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Influencing Factors of Human Errors in Metro Construction Based on Structural Equation Modeling (SEM)

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Abstract: Safety problems in metro construction occur frequently, causing substantial economic losses and even resulting in injuries and fatalities. Studies have shown that human errors, which are usually caused by complex reasons, are an important cause of safety related accidents. However, little research has analyzed the causes of accidents from the perspective of human errors. To explore the factors influencing human errors, the factors were systematically sorted out and studied based on theoretical analysis. Firstly, the theoretical hypothesis and model were formulated through a literature review. Secondly, the scale was developed for mental factors, physical factors, technical factors, environmental factors, organizational factors, cultural factors, and human errors. Thirdly, the research data were obtained by distributing questionnaires, and the validity and reliability tests were conducted using the data and the structural equation model was tested and run. Finally, the theoretical hypotheses were tested using the structural equation models and came up with the paths of the six factors of human errors. The results of the study showed that mental factors, physiological factors, and technological factors are found to be the direct influencing factors of human errors. However, environmental and cultural factors are the indirect influencing factors. The influencing paths are environment-mental-human errors, environment-physiological-human errors, culture-physiological-human errors, and culture-technology-human errors. Organizational factors can affect human errors directly or indirectly through cultural factors. These findings could provide practical implications for reducing the safety related accidents caused by human errors during metro construction.

Keywords: human errors; metro construction; SEM; influencing factors

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1. Introduction

With the continuous development of urbanization in China, the number of metro projects being built is increasing. However, due to the characteristics of complex metro construction procedures, hidden engineering, long construction period, and difficult equipment operation, safety accidents occur frequently [1]. According to Yu et al., a total of 246 subway construction accidents occurred in China during 2002–2018, of which collapse was the most frequent type of accident, with 111 accidents, accounting for 45.12% [2]. However, ALBERT et al. found that more than 55% of the hazards in the construction environment are usually not directly identified [3]. This is due to the complexity of the factors that cause construction accidents, involving human factors, management factors, environmental factors, equipment factors, etc. [4]. Among all these causes, human errors were found to be the main cause of various accidents on construction sites [5]. Heindrich concluded that up to 88% of accidents occurred due to human errors by analyzing the statistics of 75,000 safety accidents [6]. The researcher Reason believed that accidents occur as a result of cumulative organizational and human errors [7].

Previous studies on safety risk evaluation have rarely addressed the causes of unsafe human behavior in depth, e.g., Yoo and Kim established a web-based construction damage assessment system based on tunnel engineering [8], and later Yoo et al. developed an IT-based metro risk management system to identify, assess and manage potential engineering risks [9]. Martins et al. identified causes of accidents by establishing a database of aviation accidents with the help of computer technology and concluded that the degree of individual awareness of behavior is the main cause of accidents [10]. Goh and Chua identified safety in the construction process of buildings based on the analysis of a large number of case risk factors in the construction of buildings and establish an early warning indicator system [11]. Again, Rajendran and Gambatese used the Delphi method to establish an early warning indicator system for sustainable construction safety and health rating system and identified 13 categories and 50 influencing factors [12]. Most of these studies focus on technical management, early warning management, and safety evaluation systems but ignored the causes of unsafe human behavior.

Among the studies related to human errors, Reason classified human errors into behavioral, situational, and conceptual levels, which corresponded to what human errors are, where human errors occur, and how human errors occur [7]. However, Rasmussen and Jensen classified human errors into three types, including skill-based, rule-based, and knowledge-based [13]. Senders and Moray analyzed the differences between "mistakes", "errors" and "accidents" according to the characteristics of human errors [14]. Fargnoli and Lombardi argue that most human errors are action and retrieval errors, emphasizing the importance of theoretical and practical training programs to improve safety behaviors [15]. Yong et al. found that human error factors and organizational defects were the main causes of accidents in a nuclear power plant in Korea and used core injury frequencies to rank the importance of human error factors and organizational defects, respectively [16].

However, although many scholars have conducted many studies on human errors, in the field of metro construction, there is a lack of systematic sorting of the influencing factors of human error and path analysis of various influencing factors on the impact of human error.

Therefore, in order to address the shortcomings of previous studies, this study aims to identify which factors influence human errors in the metro construction process and how these factors influence human errors. This paper systematically investigates the factors influencing human errors in the metro construction process through a literature review and structural equation modeling to identify the factors and paths of human errors.

