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MEASURING THE PERCEPTION OF SAFETY AMONG TAIWAN CONSTRUCTION MANAGERS

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Abstract. Using Statistical Package for the Social Science (SPSS) and Structural Equation Modeling (SEM), this study develops a model to evaluate construction managers' perception of safety as relates to six aspects: human error (HE), safety resource and application (SRA), safety equipment and training (SET), site culture and external factors (SCF), safety inspection and audit (SIA), and accident medium and activities (AMA). The model was used to identify and compare the level of safety perceived by Taiwanese construction managers including safety managers, contractor managers, public works managers, design and audit managers, owner audit and control managers, and others. Analysis reveals that safety managers have the highest perception of safety while owner audit and control managers have the lowest. Surprisingly, public works managers and design and audit managers have lower levels of perceived safety than do contractor managers. Apparently, reinforcing the perception of safety between these two types of construction personnel is important to reducing construction accidents in Taiwan.

Keywords: construction safety perception, construction manager, construction industry, construction accidents.

1. Introduction

According to Taiwan's Labor Safety and Health Law, a fatal occupational accident (FOA) is defined as an accident involving: (1) a death or (2) the injury of at least three workers resulting in one or more lost workdays. The FOA must be reported within 24 hours to the appropriate inspection agency. Between 1998 and 2007, Taiwan companies experienced an average of 350 FOAs annually. In particular, 180 construction accidents resulted in 182 deaths. The number of fatal construction accidents in Taiwan is only second to that of mining and quarrying industries (Council of Labor Affairs 2008). Although the rate of FOAs per 1,000 workers in the construction field has declined slightly in recent years, the number is still significantly higher than in developed countries including the UK, USA, and Japan (Table 1).

A jobholder's perception can significantly affect his/her behavioral intention. A more positive perception usually accompanies high behavioral intention and vice-versa (Yu 2006). The safety perception of Taiwan's construction jobholders is restricted because Taiwan's construction occupational accident investigations mainly focus on the number of fatalities and injuries, accident type, accident medium, work trade, and location. The construction accident rate remains high because of the specific environmentand insufficient safety precautions in the industry. According to Wang *et al.* (2006), despite increased official and industrial emphasis on construction safety issues in recent years, construction accidents in Taiwan still largely result from jobholders' inadequate safety perception.

Table 1. Occupational fatalities in the construction industry of different countries

year	Injury Rate of OFAs (Per 1,000 workers)				
	Taiwan	Hong Kong	Japan	United Kingdom	U.S.A.
2000	0.223	0.364	0.124	0.064	0.130
2001	0.210	0.349	0.120	0.053	0.130
2002	0.188	0.328	0.120	0.051	0.122
2003	0.175	0.390	0.120	0.044	0.117
2004	0.131	0.268	0.120	0.049	0.119
2005	0.172	0.422	0.120	0.037	0.110
2006	0.161	0.303	0.110	0.038	0.108
2007	0.122	0.379	0.130	0.034	0.105
mean	0.174	0.350	0.121	0.046	0.118

Source: Council of Labor Affairs (2008)

Note: Excludes traffic accidents

Construction jobholders' poor awareness of safety concepts and poor enforcement of safety regulations

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mean that the management of construction safety urgently needs to be strengthened thus verifying the safety perception of various construction jobholders would help towards better construction safety control. With a focus on construction jobholders, we explore the root causes of these issues, and develop a model using questionnaire surveys and statistical analysis.

2. Previous studies

2.1. Construction accidents

Construction accidents in Taiwan are usually classified into five categories: falls from elevation, electric shock, caught in/between, struck by, and others. Determining the possible causation factors of these accident types is difficult due to the breadth of the categories (Hinze *et al.* 2005). However, management is the most critical factor in the occurrence of construction accidents (Mohan, Zech 2005; Liao, Perng 2008). A number of other factors, such as accident trends, work trade, accident type, and differences between different countries (areas) correlated with occupational injuries in the construction industry and were collected for a review of relevant studies of occupational injuries in Taiwan. Table 2 summarizes 11 studies on construction accidents, and shows that the topics most discussed included root causes, type, and medium of accident, and that risk and safety level are secondary issues. However, investigation into construction accident causes is still inadequate Cheng *et al.* (2010) explore the cause-effect relationships of occupational accidents in Taiwan's construction industry. Several factors affect construction safety management, and the special characteristics of the construction industry, such as the increasing number of large-scale projects, poor on-site conditions, and the complexities of construction trade combinations, all affect safety management. Törner and Pousette (2009) identified four main categories of construction safety preconditions and components: (1) project characteristics and nature of the work; (2) organization and structures; (3) collective values, norms, and behaviors; (4) individual competence and attitudes. According to Smith *et al.* (2006), ladder falls can lead to fractures that have more serious consequences than other ladder-related injuries. Mohan and Zech (2005) noted the high frequency of traffic-related accidents among construction workers working on roads. Idoro (2008) investigates the level of efforts made by Nigerian contractors to maintain a healthy and safe work environment. The research reveals that the management efforts made by Nigerian contractors to ensure a healthy and safe work environment are yet to have meaningful impact. It suggests increased efforts on local health and safety (H&S) regulations, structures for managing H&S in both head and site offices and provision of H&S incentives as measures for improving safety in the Nigerian construction industry. Additionally, Giretti *et al.* (2009) even developed a new, advanced

