1.a)i.3 used a driving simulator experiment to study the effects of different lighting conditions on the physiological and psychological state of drivers and driving speed when they were driving in tunnels. Alessandro Calvi et al1.a)i.4 studied the driving behavior of drivers in and out of tunnels through driving simulation, verified the usefulness of driving simulation to study driving behavior, and applied the results to road safety. Shen Yanjun1.a)i.5 et al. conducted statistics on the types, occurrence time, location and casualties of highway tunnel accidents, and found that the average number of casualties in the middle tunnel accidents was the highest. Lai Jinxing et al.1.a)i.6 analyzed and summarized the time, location, form and causes of accidents based on the data of traffic accidents in tunnels in China. Hu Yueqi1.a)i.7 researches the change characteristics of mind wandering and mental load in different tunnel sections of highway tunnel, as well as the influence of both on driving behavior and driving safety.

Vehicle speed plays an important role in the generation of traffic accidents in tunnels, and there are fewer studies on the reasonable control of vehicle speed in tunnel sections. Reasonable control of vehicle speed plays a positive role in improving traffic safety in tunnel sections.

2. Accident characteristics of tunnel road sections

Traffic accidents in tunnel sections of highways in the accident pattern, spatial and temporal distribution and other aspects of the existence of a number of different characteristics with ordinary road sections, which occurs with the road section of the geographic conditions, topographic conditions, external environment, weather changes, etc. have a close relationship.

2.1 Tunnel accident pattern

China's road traffic accidents are mainly divided into collision, crushing, scraping, overturning, crashing, fire and other accident patterns, as shown in Figure 4. In the tunnel section, vehicle rear-end collision is the most frequent accident, accounting for 60.1%; hit the wall is the second most frequent, accounting for 20.1%; fire and other accidents do not occur much.

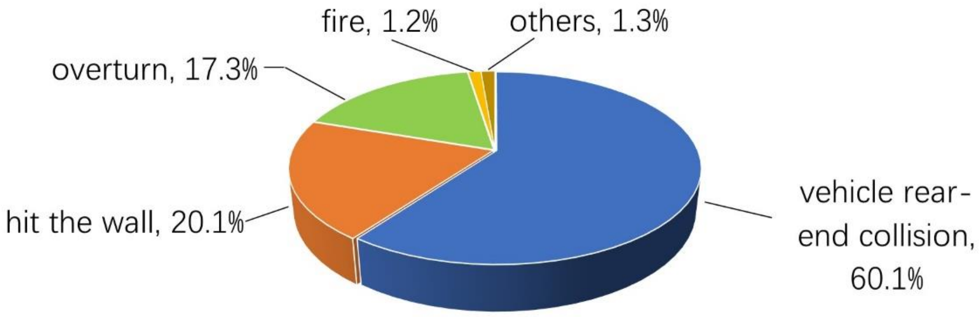

Figure 4 - Distribution of Traffic Accident Patterns in Tunnel Sections

Collisions in highway tunnels are the main form of accidents. The main reason for the collision is that the driver basically has no room to avoid danger in the lateral space, and the vehicle is traveling fast, so when it encounters an unexpected situation, if it is not operated in time, it will hit the wall of the tunnel or the vehicle traveling in front of it.

2.2 Spatial and temporal distribution law of tunnel accidents

2.2.1 Time distribution

The temporal distribution of traffic accidents refers to the statistical characteristics of traffic accidents over time. Traffic accidents are closely related to traffic activities and traffic environment. The study of the time distribution characteristics of traffic accidents can help to effectively manage and control the tunnel section and reduce the occurrence of traffic accidents. The study found that the number of traffic accidents on the tunnel section is higher in January, February, April, May and July of the year; during the week, the probability of traffic accidents is higher on weekends; and the number of traffic accidents is higher during the time periods of 9:00-10:00, 11:00-12:00 and 13:00-15:00.