2. Literature Review

Through a review of the literature, it was found in the studies of different scholars that there are many human factors influencing errors.

In terms of mental factors, Bhandari et al. found that different emotional states of construction workers can have an impact on their hazard recognition skills [17]. Cable and Edwards found nine main mental factors that cause human errors, which are: paralysis, fluke, shortcut, forced, getaway, bravado psychology, panic psychology, and rebellious psychology errors [18]. Ajzen found in a theory of planned behavior study that emotional attitudes, subjective norms, and intuitive behavior can directly influence human behavior [19].

In terms of physiological factors, Yang et al. found that during the formation process of unsafe behaviors of construction workers, the human tactile organs receive information, the information is first be transmitted to the brain, and then in the transmission to the motor organs occurs, finally making the corresponding behavioral response [20]. Wang et al. found through the study that the more focused workers' attention can reduce the occurrence of human errors [21]. Powell and Copping found that construction workers with too little sleep can trigger fatigue, and they are more likely to have safety accidents when they are fatigued in carrying out operations [22].

In terms of technical factors, Vinodkumar et al. found through a study that safety knowledge plays an important role in safety management and safety behavior [23]. Chen and Chen added that pilots' self-efficacy was positively related to safety behavior [24]. Moreover, Shin found that the skill level of workers directly affects safety [25]. Accordingly, Rundmo argued that the degree to which employees perceive safety can influence their perceptions and judgments of risk [26].

In terms of environmental factors, Roberts et al. concluded that lighting, noise, and temperature are the significant factors in underground environments [27]. A study by Wu et al. concluded that underground enclosed environments have adverse factors, such as temperature, humidity, noise, pressure, toxic gases, dust, etc., which can have an impact on the behavior of people in this environment [28]. John et al. argue that noise can cause construction workers hearing loss, and the longer the working hours, the greater the risk of hearing loss and the greater the risk of safety accidents [29].

In terms of organizational factors, Zohar and Erev argued that workers' safety behaviors are largely influenced by the organization's supervision and incentive system [30]. Additionally, Thanet et al. argued that the lower the organizational support construction workers receive, the more likely they are to engage in unsafe behaviors during construction operations [31]. Mullen found that managers' safety leadership positively influenced workers' safety behaviors [32].

In terms of cultural factors, Cooper divided safety culture into mental, behavioral, and situational elements, so there should be different forms of promotion of safety culture [33]. Colley et al., however, argued that organizational values can have a significant impact on individuals' safety perceptions [34]. Dukerich et al. found through their study that individuals who identify themselves with the organization are likely to behave positively [35]. Evia argued that good communication helps to increase the safety awareness of construction personnel, which in turn produces safe behaviors [36].

From the above, it can be concluded that although there have been many results on human errors, there is indeed a lack of in-depth studies on it in the field of metro construction. Accordingly, this paper systematically studies human error in metro construction from the perspective of multiple factors.

Through a literature review, 23 factors influencing human error were identified. These 23 factors influencing human error were then classified by inviting five university professors and five experts in metro construction projects to conduct interviews. Among them, the professors' research must be about safety management and the experts' positions must be leaders with more than 10 years of experience in the functional departments of metro construction projects. After the first round of discussions, 20 factors were successfully classified. Three factors were controversial: self-efficacy, safety perception, and organizational values, so they were not classified for the time being. Later, after three rounds of discussion, experts suggested that self-efficacy and safety perception should be classified as individual technical factors because of the characteristic, which could be developed through appropriate training [37]. And, organizational values should be classified in organizational factors because of their consistency and similarity of organizational characteristics. The factors influencing human error were finally classified into six categories, namely mental, physical, technical, environmental, organizational, and cultural factors, as shown in Table 1.

Table 1. Identification and classification of human error factors.