Table 2. Construction industry accident issues

Topic	References	Research contents
Falling accidents	Bobick (2004)	During 1992–2000, more than 50% of all fall-related deaths occurred in the Construction Division whereas, during the same period, only 11% of fall-related fatalities occurred in the Manufacturing and Agriculture, Forestry, and Fisheries Divisions combined.
	Huang *et al.* (2000)	Flaws in facility management, such as safety prevention, temperature, openings, scaffold and ladder are the major causes of occupational fatalities and serious injuries.
Root causes of accidents	Hinze *et al.* (1998)	Injuries were clustered into 20 possible cause categories, rather than the traditional five groups of falls, struck by, electric shock, caught in/between, and other. Additional or secondary cause codes were also developed.
	Arboleda and Abraham (2004)	In the year 2000, the construction industry accounted for 4.7% of USA GDP and 7% of the total workforce but 19.5% of all reported occupational fatalities.
	Lipscomb *et al.* (2010)	Contact injuries accounted for 54% of all construction-related ER visits, primarily for injuries caused by contact with discharged nails from pneumatic nail guns, with hand held power saws, and fixed saws.
Accident statistics	Beavers *et al.* (2006)	The study examined 1997–2003 Occupational Safety and Health Administration's (OSHA) fatality investigations to determine proximal causes and contributing physical factors.
	Cohen *et al.* (2006)	Work-related fatalities between the years 1998 and 2002 are described by victim demographics, types of incidents, victim occupations, and industries and locations in which they worked.
Risk planning	Lee and Halpin (2003)	Construction accidents are associated with poor planning of operational tasks, insufficiently established practices for dealing with accidents, and a lack of safety training and safety recognition. The research identified that training, supervision, and preplanning are the most critical factors related to construction accidents.
	Gangwar and Goodrum (2005)	According to the US Bureau of Labor Statstics' Census of Fatal Occupational Injuries, the total number of fatalities in the US private construction sector in 2003 was 1126, the equivalent of 11.7 worker fatalities for every 100,000 construction workers.
Level of safety	Fang *et al.* (2004)	The research uses multifactor linear regression (MLA) to conclude that on-site safety management performance is closely related to organizational and economic factors, along with factors related to the relationship between management and labor on site.
Safety knowledge	Chua and Goh (2004)	The US construction industry accounted for 20% of all occupational fatalities, but only 5% of the US workforce.

system mainly devoted to automatic real-time health and safety management on construction sites. Their research focuses mainly on the development of a reliable methodology for real-time monitoring of the position of both workers and equipment in outdoor construction sites by applying Ultra Wide Band based technologies.

2.2. Safety perception

An individual's perception depends on different external environments, personal characteristics, and individual conditions. From the perspective of management, generalized perception includes consciousness and response at the initial stage. Griffin and Neal (2000) defined safety perception as "how workers view safety related policies, procedures and other workplace attributes concerned with safety". The most relevant perceptual indicators in this regard are formal and informal policies, procedures, and practices concerning focal organizational facets, such as service and safety (Zohar 2000). Safety perception is correlated with accident rates, quality of the safety climate, workers' working attitude, management and equipment, organizational culture and management support.

Safety climate and safety culture are mutually related but distinguishable. Safety culture expresses itself through the safety climate as features that can be discerned from workers' attitudes and perceptions (Guldenmund 2000). Safety culture refers to 'the attitudes, beliefs, and perceptions shared by natural groups as defining norms and values, which determine how they react in relation to risks and risk control systems' (Hale 2000). The usefulness of safety climate as a diagnostic tool ought to reside in its ability to identify detailed and precise challenges critical to safety improvement (Meliá *et al.* 2008).

It is comparatively difficult to evaluate construction jobholders' safety perception. The occupational safety climate in Taiwan is regarded as an organizing component employees' overall safety perception (Tsai *et al.* 2003), and self-safety behavior and perception combine to form one measurement that defines safety at work. Although Wu *et al.* (2010) investigated the safety culture of Taiwan telecommunications industry, and Kuo *et al.* (2006) explored the state of the organizational safety culture in Taiwan's construction industry, they did not focus on managers' safety perception, and studies related to construction safety perception are lacking in general.

