SEM Based Analysis and Application of Intelligent Technologies in China Construction Safety Management

JinSong Gao, Muhammad Noor Hisyam Bin Jusoh
Faculty of Engineering, Technology & Built Environment (FETBE), UCSI university, Kuala Lumpur 56000, Malaysia

Abstract: The frequent occurrence of construction safety incidents has had a significant negative impact on economic and social development, posing difficulties to the stability of China's economy and society. The research aims to comprehensively analyse the primary categories of significant construction safety accidents, applying as Structural equation modelling (SEM) model to identify the indicators that influence construction safety management. Five construction safety management influencing factors were identified, which are: supervision of building construction, management of construction equipment and protective facilities, construction culture, safety climate, and construction environment. After completing the model correction, the results show that the total effects of these five main factors: supervision of building construction, construction culture, construction environment, management of construction equipment and protective facilities, and construction safety climate on the level of construction safety management are 0.427, 0.48, 0.249, 0.225, and 0.058, respectively. These influencing factors will directly or indirectly have a positive effect on the level of safety management of building construction, and the final result of the building construction safety management depends on the joint effect of these main influencing factors. Improvement solutions is proposed by incorporating intelligent technologies to address safety issues in the construction industry.

Keywords: Influence factor analysis; Safety management; SEM analysis; Building construction; Structural Equation Modelling

1. Introduction

In the early stage of construction safety management, most experts and scholars believe that construction safety management only requires effective coordination and control of factors such as construction progress, cost and construction quality [1]. However, as the problems of construction safety management have become more and more prominent, the research on the influencing factors of construction safety management has also received an increasing amount of attention, and the current research related to the influencing factors of construction safety management by experts in the construction industry mostly focuses on the identification of sources of hazards, the assessment of risks, and the improvement of the safety management as the main content.

In construction safety accidents, the construction company has economic losses, damage to equipment and facilities, endanger the safety of life and other accidents, resulting in the suspension of the original construction activities or the permanent termination of the construction activities.

Because construction safety accidents are not triggered by a single factor. Among many factors, one factor may be the cause of another called multi-causal correlation of accident generation. Additionally, the time of occurrence of accidents as well as the final results present randomness[2]. By fully understanding the causes of the occurrence of construction safety construction, it can be easily found that all types of accidents follow a certain rules of randomness in terms of the time of occurrence and its space, the indicators with management commonality were merged, and five construction safety management influencing factors were identified, which are: supervision of building construction, management of construction equipment and protective facilities, construction culture, safety climate, and construction environment.

2. Materials and Methods

2.1 Area of Studying

This survey was conducted in September 2023, accessing relevant personnel from construction projects within Shanxi, China through electronic questionnaires. The surveyed individuals belong to various positions such as management, engineering, construction, support, and design & planning across these projects.

2.1.1 Determine the Hypothesis Based on Factors

To prove that the safety management factors have a certain relationship and influence each other. It is important to investigate not only how each factor affects the overall level of safety management in building construction, but also whether there is a correlation between the different factors and their interplay [3], as these factors will affect one another and, by extension, on the level of safety management throughout the entire project [4]. In light of this, the following hypotheses are derived from a review of the literature on the subject of the components' interrelationships:

Hypothesis1: "Building construction supervision has a positive and significant effect on building construction safety management".

Hypothesis2: "Construction supervision has a positive and significant impact on the management of construction facilities and protective equipment”.

Hypothesis3: "The management of construction facilities and protective equipment has a positive and significant impact on construction safety management".

Hypothesis4: "Construction culture has a positive and significant effect on construction safety management".

Hypothesis5: "Construction culture has a positive and significant impact on the management of construction facilities and protective equipment".

Hypothesis6: "Construction culture has a positive and significant effect on construction safety climate".

Hypothesis7: "Construction safety climate has a positive and significant effect on construction safety management".

Hypothesis8: "Construction safety climate has a positive and significant impact on the construction environment"

Hypothesis9: "The construction environment has a positive and significant impact on construction safety management".