Category	Factor	Source	Code
Mental Factors	Emotional Attitude Subjective Norms Intuitive Behavior	Bhandari et al. [17], Ajzen [19] Daniel et al. [18], Ajzen [19] Ajzen [19]	MF
Physiological Factors	Visual Auditory Attention Fatigue	Yang et al. [20] Wang et al. [21] Powell and Copping [22]	PF
Technical Factors	Knowledge Level Self-efficacy Skill Level Safety Perception	Vinodkumar et al. [23] Chen and Chen [24] Shin [25] Rundmo [26]	TF
Environmental Factors	Temperature Humidity Lighting Noise Dust	Roberts et al. [27], Wu [28], John et al. [29]	EF
Organizational Factors	Safety System Organizational Support Safety Leadership	Zohar and Erev [30] Thanet et al. [31] Mullen [32]	OF
Cultural Factors	Promotion Form Organizational Values Organizational Identity Communication	Cooper [33] Colley et al. [34] Dukerich et al. [35] Evia [36]	CF

3. Hypothesis

Leung et al. used factor analysis to conclude that mental factors such as emotional stress of construction workers can have an impact on the occurrence of construction safety accidents [38]. Ju et al. also concluded that construction workers who were emotionally exhausted were more prone to human errors by conducting a survey and study of 592 construction workers [39]. He et al., however, concluded that the mental state of construction workers was negatively associated with unsafe behaviors [40]. Therefore, the hypothesis was formulated as:

Hypothesis 1 (H1). *A good personal mental state has a direct positive impact on reducing human errors.*

Abdelhamid found through a study that the application of physiology to work in the construction industry can improve the occupational safety of construction workers [41]. When a person performs work while in a state of fatigue, it increases the likelihood of occupational accidents, and some studies have shown that fatigue can be subdivided into physical and mental fatigue [42]. Kang et al., through a study of manufacturing workers, concluded that the physiological condition of workers does not match the job requirements and can easily lead to human errors [43]. Therefore, the hypotheses were formulated as:

Hypothesis 2a (H2a). *Good personal physiology has a direct positive effect on reducing human errors;*

Hypothesis 2b (H2b). *A good physiological condition has an indirect positive effect on reducing human errors by influencing the mental state.*

According to Inoue et al., workers' lack of ability to perceive safety can make them more prone to safety accidents [44]. Garrett et al. argued that construction workers' incorrect perception of knowledge and skills can lead to failure in the quality and safety of construction projects [45]. Shin found that in the tower crane installation and dismantling process, the skill level of the installation and dismantling workers can cause a significant impact on safety [25]. Therefore, the hypothesis was formulated as:

Hypothesis 3 (H3). *A high level of personal skill has a direct positive impact on reducing human errors.*

A study by Leung et al. found that a poor working environment causes stress among construction workers and the higher the stress the more likely dangerous situations are to occur [38]. Liu et al. argued that improving the working environment can be beneficial in reducing human errors of construction workers [46]. Li et al. added that an unfavorable working environment can put construction workers' health at risk, which in turn leads to human errors [47]. However, Yeow et al. found that a good working environment is necessary to reduce human errors [48]. Therefore, the hypotheses were formulated as:

Hypothesis 4a (H4a). *A good work environment has a direct positive effect on reducing human errors;*

Hypothesis 4b (H4b). *A good work environment has an indirect positive effect on the reduction of human errors by influencing mental state;*

Hypothesis 4c (H4c). *A good working environment has a positive impact on reducing human errors indirectly by affecting the physiological state.*

Garrett et al. also argued that problems in organizations can lead to incidents of failures and even accidents [45]. Robson believes that the education and training of workers by organizations can increase their knowledge level, which in turn has a positive effect on their occupational health and safety [49]. Mullen, however, argued that managers can have an individual's perceptions of the safety culture with a direct impact [32]. Therefore, the formulated hypotheses are that:

Hypothesis 5a (H5a). *Reasonable organizational management has a direct positive effect on reducing human errors;*

Hypothesis 5b (H5b). *Reasonable organizational management has an indirect positive effect on the reduction of human errors by influencing technical level;*

Hypothesis 5c (H5c). *Reasonable organizational management has a positive impact on reducing human errors indirectly by influencing culture.*

A good organizational culture enables people to be physically and mentally healthy and safe and to be able to perform their work comfortably and efficiently [50]. In a study by Neal et al., it was found that organizational culture affects the technical level of employees [51]. Therefore, the following hypotheses were formulated.

Hypothesis 6a (H6a). *A good organizational culture has a direct positive impact on reducing human errors;*

Hypothesis 6b (H6b). *A good organizational culture has an indirect effect on the reduction of human errors by influencing the mental condition of people;*

Hypothesis 6c (H6c). *A good organizational culture has an indirect effect on reducing human errors by influencing the physiological condition of people;*

Hypothesis 6d (H6d). *A good organizational culture has an indirect effect on the reduction of human errors through influencing individual technical level.*

A preliminary relationship model was developed based on the hypothesis, as shown in Figure 1.