3. Data collection

The aim of this study is to build a perception scale to measure construction jobholders' safety perception levels. The concept of safety perception here is derived from selections of indicators affecting construction safety, as well as perception indicators based on studies on construction safety. Fig. 1 shows the procedure and applied methods of the perception evaluation model. First, we interviewed various practitioners to verify extracted variables. Next, several questionnaires were distributed to construction jobholders and the results were analyzed using statistics software and exploratory factor analysis (EFA). Finally, the model variables and path effect were developed to evaluate construction jobholders' safety perceptions.

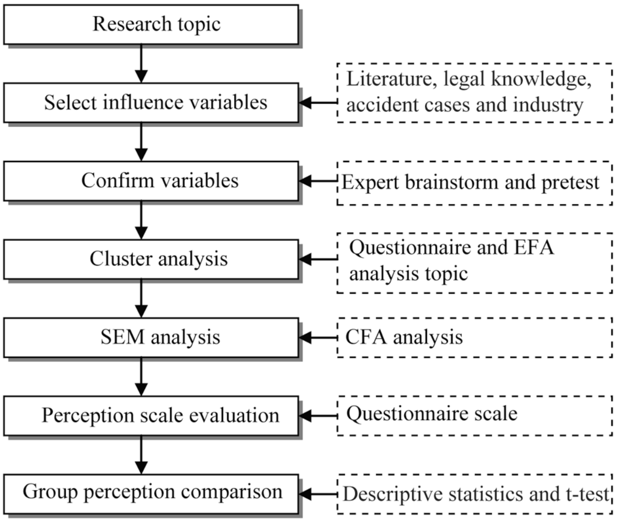

Fig. 1. Procedure and applied methods of perception analysis

The perception-related variables used here are taken from the occupational safety literature, including nine international and two local construction-related journals. We summarize 234 variables affecting construction safety perception by reviewing 34 articles published from 1997 to 2008 and referring to accidents in Taiwan's construction industry. Among these variables, 43 were selected and reviewed by 15 construction experts (5 public works experts, 2 engineering advisers company experts, 4 contractor experts, 2 labor safety experts, and 2 architects) equipped with at least 17 years experience in construction safety (Table 3). Based on the interview results, the list of variables was reduced to 36, representing 36 questions of the questionnaire. Adopting a 7-point Likert scale in the questionnaire, the options were divided into different categories of importance from "very important" (7 points) to "very unimportant" (1 point).

According to Stevens (2002), the sample size used for factor analysis should be 2–20 times greater than the number of variables to be analyzed, and at least five observations for each variable are indispensable for the development of a reliable factor framework. The pretest questionnaire of this study was distributed to construction jobholders and 110 valid questionnaires (over three times the number of variables) were collected. Reliability analysis of the valid questionnaires indicated that Cronbach's α was 0.960; variable correlation was medium to high (0.423~0.728); variables were extracted between 0.543 and 0.781 via principal component analysis (with extracted values all greater than 0.5). All 36 variables were retained and incorporated into the formal questionnaire.

Construction jobholders generally include contractors, design consultants or architects, owner personnel, public works units, and laborer safety/research personnel. The study distributed 480 questionnaires to design and audit managers (e.g., architects and professional engineers, design and audit managers, and project managers), contractors (e.g., superintendents, safety managers, foremen, and supervisors), government officials and scholars (e.g., occupational safety officers, engineers, and engineering audit and control managers), and others (owners and engineers). Of the 387 returned questionnaires, 364 were valid (over 10 times the number of investigated variables). SPSS V15.0 was first used to carry out the exploratory factor analysis (EFA) and extract principal factors. Various statistical analyses, including the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test, Communalities, Total Variance Explained, Screen Plot, Component Matrix, Rotated Component Matrix, and Component Transformation Matrix were conducted sequentially to delete some variables for better results. Table 4 displays the procedure of deleting variables and Table 5 shows the fifth stage analysis of the rotated cluster matrix.

4. Model building and validation

In this study, EFA was conducted with the variables of relevant factors and the initial analysis results for clusters of variables were then referred to confirmation factor analysis (CFA). According to Hair *et al.* (2006), SEM may be used for a variety of purposes, including both interdependence and dependence analyses. To either demonstrate path relationships or verify a scale's internal framework, SEM depends on exact variances and properties of one study to describe hypothetical relationships between variables and to realize verification statistically. The SEM model fit is evaluated in two stages: 1) validating the measurement model; and 2) validating the structural model. The first-order SEM emphasizes the relationships between the structural models and variable loading analyses. The second-order SEM emphasizes both the variable loading and path analysis of the framework. Referring to Fig. 2, we present a scale for construction jobholders' empirical safety perception and perform SEM analysis through Analysis of Moment Frameworks (AMOS) 7.0.