2.2.2 Spatial Distribution

Different traffic environment and traffic composition lead to different distribution characteristics of traffic accidents in different road sections. It is found that the probability of traffic accidents increases with the length of highway tunnels, mainly due to the fact that few highway tunnels are equipped with landscaping zones, and drivers are easily fatigued when driving for a long period of time in a monotonous environment. The increase in traffic volume in the tunnel leads to a decrease in visibility due to increased smoke emissions, and the likelihood of accidents increases accordingly. Moreover, accidents in tunnels are neither uniformly distributed nor randomly distributed, and are mainly concentrated near the entrances and exits of the tunnels, especially in the 200-400m section of the entrance, which accounts for a larger proportion of the accidents.

2.3 Factors affecting traffic accidents in tunnels

Highway traffic accidents are in the "people-vehicles-roads-environment" system, due to their own or interaction disorders caused by.

2.3.1 Human factors

Drivers are mainly affected visually and psychologically when driving in mountain highway tunnels. Drivers are prone to traffic accidents at the entrance and exit of tunnels due to the phenomenon of light and dark adaptation. At the same time, the tunnel is illuminated only by lights with a limited range of vision, which makes drivers prone to feeling depressed and uncomfortable. Noise and air pollution in tunnels can cause psychological irritation and obstructed vision for drivers, which in turn can lead to traffic accidents.

2.3.2 Vehicle factors

Motor vehicles play a decisive role in traffic safety on mountain highways. In addition to overloading, routine overhaul and maintenance work is not in place, and other reasons, but also with the vehicle performance has a great relationship, such as maneuvering stability, braking, tire performance and so on.

2.3.3 Road factors

Highway tunnel section traffic safety is the road factors mainly refers to the road geometry line shape is poor, the road surface anti-skid is not good, etc., easy to form accident black spots, resulting in multiple accidents.

2.3.4 Environmental factors

Environmental factors are mainly reflected in the tunnel environment, low illumination, poor visibility; environmental noise, affecting the driver's normal thinking judgment and reaction ability.

3.Main causes of traffic accidents in tunnels

The basic idea of principal component analysis is to synthesize a large number of correlated indicators into a small number of geometrically unrelated new composite indicators by means of linear combinations. Generally, the first linear combination of the largest variance, so that it contains the most information, if the variance of the first principal component is not large enough, and then select the second principal component, and so on, until the selection of the principal component can contain the information that needs to be evaluated. The main calculation steps are

(1) Identify the sample data and represent it in matrix form.

$$X_{n\times p} = \begin{pmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{pmatrix} \tag{1}$$

(2) Calculate the sample mean and standard deviation

$$\bar{X}_j = \frac{1}{n}\sum_{i=1}^{n} X_{ij} \tag{2}$$

$$\sqrt{S_{ij}} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_{ij}-\bar{X}_j)^2} \quad j=1,2,3\dots p \tag{3}$$

(3) Normalize the data and calculate the correlation matrix. Let

$$Y_{ij} = \frac{X_{ij}-\bar{X}_j}{\sqrt{S_{ij}}} \quad i=1,2,3\dots n;\ j=1,2,3\dots p \tag{4}$$

Normalize Y_{ij}.

$$r_{ij} = \frac{1}{n-1}\sum_{k=1}^{n} Y_{ki}Y_{kj} = \frac{S_{ij}}{\sqrt{S_{ii}}\sqrt{S_{jj}}} \tag{5}$$

(4) The normalization matrix is obtained.

$$Y = (r_{ij}) = \begin{pmatrix} 1 & & & \\ r_{21} & \ddots & & \\ \vdots & & \ddots & \\ r_{p1} & \cdots & r_{p,p-1} & 1 \end{pmatrix} \tag{6}$$

Find the eigenvalues and eigenvectors of Y.

$$\begin{pmatrix} \lambda_1 & & & \\ & \lambda_2 & & \\ & & \ddots & \\ & & & \lambda_p \end{pmatrix} \tag{7}$$

Then λ_1, λ_2, …, λ_p are the p eigenvalues of Y. Let $\lambda_1 \geq \lambda_2 \geq \dots \lambda_p > 0$, then let $\alpha_j = \begin{pmatrix} \alpha_{1j} \\ \vdots \\ \alpha_{pj} \end{pmatrix}$, with j=1, 2, …, p, which is the corresponding unit orthogonal eigenvector.