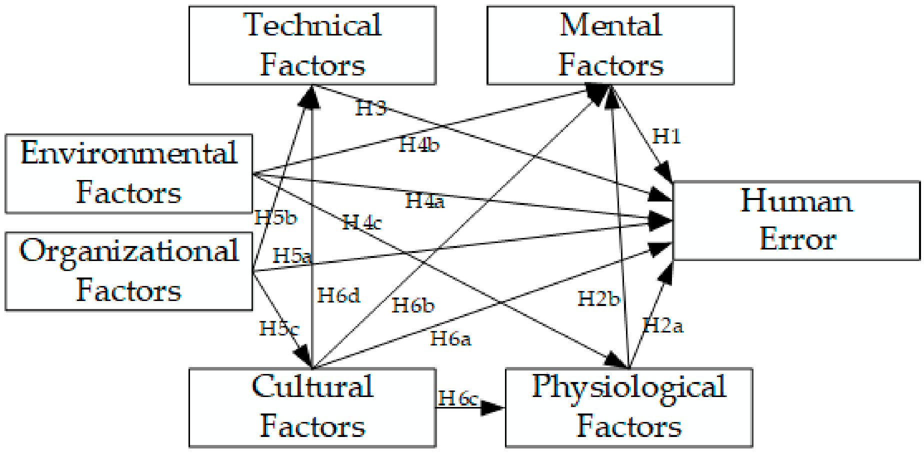

Figure 1. Schematic diagram of the model.

4. Methodology

4.1. Questionnaire Design

The questionnaire is divided into three parts: The first part provides general information about the aim of the research and the questionnaire, so that respondents can quickly appreciate the purpose and use of the questionnaire to improve participation and response rate; the second part is to collect respondents' personal information, including age, education level, length of service, type of job and type of work unit; and the third part is the measurement questions, which are scored using a five-point Likert scale.

The design of the mental factors scale is based on the theory of planned behavior by Ajzen [19], with reference to the Positive and Negative Affect Scale developed by Watson et al. [52], which gives the question of affective attitudes. "In metro construction, a happy mood is conducive to smooth work and increased work efficiency". Referring to Fogarty and Shaw's study on predicting unsafe behaviors, two scales of personal attitudes and intentions toward violations were designed [53], which gave the questions on subjective norms and intuitive behaviors as "The presence of luck in construction increases the probability of personal operational errors" and "In the process of construction, the eagerness to complete tasks makes it easy to make oversights".

The physiological factors scale was designed with reference to the Checklist Individual Strength [54], and the following questions were given for visual, auditory, attention, and fatigue: "When working underground, you are prone to deviations in your work if the light is dim", "In a noisy construction environment in the city center, you are prone to errors when transmitting information to and from colleagues", "When transmitting and receiving information asymmetrically during construction, you feel that this is due to lack of concentration" and "Due to lack of sleep or high intensity of work, you do not pay enough attention to passers-by or oncoming traffic".

The self-efficacy questions of the technology factors scale refer to Zhang and Schwarzer's General Self-Efficacy Scale and set the question as "You know exactly what aspects of your work are safety hazards, so you can avoid accidents very well" [55]. The question on safety perception refers to Eysenck and Eysenck's Impulsiveness and Venturesomeness Questionnaire, and ask the question "During construction, you often underestimate the risk of events based on existing phenomena" [56]. Rasmussen and Jensen identified human errors as skill-based and rule-based knowledge-based [13], so the scale refers to this finding by giving the questions "In the construction of metros, you feel that construction experience is more important than education" and "The stronger the technical ability at work, the lower the probability of errors".

Environmental factors can be measured more intuitively, combining relevant studies by Roberts et al. [27], Wu et al. [28], asking the questions "When working in hot weather, you would choose a convenient way to complete your work, even if there are certain unsafe factors", "It is easy to feel fatigued when you are in a humid environment for a long time", "You are more likely to be injured when working at night than during the day", "The strong noise will have a great disturbance to your work, easy to make mistakes in judgment" and "if in the dusty environment, it will be easy to ignore the safety issues, resulting in many unnecessary work errors.