4.1. Model building and correction

Within the framework for the perception model and SEM principles for constructing a path diagram for SEM causal relationships of jobholders' perception, the path diagram can be transferred to the measurement model and the structural model of SEM, wherein variables and measurement errors to be estimated should be marked. In accordance with variables under each component, the rotated component matrix was used to analyze results and denominate them with six EFA aspects. With 364 valid samples, 26 observed variables, six endogenous latent variables (η), and one exogenous latent variable (ξ) (Table 6), the goodness-of-fit for the theoretical SEM model was examined stepwise.

Table 3. Description of initial variables

Classification	Variables (No.)	References
Human related	Unfamiliarity with work, time shortage, new methods and technologies, defective equipment or inappropriate use, misjudgment, distractions, etc. (6)	Huang and Hinze (2003); Wantanakorn *et al.* (1999); Navon and Kolton (2006)
Performance related	Fatal accidents, injuries, time or resources lost due to injuries, absenteeism, safety inspection and culture, and injuries requiring first aid, etc. (5)	Saurin *et al.* (2004); Cox *et al.* (2003); Hinze and Godfrey (2003); Arboleda and Abraham (2004)
Accident related	Unsafe site conditions, unsafe methods or sequencing, labor law violations, external factors, company audit, lack of safety training, and lack of safety equipment or tools (7)	Beavers *et al.* (2006); Arboleda and Abraham (2004); Navon and Kolton (2006)
Risk related	Insufficient risk perception, project design factors, insufficient risk assessment, insufficient training, inadequate safety culture and policies, and a lack of safety equipment or tools (6)	Lee and Halpin (2003); Chua and Goh (2004); Thevendran and Mawdesley (2004); Navon and Kolton (2006)
Management related	Safety laws, safety investment, cooperation and communication, safety education, subcontractor management, site safety environment, jobsite safety inspections, etc. (7)	Gyi *et al.* (1999); Saurin *et al.* (2004); Tam *et al.* (2003); Fang *et al.* (2004)
Control related	Site safety meetings, pre-tender risk assessment, punishment for rule violations, renewed safety policies, emergency response system, and safety audits (6)	Huang and Hinze (2006); Wang *et al.* (2006)
Statistics related	Rates of occupational fatalities, medium and category of accident, annual accident rate, related categories and activities, high risk activities, and definition of severe accidents (6)	Huang and Hinze (2003); Hinze *et al.* (2005); Beavers *et al.* (2006); Chi and Wu (1997)

Table 4. Summary procedure of factor analysis for deleted variables

Stage	Cronbach's α	No. of variables used	No. of variables deleted	Criteria of deleted variable
1st	0.923	36	2	Difference of factor loading < 0.5 (SC18, SC30)
2nd	0.922	34	2	Factor compose only two variables (SC2, SC3)
3rd	0.926	32	4	Difference of factor double loading < 0.3 (SC8, SC12, SC22, SC29)
4th	0.911	28	2	Difference of factor double loading < 0.3 (SC7, SC24)
5th	0.901	26	0	Factor loadings > 0.5; Difference of double loading < 0.3

Table 5. Rotated cluster matrix of the 5th stage analysis

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
SC31	0.650					
SC32	0.719					
SC33	0.788					
SC34	0.702					
SC35	0.766					
SC36	0.818					
SC9		0.651				
SC10		0.680				
SC11		0.665				
SC21		0.614				
SC23		0.527				
SC1			0.753			
SC4			0.712			
SC5			0.649			
SC6			0.658			
SC16				0.787		
SC17				0.756		
SC19				0.716		
SC20				0.805		
SC13					0.708	
SC14					0.756	
SC15					0.641	
SC25						0.708
SC26						0.606
SC27						0.715
SC28						0.589