Hypothesis10: "Construction supervision has a positive and significant effect on the construction environment".

2.2 Structural equation modelling (SEM)

Structural equation modelling (SEM) is a prevalent methodology utilized in case study research, encompassing both structural modelling and measurement modelling components [5]. The utilization of structural modelling facilitates the comprehension of causal connections among variables, enables hypothesis testing, facilitates the prediction of phenomena, and provides guidance for decision-making to researchers. Structural Equation Modelling (SEM) is generally used to investigate the relationship between latent variables, which are classified as external latent variables or internal latent variables based on their causal connection. The following are the fundamental expressions:

(1). Measurement modelling

$$\begin{cases} x = \Lambda_x \xi + \delta \\ y = \Lambda_y \eta + \varepsilon \end{cases} \tag{1}$$

Where:

x and y are observed variables;

Λx is the relationship between explicit exogenous variables and exogenous latent variables;

Λy is the relationship between explicit endogenous variables and endogenous latent variables;

ξ is the endogenous latent variable;

η is the exogenous latent variable;

δ is the error term of the exogenous manifest variable;

ε is the error term of the endogenous manifest variable.

(2). Structural modelling

$$\eta = \beta\eta + \Gamma\xi + \zeta \tag{2}$$

Where:

η is the endogenous latent variable;

β is the relationship between intrinsic latent variables;

ξ is the exogenous latent variables;

Γ is the effect of extrinsic latent variables on intrinsic latent variables;

ζ is the error term, indicating the unaccounted influence or randomness in the model.

2.2.1 Path Diagram

The main influencing factors affecting the level of building construction safety management-latent variables and their specific indicators-observed variables were refined. From a more macroscopic perspective, the factors of building construction safety management contain three observed variables, which are policy system, project risk assessment, and safety technology innovation. All observational variables are numbered with the abbreviated names of the corresponding latent variables and are presented in a tabular form in Table 1.

Table 1: Variables Affecting Building Construction Safety.

Latent Factors	Observed Factors
Supervision of building construction (SBC)	(SBC1). Safety performance evaluation; (SBC2). Construction site supervision and guidance; (SBC3). Management Competency System; (SBC4). Construction material quality inspection; (SBC5). Construction equipment inspection.

Management of construction equipment and protective facilities (MCE)	(MCE1). Facilities allocation; (MCE2). Safety markings for on-site construction; (MCE3). Safety program for on-site construction; (MCE4). Specification of equipment utilization; (MCE5). Reliability of protective devices and equipment.
Construction Culture (CC)	(CC1). Employee Participation; (CC2). Employee Education and Training; (CC3). Leadership; (CC4). Safety Management System; (CC5). Continuous Improvement.
Construction environment (CE)	(CE1). Employee work pressure; (CE2). Project danger levels; (CE3). Environmental conditions at the construction site; (CE4). Safety conditions at the construction site; (CE5). Employee safety awareness.
Construction Safety Climate (CSC)	(CSC1). Project team's safety attitude; (CSC2). Reward and punishment program; (CSC3). Employee communication and feedback; (CSC4). Employee behaviour for safe construction; (CSC5). Insurance for employee safety.
Safety management in building construction (SMB)	(SMB1). Policies and regulations; (SMB2). Project Risk Assessment; (SMB3). Safety technologies and innovations.

Based on the above research assumptions and structural equation modelling rules, it constructs a hypothetical structural equation model of the factors influencing safety management in building construction using AMOS24.0 software, and Fig 1. shows the model description by a path diagram to clarify the relationship of the variables.

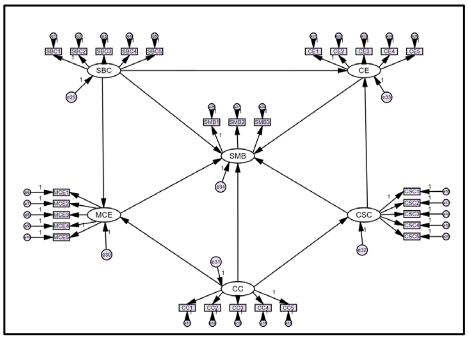

Figure 1: Path Diagram.