The questions on the organizational factor scale refer to the safety management section of the safety climate scale designed by Liu et al. [57], and the questions "If you commit an unsafe act, you will be punished if you are found by the project manager or safety manager", "You are familiar with the safety rules and construction essentials to avoid many mistakes", and "If safety management measures are not in place, you are willing to reflect the situation to your supervisor".

The design of the items of the cultural factor scale was based on the scale designed by Zohar [58] in his study of the multilevel model of safety climate, and the items "You are very clear about the form of safety promotion in your organization", "You are very clear about the corporate philosophy and safety philosophy of your company", "You are happy to work in your organization", and "You are willing to communicate with your leaders or colleagues about safety problems in the construction process" were given for the form of cultural promotion, organizational values, organizational identity, and communication, respectively.

The Human Factors Error Scale was designed based on the work of Reason, who divided human factors errors into two categories: negligence and error [7]. Referring to Neal and Griffin's Safety Behavior Scale [59], nine questions were set, such as "You would not enter a construction site on your own without relevant skills training when performing a new technical job", "You would put protective measures in place before entering a construction site for safety reasons", and "You would double-check the completion of the work to ensure the safety of the work".

4.2. Sampling and Data Collection

A random sampling process is used to distribute the questionnaire to people with front-line construction experience in metro projects. The research was conducted in 12 provinces, such as Jiangsu Province, Guangdong Province, Shandong Province, Hubei Province, Anhui Province, Henan Province, etc. Since this survey was sent by email, in order to reduce the barriers in information communication, respondents can ask the author directly by phone if they have any questions when filling out the survey.

Tabachnick and Fidell (2007) suggested that the sample number should be at least 200 to construct an SEM to make empirical research on it, with the sample number ranging from 200 to 500 [60]. After discussion, it was initially predicted that 300 copies would be sufficient for the analysis. Therefore, the plan was to send 300 copies first, and then replenish them if they were insufficient. A total of 300 questionnaires were distributed and 260 questionnaire responses were received over a period of 4 months. Recovered questionnaires with incomplete answers, less than three minutes to answer, and answers with obvious irregularities did not meet the study criteria. According to the above screening criteria, a total of 244 valid questionnaires were available for the data analysis with a valid response rate of 93.8%.

The 244 valid samples were analyzed in terms of age, education level, length of service, type of job position, and type of work unit, as shown in Table 2. From the table, it is clear that the sample of this study is consistent with the overall population characteristics of construction workers.

Table 2. Sample demographic characteristics.

Variable	Category	Number	Percentage
Age	≤25	62	25.41
	26–30	100	40.98
	31–35	43	17.62
	36–40	18	7.38
	>40	21	8.61
Education level	Graduate degree or above	48	19.67
	Bachelor degree	148	60.66
	Technical school	41	16.80
	High school or below	7	2.87
Length of service	≤2	81	33.20
	3–5	57	23.36
	6–10	60	24.59
	>10	46	18.85
Work type	Project department general employee	116	47.54
	Project department technician	46	18.85
	Functional department general employee	60	24.59
	High-level functional departments	21	8.61
	Enterprise high-level	1	0.41
Work unit type	Supervision enterprise	45	18.44
	Agent construction unit	12	4.92
	Construction enterprises	95	38.93
	Government institutions	45	18.44
	Other enterprises	47	19.26
Province	Jiangsu	109	44.67
	Shandong	35	14.34
	Shanghai	33	13.52
	Guanddong	23	9.43
	Beijing	12	4.92
	Anhui	9	3.69
	Hubei	9	3.69
	Liaoning	4	1.64
	Fujian	3	1.23
	Jiangxi	3	1.23
	Henan	2	0.82
	Shanxi	2	0.82

5. Research Procedure and Results Analysis

5.1. Reliability and Validity Test

The Cronbach's α coefficients for each factor were obtained by analyzing the data recovered from each scale using SPSS 17.0 software as shown in Table 3. The KMO test and Bartlett's sphericity test were conducted for each measure affecting human errors, and their results are shown in Table 4.

Table 3 shows that the subscales Cronbach's α coefficients are all greater than 0.70, so the scale has good reliability [61]. Table 4 also shows that the KMOs of the scales are all above 0.5 and sig = 0.00, which is less than 0.01, so factor analysis can be performed. The results of the factor analysis are shown in Table 5, and all loadings are greater than 0.5, so the data of this survey has good reliability and validity [62].

Table 3. Analysis of the reliability of each dimension.