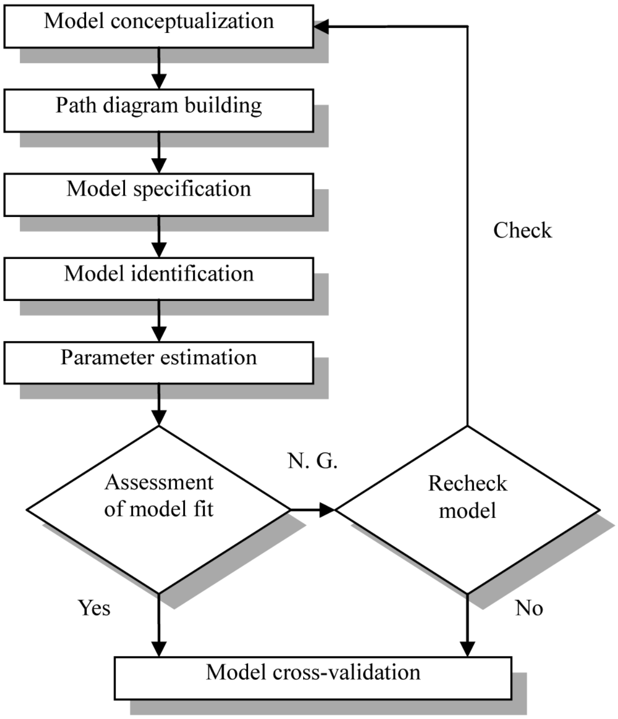

Fig. 2. Procedure of performing SEM analysis

Table 6. Variables of SEM analysis

Observed variables	Endogenous and exogenous latent variables
SC1. Unfamiliarity with work (HE1)	η1. Human error (HE)
SC4. Defective equipment or inappropriate use (HE2)	η2. Safety resource and application (SRA)
SC5. Misjudgment (HE31)	η3. Safety equipment and training (SET)
SC6. Distractions (HE4)	η4. Site culture and external factors (SCF)
SC9. Safety inspection and culture (SRA1)	η5. Safety inspection and audit (SIA)
SC10. Injuries requiring first aid (SRA2)	η6. Accident medium and activities (AMA)
SC11. Unsafe site conditions (SRA3)	ξ1. Safety perception (SP)
SC21. Safety investments (SRA4)	
SC23. Cooperation and communication (SRA5)	
SC13. Lack of safety training (SET1)	
SC14. Lack of safety equipment or tools (SET2)	
SC15. Unsafe methods or sequencing (SET3)	
SC16. Labor law violations (SCF1)	
SC17. External factors (SCF2)	
SC19. Psychology and education (SCF3)	
SC20. Safety culture and policies (SCF4)	
SC25. Jobsite safety inspections (SIA1)	
SC26. Subcontractor management (SIA2)	
SC27. Site safety environment (SIA3)	
SC28. Safety audit (SIA4)	
SC31. Punishment for rule violations (AMA1)	
SC32. Medium and category of accidents (AMA2)	
SC33. Annual accident rate (AMA3)	
SC34. Related category and activities (AMA4)	
SC35. High risk activities (AMA5)	
SC36. Definition of severe accident (AMA6)	

Table 7. Goodness-of-fit measurement of the CFA model

Evaluation indexes	Suggested value	First-order corrected model	Second-order original model	Second-order fourth corrected (Final) model	Comments on final model
1. Absolute fit indexes					
CMIN (χ^2)	The least	628.398	647.298	485.777	OK
Degree of Freedom (D. F.)	Without	284	293	284	OK
P-value	>0.05*	0.000	0.000	0.000	N > 200, ignored
RMR	<0.05	0.026	0.027	0.024	OK
RMSEA	<0.05	0.058	0.058	0.044	OK
GFI	>0.9	0.886	0.883	0.911	OK
2. Relative fit indexes					
NFI	>0.9	0.848	0.844	0.883	>0.8, accepted
IFI	>0.9	0.911	0.908	0.948	OK
CFI	>0.9	0.910	0.907	0.947	OK
3. Parsimonious fit indexes					
NCI (χ^2/ D. F.)	<2	2.213	2.209	1.710	OK
PNFI	>0.5	0.741	0.761	0.771	OK
PCFI	>0.5	0.795	0.818	0.828	OK
Hoelter's Critical N	≥200	188	188	243	OK
4. Cross-validation					
AIC	The least	762.398	763.298	619.777	OK
ECVI	The least	2.100	2.103	1.707	OK
Conclusions		Goodness-of-fit N. G. and partial correlation coefficient >0.7	Goodness-of-fit N. G.	Goodness-of-fit Indexes may be accepted.	

Note: Suggested value could be ignored if the number of returned questionnaires exceed the number of questions by more than ten times (Stevens 2002)

Applying a model including 26 observed variables and 6 endogenous latent variables to the first-order correlated SEM, we obtained the various indices shown in Table 7. The values of root mean square error of approximation (RMSEA), goodness-of-fit index (GFI), normal fit index (NFI), normed chi-square index (NCI), and Hoelter's Critical N do not match the suggested values, and the correlation coefficients of some endogenous latent variables (e.g., HE, SRA, SET, SCF, SIA, and AMA) exceeded 0.7. Some higher-order common factors might exist within these latent variables.

The model with 26 observed variables, six endogenous latent variables, and one exogenous latent variable was used for the second-order original SEM. As seen from Table 7, the values of the abovementioned indices did not improve to pass their respective thresholds, thus the model required further correction. After two rounds of correction, most indices of the model approached the suggested values. With the variable-observed correlations added into the second-order model, the results generated by AMOS improved. The model is considered qualified in terms of GFI (Table 7). The path estimate coefficients are shown in Fig. 3.