(5) Determine the principal components

The k values were selected according to the criterion of cumulative variance contribution ratio $\sum_{j=1}^{k}\lambda_j / \sum_{j=1}^{p} r_{jj} > 85\%$, and the k principal components were determined, namely:

$$Z_j = \alpha_j^T Z = \alpha_{1j}Y_1 + \alpha_{2j}Y_2 + \cdots + \alpha_{pj}Y_p \quad j=1, 2, \dots, k \tag{8}$$

where Y_1, Y_2, …, Y_p are standardized indicator variables and Z is the value of the main component (new indicator).

(6) Analyzing the results and identifying the main causes of accidents

4.Tunnel section speed control technology

It is of great significance to study the method of speed limitation at tunnel entrances and exits and to establish a speed management system for tunnel entrances and exits to improve the safety level of tunnel entrances and exits.

4.1 Calculation model of minimum front distance for speed limit sign setting

From the driver's discovery of the speed limit sign to the completion of the speed adjustment, generally including the discovery of the sign, recognition of the sign, action to identify and take action in four processes. According to the above process, the visual recognition model of the speed limit sign at the entrance of the tunnel is established, as shown in Figure 5.

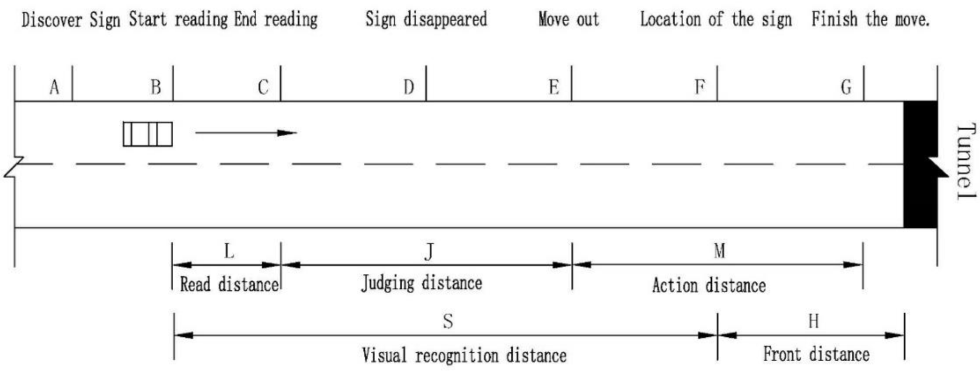

Figure 5 - Model for recognizing speed limit signs at tunnel entrances.

Vehicle driving according to the direction shown in Figure 5, when the vehicle driving to point A when the driver found the sign F, in point B began to read the speed limit information, to point C read finished, this distance is called recognition distance L. After reading the speed limit information, the driver to make deceleration and other actions of judgment, this distance is called the judgment distance J. The driver began to take action, driving to point G action is completed, this distance is called the action distance M. The distance from the start reading point B to the sign position F is called the visual recognition distance S, the distance from the sign position F to the starting point of the speed limit is the speed limit sign front distance H. According to the analysis of the above process and combining with Figure 5, it can be seen that the speed limit sign front distance should satisfy the equation 9.

$$H_{min} = L + J + M - S \tag{9}$$

which recognizes the distance and judges the distance, respectively:

$$L = v_1 t_1 \tag{10}$$

$$J = v_1 t_2 \tag{11}$$

In the formula: v_1 - the traveling speed of the wheels in front of the tunnel entrance (m/s); t_1 - time for reading traffic signs (s), take 2.616s; t_2 - judgment time, generally 2.0 ~ 2.5s, this paper takes 2.5s.