Variable	Number of Item	Cronbach's α Value	Cronbach's α Value of Scale
Mental factors	3	0.794	
Physiological factors	4	0.732	
Technical factors	4	0.888	
Environmental factors	5	0.878	0.870
Organizational factors	3	0.864	
Cultural factors	4	0.718	
Human errors	9	0.923	

Table 4. KMO and Bartlett test sphericity test results.

Variable	KMO	χ^2	df	Sig
Mental factors	0.642	264.693	3	0.000
Physiological factors	0.694	212.086	6	0.000
Technical factors	0.834	542.811	6	0.000
Environmental factors	0.839	627.363	10	0.000
Organizational factors	0.724	352.065	3	0.000
Cultural factors	0.721	210.599	6	0.000
Human errors	0.604	155.385	3	0.000

Table 5. Value of factor load.

Variable	Index	Factor Load	Variable	Index	Factor Load
Mental Factors	MF11	0.938	Organizational Factors	OF51	0.749
	MF12	0.750		OF52	0.833
	MF13	0.580		OF53	0.871
Physiological Factors	PF21	0.571	Cultural Factors	CF61	0.712
	PF22	0.691		CF62	0.800
	PF23	0.748		CF63	0.605
	PF24	0.644		CF64	0.523
Technical Factors	TF31	0.799	Human Error	HE71	0.618
	TF32	0.789		HE72	0.722
	TF33	0.863		HE73	0.601
	TF34	0.821		HE74	0.551
Environmental Factors	EF41	0.800		HE75	0.572
	EF42	0.728		HE76	0.609
	EF43	0.831		HE77	0.589
	EF44	0.745		HE78	0.624
	EF45	0.754		HE79	0.660

5.2. Model Test and Modification

To test the hypotheses, the structural equation model (SEM) was initially fitted with AMOS 17.0 software according to the theoretical model of human error influence factors constructed in Figure 1, and the calculated results are shown in Table 6. It can be seen that, although the model fit mostly meets the criteria, the degree of model fit needs further improvement. Therefore, it is necessary to make corrections to the initial model. The C.R. values between the latent variables of the initial model in Figure 2 show that a total of six C.R. values are less than 1.96, so it is necessary to revise the initial model.

Based on the calculated results of the initial model and the principles of model modification, the method of deleting unreasonable paths according to C.R. values and correlating the related residual terms according to Modification Indices [63,64]. After repeated debugging and running, a total of four paths from environmental factors to human errors, cultural factors to human errors, physiological factors to mental factors, and organizational factors to technical factors were deleted. A total of five new covariate relationships between emotional state and temperature residuals, knowledge level and noise residuals, lighting and humidity residuals, humidity and temperature residuals, and safety leadership and organizational identity were added. By calculating the fitness index of the model (as shown in Table 6), all values were found to satisfy the criteria except for GFI = 0.851 < 0.90. However, when CFI > 0.90, GFI > 0.85, it is generally considered to be acceptable [65]. Therefore, it can conclude that the modified model fit is acceptable and optimal.

Table 6. The adaptation degree results of the optimal model.

Index	Initial Model	Modified Model	Ideal Value
RMR	0.067	0.046	<0.05
RMSEA	0.065	0.042	<0.08
GFI	0.814	0.851	>0.90
AGFI	0.936	0.905	>0.90
NFI	0.770	0.937	>0.90
TLI	0.855	0.938	>0.90
CFI	0.967	0.910	>0.90
PGFI	0.796	0.710	>0.50
PNFI	0.702	0.737	>0.50
χ^2/df	2.017	1.431	<2.00