3. Results

3.1 Descriptive Analysis

A total of 120 survey questionnaires were distributed, and after excluding invalid responses, 114 valid responses were obtained, resulting in an impressive response rate of 95.0%. Considering the descriptive statistical results formed in conjunction with Table 2, this survey employed the Likert 5-point scale method, with minimum and maximum values for the survey sample being 1 and 5, respectively. The average statistical result for each observed variable ranged between 2 and 3. This indicates that the surveyed individuals perceive the impact of most observed variables on construction safety to be relatively significant. The maximum absolute skewness value obtained was 0.685, and the maximum absolute kurtosis value was 1.084, both falling within the ideal range of -1.960 to +1.960. Therefore, the data collected from the questionnaire aligns with the requirements of normal distribution, allowing for further research.

Table 2: Sample Descriptive Statistical Analysis.

Observed Variable	Mean	Median	Mode	Std. Deviation	Variance	Skewness	Kurtosis
SBC1	2.56	2.50	2	0.950	0.903	0.230	-0.423
SBC2	2.38	2.00	2	0.963	0.927	0.568	0.091
SBC3	2.54	2.50	2	0.923	0.853	0.239	-0.239
SBC4	2.54	2.00	2	1.032	1.065	0.199	-0.771
SBC5	2.61	3.00	3	1.078	1.161	-0.062	-0.770
MCE1	2.59	2.00	2	0.994	0.988	0.413	-0.287
MCE2	2.54	2.00	2	0.951	0.905	0.217	-0.674
MCE3	2.32	2.00	2	1.035	1.071	0.433	-0.557
MCE4	2.53	3.00	3	1.015	1.030	0.289	-0.276
MCE5	2.64	3.00	2	1.161	1.347	0.119	-1.084
CC1	2.68	3.00	2	1.025	1.050	0.268	-0.420
CC2	2.52	2.00	2	1.033	1.066	0.394	-0.573
CC3	2.57	2.00	2	1.197	1.433	0.351	-0.761
CC4	2.55	2.00	2	1.065	1.134	0.173	-0.919
CC5	2.60	2.00	2	1.142	1.305	0.411	-0.666
CE1	2.52	2.50	3	1.041	1.084	0.216	-0.602
CE2	2.53	2.00	2	1.099	1.207	0.258	-0.875
CE3	2.77	3.00	3	1.081	1.169	0.169	-0.553
CE4	2.68	3.00	3	1.075	1.156	0.140	-0.629
CE5	2.36	2.00	2	1.049	1.100	0.685	-0.128
CSC1	2.42	2.00	2	1.063	1.131	0.390	-0.419
CSC2	2.73	3.00	2	1.170	1.368	0.346	-0.724
CSC3	2.58	3.00	2	0.977	0.954	0.180	-0.567
CSC4	2.68	2.00	2	0.971	0.944	0.379	-0.631
CSC5	2.54	2.00	2	1.184	1.401	0.290	-0.974
SMB1	2.71	3.00	2	1.079	1.163	0.086	-0.820
SMB2	2.52	2.00	2	1.083	1.172	0.252	-0.797
SMB3	2.57	3.00	3	1.121	1.256	0.224	-0.727

3.2 Confirmatory Factor Analysis

Table 3. presents the results of Bartlett's test of sphericity for the questionnaire survey, yielding Bartlett's $\chi 2$=2192.333, p<0.001, indicating the presence of common factors in the variables of the questionnaire. By analysing the correlation matrix, the calculated KMO result is 0.842, indicating suitability for conducting factor analysis.

Table 3: Questionnaire KMO and Bartlett's Test.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.842
Bartlett's Test of Sphericity	Approx. Chi-Square	2192.333
	df	378
	Sig. (p)	0.000

In statistics, to better analyses and assess the collected questionnaire data, reliability analysis is employed to measure the level of consistency present in the results obtained from the scales [6]. As shown in Table 4 the number of observed variables contained in the 6 latent variables and the reliability of these corresponding latent variables are 0.778, 0.893, 0.854, 0.936, 0.887, and 0.872, indicating good reliability of the questionnaire and meeting the needs of the outcomes.