The goodness-of-fit values from SEM statistical analyses and requirements recommended for the constructed model indicated a poor goodness-of-fit in the first-order original SEM. The first-order correlated SEM gradually caused some goodness-of-fit indicators to match the suggested requirements for constructing a new model for comparison with the original model. Nevertheless, we incorporated the second-order model in the analyses because incorporating the converged first-order SEM results into the required conditions would cause the model to be very complicated and some factors' correlation coefficients to be extremely high.

With several corrections applied to the second-order model, the GFI, IFI and CFI for the fourth corrected (final) model are all greater than 0.90, matching requirements for the statistical indicators, with the exception of NFI (Jöreskog, Sörbom 1998). The study's NFI (= 0.883) was slightly smaller than the suggested value (0.9). Additionally, some authors, such as Bagozzi and Yi (1988), have used a more liberal cutoff NFI value of 0.80. Furthermore, the non-absolute normal values may determine the observation variables and the modeling goodness-of-fit, meaning that PNFI is much more proper than NFI. As seen in Table 7, the PNFI of the proposed model is 0.771, which is much greater than the suggested value (0.5), indicating the acceptance of the developed model.

Although the acceptance of SEM is dependent on the overall index, the smaller the χ^2, the more robust the SEM will be. There is no suggested value for degree of freedom (DF) which is related to NCI. Thus, the two indices cannot be considered independently (Jöreskog, Sörbom 1998; Kaplan 2000; Carmines, McIver 1981). After correcting the model, the cross-validation test for the final model indicated that the values of the Akaike information criterion (AIC) and the expected cross-validation index (ECVI) were significantly reduced. As seen in Table 7, the ideal situation would be a smaller AIC and an ECVI value that corresponds to the requirement of Default < Independence < Saturated model. Thus, this study's safety perception model can be applied to empirical analyses.