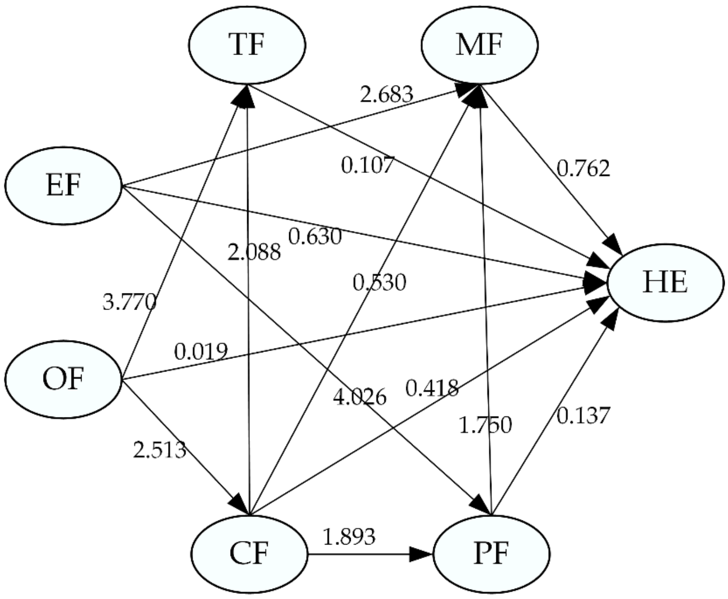

Figure 2. C.R. value between the latent variables.

5.3. Validation of Research Hypotheses

The modified optimal SEM is shown in Figure 3. The results of the hypothesis tests for the critical ratio values, and significance levels, i.e., responses among the variables are detailed in Table 7. It can be seen that all the hypotheses hold except for hypotheses H2b, H4a, H5b, and H6a.

Table 7. The response hypothesis testing results of C.R. value, significance level.

Influence Path			C.R.	*p*-Value	Results
H1:	MF→HE		3.189	***	Proved
H2a:	PF→HE		4.865	***	Proved
H3:	TF→HE		2.015	0.037	Proved
H4b:	EF→MF→HE	EF→MF	5.246	***	Proved
		MF→HE	3.189	***	

Table 7. *Cont.*

Influence Path			C.R.	*p*-Value	Results
H4c:	EF→PF→HE	EF→PF	2.984	***	Proved
		PF→HE	4.865	***	
H5a:	OF→HE		2.494	0.015	Proved
H5c:	OF→CF		4.897	***	Proved
H6b:	CF→MF→HE	CF→MF	2.672	***	Proved
		MF→HE	3.189	***	
H6c:	CF→PF→HE	CF→PF	5.358	***	Proved
		PF→HE	4.865	***	
H6d:	CF→TF→HE	CF→TF	3.486	***	Proved
		TF→HE	2.015	0.022	

Note: in statistics, when the *p*-value is less than or equal to 0.001, it is denoted by ***.