Table 4: Reliability Analysis of Survey Results.

Latent Variables	No. of Items	Cronbach's Alpha
Supervision of building construction (SBC)	5	0.778
Management of construction equipment and protective facilities (MCE)	5	0.893
Construction Culture (CC)	5	0.854
Construction environment (CE)	5	0.936
Construction Safety Climate (CSC)	5	0.887
Safety management in building construction (SMB)	3	0.872

3.3 Validity Testing

From Table 5, it can be observed that the $\chi 2$ /df value is 1.472, RMSEA is 0.065, NFI is 0.792, CFI is 0.922, TLI is 0.912, and IFI is 0.924. All these values meet the corresponding criteria for model fit, indicating that the structural validity of the confirmatory factor analysis model is satisfactory.

Table 5: Goodness-of-fit Indices of the Confirmatory Factor Analysis Model.

Fitness index	$\chi 2$	df	$\chi 2$ /df	RMSEA	NFI	CFI	TLI	IFI
Criteria			<3.00	<0.08				
SEM	493.128	335	1.472	0.065	0.792	0.922	0.912	0.924

The results shown in Table 6 show that all six variables have factor loadings greater than 0.5.

Excluding from SBC, all of the other latent variables consistently have CR values greater than 0.7, and the AVE values are consistently greater than 0.5. There is a possibility that the lower CR value for SBC can be linked to problems that are associated with the sample size or quality. There is also the possibility that the model does not effectively capture the predicted latent variable structure, which ultimately results in lower internal consistency. Estimates of factor loading should have an absolute value of at least 0.5, AVE values should be greater than 0.5, and composite reliability values should be greater than 0.7, each of which is according to the recommendations made by Hair (1998) and other individuals for validity assessment [7]. The chosen measurement tool has shown strong reliability and validity in prior assessments, and it is well-acknowledged in the relevant literature. This is even though the CR value for SBC is considered to be lower. Additionally, in subsequent research, a bigger sample size will be incorporated to improve the consistency and dependability of the model parameters.

Table 6: Statistics on the Estimated Values of Each Parameter of the Model.

Latent Variables	Objective Variable	Variables Loading	CR	AVE
Supervision of building construction (SBC)	SBC1	0.603	0.68	0.7765
	SBC2	0.615		
	SBC3	0.614		
	SBC4	0.652		
	SBC5	0.715		
Management of construction equipment and protective facilities (MCE)	MCE1	0.757	0.70	0.9044
	MCE2	0.935		
	MCE3	0.669		
	MCE4	0.962		
	MCE5	0.691		
Construction Culture (CC)	CC1	0.655	0.70	0.8571
	CC2	0.787		
	CC3	0.713		
	CC4	0.808		
	CC5	0.724		
Construction environment (CE)	CE1	0.771	0.70	0.9364
	CE2	0.857		
	CE3	0.948		
	CE4	0.931		
	CE5	0.803		
Construction Safety Climate (CSC)	CSC1	0.82	0.70	0.8919
	CSC2	0.746		
	CSC3	0.854		
	CSC4	0.827		
	CSC5	0.691		
Safety management in building construction (SMB)	SMB1	0.834	0.70	0.8724
	SMB2	0.834		
	SMB3	0.833		

3.4 Model Revision

Based on the principle of model revision in SEM, it is necessary to remove non-significant paths, obtain the revised structural equation model, and estimate the revised model after re-importing the sample data. The resulting SEM standardized path coefficient diagram after revision is shown in Fig 2.