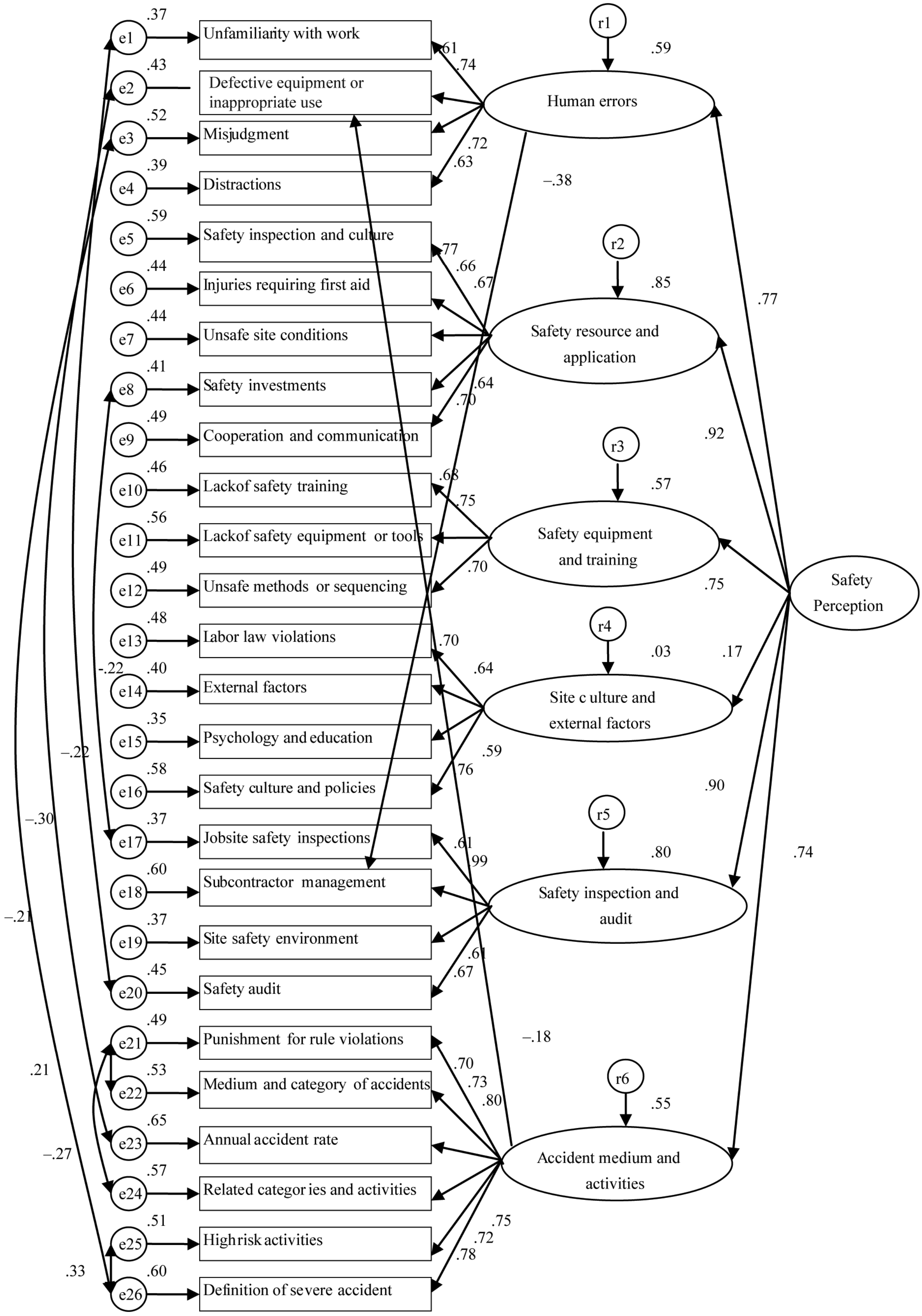

Fig. 3. Second-order fourth corrected (final) model

4.2. Model effects

Direct, indirect and total effects can be used to interpret SEM. The direct effect is a structural coefficient indicating a relationship between two variables with a single straight line. The indirect effect is another structural coefficient indicating a relationship between two variables, but affected by another path rather than a direct straight line. The total effect is a combination of the direct and indirect effects. A path displays the direction-affecting setup of one model and interpretations can be reversely obtained along a path's arrow (Kaplan 2000).

From Fig. 3, the second-order model has six paths equipped with the direct effect. They are: human error (0.770), safety resources and application (0.921), safety equipment and training (0.753), site culture and external factors (0.174), safety inspection and audit (0.896), and accident medium and activities (0.744). Paths of the first-order model also have different direct effects, such as human error (4 paths), safety equipment and training (3 paths), safety resource and application (5 paths), safety inspection and audit (4 paths), site culture and external factors (4 paths), accident medium and activities (6 paths). Additionally, cross-loading path effects can be found in two paths including human error to subcontractor management (SIA2) and accident statistics to defective equipment or inappropriate use (HE2).

In this study, the direct effects of high-order latent variables on the six paths are indicated with their coefficients which are between 0.174 and 0.921. Except for management action and risk with weakened effects causing a low perception path estimate coefficient, other latent variables have strong effects on the path estimate coefficient. The latent variables' effects on observed variables could be detected in 28 paths. A path's standardized coefficient should be between –0.377 and 0.987. Except where cross loading occurs, most effect paths with coefficients between 0.5 and 0.95 indicate a good goodness-of-fit for the developed model (Hair *et al.* 2006).

5. Safety perception analyzing

Following the SEM model variables, we developed an evaluation table with 26 questions, which was then given to construction jobholders for the evaluation of safety perceptions. Groups were created and comparison analysis was performed based on the SEM model's path effects.

5.1. Group perception comparison

Through confirmatory SEM analysis, the Questionnaire Perception Estimate (QPE) was developed for each variable. Based on 26 variables selected by SEM, 26 questions were designed and five experts (1 construction safety, 1 design, 1 public works, and 2 contractors) verified the goodness-of-fit of these questions. The questionnaire was then distributed to 360 construction jobholders including safety managers, contractor managers, design and audit managers, public works managers, owner audit and control managers, and others. Of 253 returned questionnaires, 242 were valid (response rate 67.2%). A 7-point scale, in which 1 indicates "closest to the investigated fact" and 7 indicates "deviated far from the fact," was used to measure respondents' perception.

The procedure used to measure group perception was as follows: (1) computation of perception scores based on 242 valid questionnaires; (2) second-order fit model, derived from CFA, was incorporated into the analyses of all paths (L_i); (3) the perception score (W_i) from a corresponding question was multiplied by (E_i); (4) cumulative results for all factors were multiplied by a high-order SEM path estimate coefficient for higher-order computations using this principle. With E_i multiplied by W_i, the results were accumulated according to all paths for comparisons of six groups of jobholders' perceptions.

Table 8 shows how the perception scores are calculated. The order for all group scores (in descending order) is safety managers, contractor managers, public works managers, design and audit managers, owner audit and control managers, and others (Table 9). Significant differences were found between the perception of safety managers and that of the other five groups of jobholders. The average difference of 12.18 points (76.35 – 64.17 = 12.18) between safety managers and owner audit and control managers indicates a notable difference in safety perception among these groups of jobholder.

The benchmark confidence level for determining difference in perception is 95–99%. Thus, there was a significant difference between safety managers and other groups and between contractor managers and owner audit and control managers or others, but not between contractor managers and design and audit managers or public works managers (Table 10). There was no significant difference between design and audit managers (who had perceptions similar to those of owner audit and control managers) and public works managers or others; between public works managers (who had perceptions similar to those of owner audit and control managers) and others; and there was no significant difference between owner audit and control managers and others.