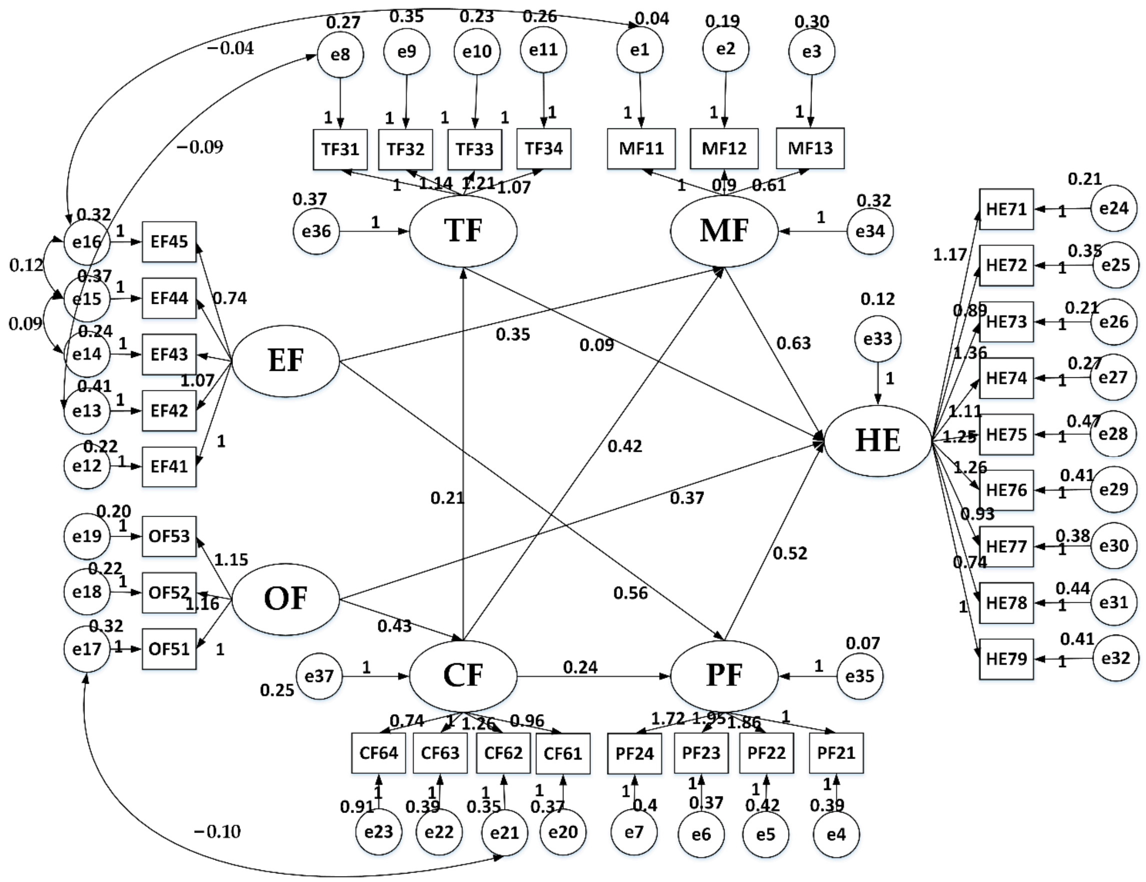

Figure 3. The operation result of optimal structural equation model.

6. Discussion

Through the field survey, it was found that the construction workers already had a basic understanding of the working environment and made certain preparations before carrying out the work, so the working environment did not have a direct impact on human errors; the workers' perception of the safety culture and safety form of the whole enterprise was basically through the enterprise propaganda, and they did not recognize that the safety culture and related factors have a promotional effect on individuals; before engaging in metro construction, they need to go through pre-service training, and for special types of work, and they need to obtain the corresponding qualification certificate, so the influence of organizational factors on an individual technical level is not very obvious. Although the work of metro construction is relatively hard and technical in nature, the work and rest arrangement of project organization is still relatively scientific, so the physiological factors do not affect the mental factors.

A previous study by Paary classified the causes of human behavior formation as indirect and direct types [66]. However, in this study, it was found that the mental, physiological, and technical factors of metro construction workers are direct factors influencing human errors. Environmental factors are indirectly influencing human errors by affecting mental and physiological factors. Cultural factors can indirectly influence human errors by affecting physiological and technical factors. This finding confirmed Paary's research results [66]. However, inconsistency exists where organizational factors can act on human errors both directly and by influencing the safety culture of the organization before acting on human errors. This may be due to the fact that safety culture exists within the organization and this study is too detailed in its delineation of factors external to human errors.

This study identified influencing paths of various factors on human errors, which confirmed Reason's view. Reason divided human errors into three levels, namely: the behavioral level, situational level, and conceptual level, which can correspond to "what happened", "where it happened", and "how it happened", respectively [7]. The study on the pathways of various factors influencing human errors is consistent with the third level of human errors as described by Reason.

7. Conclusions

Safety accidents occur frequently in metro construction, where human errors are a significant reason. In order to derive the influence paths of various factors on human errors, this study developed corresponding scales for mental, physiological, technical, organizational, environmental, cultural, and human error factors. Cronbach's alpha coefficient shows that each scale has good reliability. These scales were then distributed to the frontline workers of various metro projects in 12 provinces in China. After obtaining the research data, structural equation models were constructed. Finally, the influences of each factor on human errors and the interconnection among each factor were analyzed.

The research scales and measurement tools for mental, physiological, technical, environmental, organizational, cultural factors, and human errors were developed on the basis of a comprehensive literature review. The mechanism and influencing paths of each factor on human errors were verified empirically, and the research results were analyzed to enrich the research theory on human errors in the field of metro construction.

A structural equation model was developed for the factors influencing human errors, and the relationship between the factors and the relationship between the factors and human errors was quantitatively analyzed by hypothesizing the interrelationship between the factors and the relationship between the factors on human errors. This finding provides theoretical support for future measures to be taken for the six factors of mental, physiological, technical, environmental, organizational, and cultural factors in metro construction.

As a limitation, this research mainly focused on human errors during metro construction projects. It is known that the metro construction process is complex and variable, and there is more than one kind of human error, e.g., human error types and negligence types. It is recommended to compare the influencing magnitudes of different human errors in a future study. In addition, self-efficacy is a belief in one's own ability to perform a behavior, but in this paper, it is considered that self-efficacy, like work ability, can be improved by training, and therefore it is used as a technical factor for construction workers. In future studies, try to put self-efficacy into mental factors for further exploration.

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