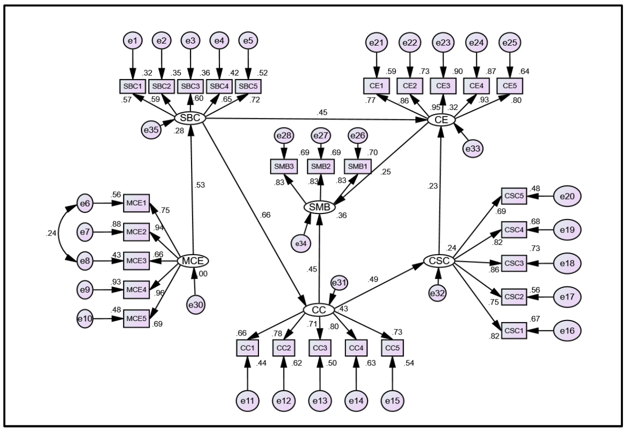

Figure 2: Fit in SEM.

Table 7: Modified Model Path Coefficients.

			Standardized coefficient	S.E.	C.R.	P
SBC	→	CC	0.883	0.197	4.472	***
CC	→	CSC	0.562	0.125	4.507	***
SBC	→	CE	0.672	0.187	3.6	***
CSC	→	CE	0.229	0.095	2.401	0.017
CC	→	SMB	0.554	0.138	4.013	***
MCE	→	SBC	0.779	0.197	3.956	***
CE	→	SMB	0.273	0.11	2.485	0.017

Table 7 displays the path coefficients of the modified model. Through the analysis of various paths in the structural equation model, it is evident that SBC has a positive and highly significant effect on CC, CC on CSC, SBC on CE, CC on SMB, MCE on SBC, and CE on SMB (all with p-values < 0.001), effectively confirming the hypothesis of significant positive relationships between these latent variables. While the path coefficient from CSC to CE is significant, it is relatively weak at 0.229, indicating a comparatively smaller impact. The path coefficient from CE to SMB is 0.273, significant but relatively weak. Notably, the path coefficients from SBC to CC (0.883), CC to CSC (0.562), MCE to SBC (0.779), SBC to CE (0.672), and CC to SMB (0.554) demonstrate strong influence, further supporting the hypothesis of complex relationships among these latent variables.

3.5 Explanation of Effects

For each path in the structural equation model that was applied to SMB, Table 8 presents the overall effects and results of the significance test. Latent variables SMB, SBC, CC, CE, MCE, and CSC were shown to have statistically significant positive effects according to the structural equation model analysis. This is proven by the fact that the p-values are less than 0.05 and the overall effects are positive. Based on this, we may conclude that SMB is significantly affected by latent variables in the model.

Table 8: Total Effects of Latent Variables on Construction Safety Management.

Path	Standardized coefficient	Confidence interval		P value
		Up bound	Lower bound	
SBC to SMB	0.427	1.347	0.353	0.001
CC to SMB	0.48	0.948	0.301	0.001
CE to SMB	0.249	0.582	-0.04	0.044
MCE to SMB	0.225	0.434	0.097	0.001
CSC to SMB	0.058	0.191	0.01	0.001

4. Discussion

According to the modified structural equation model, the direct effect, indirect effect, and combined total effect among the latent variables indicate that the five latent variables, SBC, CC, CE, MCE, and CSC, have a significant positive effect on SMB, as indicated by the positive total effect and p-value of less than 0.05. Among them, SBC, MCE, CC, CE and CSC on construction safety management are 0.427; 0.48; 0.249; 0.225; and 0.058, respectively.

In the current stage of building construction safety management mode, how to improve each building construction safety management influencing factors will be the main way to improve safety performance. Five key factors were derived from the data analysis, including building construction supervision, construction equipment and protective facilities management, construction culture, construction environment and construction safety atmosphere.

Improvement in building construction supervision requires a synergistic feedback mechanism between the government, construction industry associations, supervisors and construction organizations, including efficient on-site supervision and guidance, a sound management competency system, inspection of construction materials, and regular inspection of construction equipment. Improvements to the management of construction equipment and protective facilities emphasize clear safety markings and standardized equipment use, through which the risk of equipment operation can be reduced to ensure that the equipment operates within its normal operating range. In addition, improvements to the construction culture include the establishment of a robust management competency system, which improves the organization's execution and productivity by clarifying responsibilities, optimizing processes, and increasing overall efficiency. Attention to the construction environment includes inspection and management to ensure that the construction site is clean and organized and that employees' work stress, project hazard levels, and environmental conditions are taken into account. Finally, improving the construction safety climate requires active employee participation, comprehensive employee education and training, strong leadership, a well-implemented safety management system, and continuous improvement efforts. Together, these factors form an important part of construction safety management in China.