Since lane changing is generally prohibited before the tunnel entrance, the main action taken by the driver after obtaining the speed limit information from the speed limit signage is braking and decelerating the vehicle, which results in an action distance:

$$M = \frac{(v_2^2 - v_1^2)}{2a} \tag{12}$$

In the formula: v_2 - the traveling speed of the vehicle at the entrance of the tunnel (m/s); a - deceleration (m/s^2), generally 0.75 ~ 1.50m/s^2, this paper takes 1.5m/s^2.

Collating the above equations yields a minimum frontage distance for signage:

$$H_{min} == v_1(t_1 + t_2) + \frac{(v_2^2 - v_1^2)}{2a} - S \tag{13}$$

4.2 Calculation model for maximum front distance of speed limit sign setting at tunnel entrance

In addition to the above minimum front distance restriction, the front distance of the speed limit sign should not be too large, the front distance is too large, the driver may re-accelerate after the vehicle has traveled for a certain distance, which leads to the driver not being able to decelerate in time when he finds the entrance of the tunnel, so there is also a maximum front distance of the speed limit sign. The following combines the driver's short-term memory characteristics to study the maximum front distance of the speed limit sign.

In the process of vehicle driving, the driver's memory of the speed limit sign information is short-term memory, and the preservation time of short-term memory is limited, and the related research believes that the short-term memory will generally maintain about 20s without repetition, and the memory will disappear after exceeding this time. It is found that the memory percentage drops to below 20% after 12s, therefore, this paper takes the driver's memory time for speed limit information as 12s.

When the speed limit sign disappears from the driver's field of vision, the driver ends the memory of the speed limit information, and the distance from the sign disappearance point to the sign is called the disappearance distance m. The driver does not find the tunnel entrance after the end of the vehicle braking, and the driver keeps the vehicle traveling at a constant speed for a certain distance, which is called the stabilization distance D_s. When the memory of the speed limit information is about to disappear from the driver's memory, and the driver finds the entrance of the tunnel, he or she continues to keep the vehicle speed through the tunnel entrance, as shown in Figure 6.

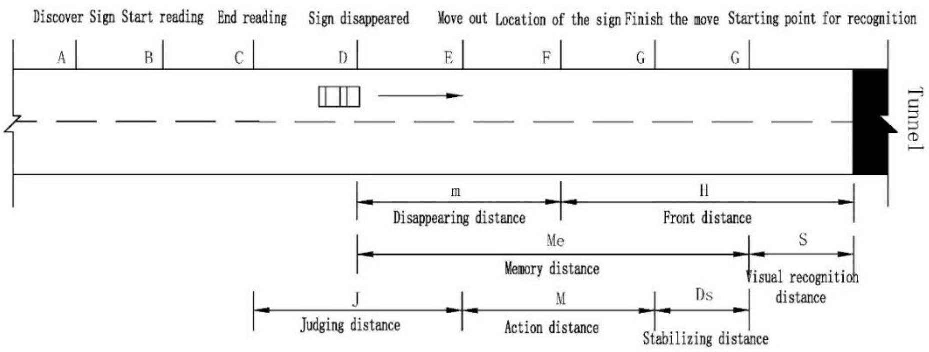

Figure 6 - Maximum front distance setting for speed limit signs

Based on the above process it can be seen that the speed limit sign front distance satisfies equation 14.

$$H = M_e + S - m \tag{14}$$

Signage disappearance distances are calculated in equation 15.

$$m = \frac{d}{\tan\theta} \tag{15}$$

In the formula: d - the driver's line of sight and the lateral distance from the roadside sign or the vertical distance from the gantry sign (m); θ - sign disappearing point and the roadside or gantry sign of the angle (°), for the roadside signs generally take 15 °, gantry signs generally take 7 °.

The memory segment distance M_e includes all or part of the judgment distance J, the action distance M, and the stabilization distance D_s, and the total time that the vehicle travels in segment M_e is a short-term memory time of 12 s. And,

$$J = v_1 t_2 \tag{16}$$

$$M = \frac{v_2^2 - v_1^2}{2a} \tag{17}$$

$$D_s = v_2 t_4 \tag{18}$$

Analysis shows that M is a fixed value, and $v_1 > v_2$, then when running at speed v_1 the longer the time, in a fixed short-term memory time M_e maximum, that is, the speed limit sign front distance is the largest, at this time J to take the full-length portion, that is, to take the limiting state, the driver in the sign before the disappearance of the signage just to read the sign information. Then the maximum front distance of the speed limit sign is calculated as equation 19.

$$H_{max} = M_{e\,max} + S - m = v_1 t_2 + \frac{v_2^2 - v_1^2}{2a} + v_2 t_4 + S - \frac{d}{\tan\theta} \tag{19}$$

In the formula: t_4 - the time (s) for the vehicle to maintain a constant speed.

From equation 19, the proposed value of the maximum front distance of the deceleration sign under different tunnel restriction speeds can be calculated, and the model for calculating the minimum distance between the speed limit sign and the tunnel exit can be lifted.

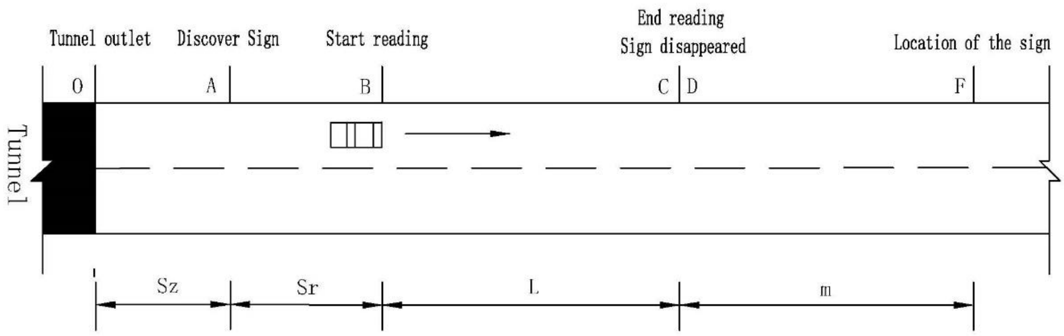

Figure 7 - Tunnel Outlet Speed Limit Sign Recognition Model

When the vehicle exits from the tunnel, the drastic difference in illumination inside and outside the tunnel is likely to cause visual obstacles to the driver for a sustained period of time, resulting in the driver's inability to accurately recognize the lifting of the speed limit sign, a phenomenon known as visual shock, during which the vehicle travels a distance known as the visual adaptation distance S_z. After the driver adapts to this phenomenon, he or she discovers the lifting of the speed limit sign at point A, and then begins to read the sign at point B, a distance known as the visual recognition reaction distance S_r. When the driver finishes reading, the speed limit lifting sign disappears in the driver's field of vision, i.e., the CD distance is zero, and the distance between the speed limit lifting sign and the exit of the tunnel at this time is the minimum setup distance, as shown in Figure 7. Then the distance H_0 between the tunnel exit and the lifting speed limit sign is:

$$H_0 = S_z + S_r + L + m \tag{20}$$

In the formula: S_z - visual adaptation distance (m); S_r- visual recognition reaction distance (m); L - sign recognition distance (m); m - sign disappearance distance (m)

Since the change in vehicle acceleration within a certain distance from the tunnel exit is generally less than 0.5m/s^2, the change in vehicle speed during visual adaptation and visual recognition reaction to the lifting of the speed limit sign and its recognition is ignored for the sake of simplicity of calculation, then:

$$S_z = v_3 t_5 \tag{21}$$

$$S_r = v_3 t_6 \tag{22}$$

In the formula: v_3--The traveling speed of the vehicle at the tunnel exit (m/s); t_5 - converted visual shock duration (s), according to the results of the visual shock experiment1.a)i.9, the design speed of 100km/h, 80km/h and 60km/h when the visual shock duration of 1.21s, 0.63s, 0.61s, respectively; t_6- sign visual recognition reaction time (s), taken as 0.2s.