A system for managing construction safety has been created to better address control requirements that traditional management models cannot achieve. Taking into account the need for controlling elements that impact construction safety management as well as the features of intelligent technologies like the Internet of Things (IoT). The structure of this management system comprises five hierarchical levels: the perception layer, device layer, communication layer, application layer, and execution layer. The specific system model is illustrated in Fig 3.

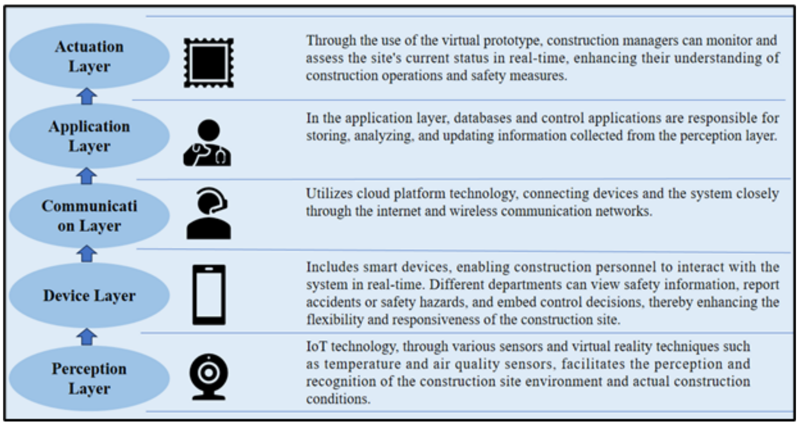

Figure 3: Intelligent Building Construction Safety Management System.

5. Conclusions

From practical construction and system management perspectives, this research shows how to improve the control status and issues of these significant influencing factors. To meet these control requirements, the necessity of introducing intelligent technologies such as the Internet of Things (IoT), cloud platforms, and visualization is elucidated by addressing current safety management practice issues. Following the analysis of the influencing factor control requirements and the necessity of introducing intelligent technologies, a construction safety management system was consequently designed to enhance the ability of construction personnel to identify and respond to potential risks.

References

[1] Tam, C. M., Zeng, S. X., & Deng, Z. M. (2004). Identifying elements of poor construction safety management in China. Safety Science, 42(7), 569–586. https://doi.org/10.1016/j.ssci.2003.09.001

[2] Wan, P., Wang, J., Liu, Y., Lu, Q., & Yuan, C. (2022). On risk probability of prefabricated building hoisting construction based on multiple correlations. Sustainability, 14(8), 4430. https://doi.org/10.3390/su14084430

[3] Wang L, Cheng Y (2022), "Exploring a comprehensive knowledge map for promoting safety management research in the construction industry". Engineering, Construction and Architectural Management, Vol. 29 No. 4 pp. 1678–1714, doi: https://doi.org/10.1108/ECAM-11-2020-0984

[4] Wu Mingxi. Study on WD Petrochemical Company Safety Management Improvement. Academic Journal of Engineering and Technology Science (2021) Vol. 4, Issue 9: 16-28. https://doi.org/10.25236/AJETS.2021.040904.

[5] Chinda, T., & Mohamed, S. (2008). Structural equation model of construction safety culture. Engineering, Construction and Architectural Management, 15(2), 114–131.https://doi.org/10.1108/09699980810852655

[6] Bonett, D. G., & Wright, T. A. (2015). Cronbach's alpha reliability: Interval estimation, hypothesis testing, and sample size planning. Journal of Organizational Behavior, 36(1), 3-15. doi: https://doi.org/10.1002/job.1960

[7] Hair, J.F, R.E. Anderson, R.L. Tatham. Multivariate data analysis (5th ed): Prentice Hall College Div,1998.