Collating the above equations gives the minimum distance between the lifted speed limit sign and the tunnel exit:

$$H_0 = v_3(t_1 + t_5 + 0.2) + \frac{d}{\tan\theta} \tag{23}$$

From equation 23, the recommended minimum distance between the lifting speed limit sign and the tunnel exit can be calculated for different tunnel speed limits.

5. Conclusion

In this paper, through the investigation and analysis of the characteristics of traffic accidents and distribution characteristics of the tunnel section of mountain highways, combined with the characteristics of the road environment of the tunnel section, the traffic accidents in the tunnel section from the human-vehicle-road environment of the four aspects of the accident causation research, the use of the method of compositional analysis of the causes of accidents to provide theoretical support. On this basis, from the aspect of speed control technology, the research is suitable for mountain highway tunnel dense section of the safety measures, to provide theoretical guidance for the setting of speed limit signs in tunnel sections, and to provide technical support for the safe operation of China's mountain highways.

REFERENCES

1. Lemke, K. Road Safety in Tunnels / Transportation Research Record. – 2000. – No. 1740(1). – p. 170-174.

2. Ciro Caliendo, Maria Luisa De Guglielmo & Maurizio Guida. Comparison and analysis of road tunnel traffic accident frequencies and rates using random-parameter models / Journal of Transportation Safety & Security. – 2016. – No. 8:2. – p. 177-195.

3. Lorenzo Domenichini, Francesca La Torre, Dario Vangi, Antonio Virga & Valentina Branzi Influence of the lighting system on the driver's behavior in road tunnels: A driving simulator study / Journal of Transportation Safety & Security. – 2017. – No. 9:2. – p. 216-238.

4. Alessandro Calvi, Maria Rosaria De Blasiis, Claudia Guattari. An Empirical Study of the Effects of Road Tunnel on Driving Performance / Procedia - Social and Behavioral Sciences. – 2012. – No. 53. – p. 1098-1108.

5. Shen, Yanjun. Yang, Yang. Zou, Xiaolong. et al. Statistics on Traffic Accidents Occurred in Operating Highway Tunnels in China and Their Casualties Evaluation / Tunnel Construction. – 2018. – No. 38(04). – p. 564-574.

6. Lai, Jinxing. Zhang, Peng. Zhou Hui. et al. Study of Rules of Traffic Accidents in Expressway Tunnels / Tunnel Construction. –2017. – No. 37(1). – p. 37-42.

7. Hu, Yueqi. Study on Drivers' Mind Wandering, Mental Workload and Safety Risks in Highway Tunnles / Chang'an University. –2022.

8. Ni, Na. Research on Traffic Characteristics and Security Assurance Technologies of Tunnel Intensive Section in Mountainous Expressway / Chang'an University. –2017.
9. Du,Zhigang. Pan, Xiaodong. Yang, zhen. et al. Research on Visual Turbulence and Driving Safety of Freeway Tunnel Entrance and Exit / China Journal of Highway and Transport. –2007. – No. 20(5). – p. 101-105.

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STANDARDIZATION SYSTEM INTEGRATION OF ARCHITECTURAL DESIGN BASED ON DIGITAL METHODS

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This paper analyzes the standardization development path of prefabricated buildings in China and summarizes the new theories in the standardization development of prefabricated buildings in the new era—the definition and characteristics of the standardization system integration of architectural design based on digital methods. Through systematic digital design, industrial digital processing, on-site assembly construction, and intelligent informatization operation and maintenance, a technical path of high efficiency, high quality, low consumption, and low emission is formed throughout the entire lifecycle of the building. Finally, this paper introduces the system integration standardization strategy of prefabricated buildings adopted in the design and construction process of an actual case—the Asia Financial Tower project, which the author presided over. The application of full lifecycle BIM digital design, synchronized docking with factory processing, assembly construction, and intelligent operation and maintenance, has realized high-quality construction and efficient operation and management of the project. It is an innovative application of the integrated assembly building system, aiming to provide a Chinese case for enhancing the connotation of architectural standardization in the digital economy era.

Keywords: System integration standardization of architectural design, prefabricated building system, digital methods, upgrading of the construction industry