5.2. Results analysis

Compared with the perception difference, safety managers have a much higher perception level than do the other five groups. The perception of contractor managers was similar to that of public works managers and design and audit managers. There was no significant difference observed between owner audit and control managers and others. The owner audit and control managers had the lowest perception level, because Taiwan's construction project owners heavily focus on schedules and costs but ignore safety (Wang *et al.* 2006).

We took the average perception of the safety managers as benchmark for construction jobholders' safety perception. In comparison, the contractor managers had a perception level of 92.1%, while the other four groups had average perception levels ranging from 84% to 89.5%. Despite not finding any jobholder group with a particularly low perception level, significant differences exist between some groups' safety perception levels, with a gap of 36.59 points (= 87.41~50.82) between the maximum and the minimum based on the QPE (Table 9).

Table 8. Path effects and perception calculation example

Second-order ΣL_i $(\Sigma(E_i * W_i))$	First-order (Li) $\Sigma(Ei * W_i)$	Variable	Estimate (E_i)	Perception score (W_i)
Perception $\Sigma = 77.355$	Human error (HE) (L_i=0.770) $\Sigma = 14.072$	HE1	0.608	7
		HE2	0.743	7
		HE3	0.718	4
		HE4	0.626	7
		SIA2	–0.377	7
	Safety resource and application (SRA) (L_i = 0.921) $\Sigma = 19.324$	SRA1	0.771	5
		SRA2	0.663	7
		SRA3	0.666	7
		SRA4	0.640	2
		SRA5	0.698	7
	Safety equipment and training (SET) (L_i = 0.753) $\Sigma = 11.284$	SET1	0.679	7
		SET2	0.747	5
		SET3	0.699	4
	Site culture and external factors (SCF) (L_i = 0.174) $\Sigma = 12.697$	SCF1	0.696	1
		SCF2	0.636	4
		SCF3	0.591	7
		SCF4	0.760	7
	Safety inspection and audit (SIA) (L_i = 0.896) $\Sigma = 20.076$	SIA1	0.607	7
		SIA2	0.987	7
		SIA3	0.606	7
		SIA4	0.668	7
	Accident medium and activities (AMA) (L_i = 0.744) $\Sigma = 26.919$	AMA1	0.700	7
		AMA2	0.731	7
		AMA3	0.804	4
		AMA4	0.754	7
		AMA5	0.716	7
		AMA6	0.776	6
		HE2	–0.180	7

Table 9. Questionnaire perception estimate of group ranking

Groups	Sample no.	Perception estimate			Std.	Rank	Ratio of individual group to G1 (%)
		Min.	Max.	Mean			
G1. Safety managers	28	61.19	87.41	76.35	6.37	1	100
G2. Contractor managers	61	57.10	79.70	70.29	5.52	2	92.06
G3. Design and audit managers	31	56.66	79.34	67.88	5.08	4	88.91
G4. Public works managers	37	56.83	76.70	68.37	5.53	3	89.55
G5. Owner audit and control managers	33	50.93	77.26	64.17	6.83	6	84.05
G6. Others	52	50.82	76.42	66.62	5.11	5	86.99
All samples	242	50.82	87.41	68.77	6.55		

Table 10. Significance of group t-test

Groups t-test	Significance (p value; 2-tailed)/ 95%–99% confidence level					
	G1	G2	G3	G4	G5	G6
G1. Safety managers	–	0.000	0.000	0.000	0.000	0.000
G2. Contractor managers	Difference	–	0.044	0.089	0.000	0.000
G3. Design and audit managers	Difference	Equal	–	0.777	0.022	0.197
G4. Public works managers	Difference	Equal	Equal	–	0.009	0.056
G5. Owner audit and control managers	Difference	Difference	Almost	Almost	–	0.272
G6. Others	Difference	Difference	Equal	Equal	Equal	–

Note: Equal- p value < 0.005; Almost- p value ≥ 0.005 or < 0.025; Difference- p value ≥ 0.025

To implement safety protection and accident prevention in construction projects, the safety concept of some managers with low perception levels should be comprehensively reinforced to prevent a potentially catastrophic conditions gradually developing because of chronically poor construction safety. Safety perception is regarded a standard of construction safety performance and, in fact, most safety managers with labor safety certificates and safety-related training had higher average perception scores; however, design and audit managers with different specialties were found to have low average scores.

5.3. Strategies for accident reduction

The basic framework of strategies for construction accident reduction goes hand in hand with all levels of management. As indicated by the Construction Design and Management (CDM) regulations in the UK, owners, designers, and contractors have their own safety duties. However, most of Taiwan's construction owners rarely respect safety controls because they argue that contractors are fully responsible for safety (Zou 2008).

One of the root causes of problems related to Taiwan's construction safety is the incomplete implementation of a construction supervision system. Architects' failure to reach a consistent consensus on the supervision of construction safety has resulted in insufficient supervision of construction safety. Although related guidelines explicitly regulate the construction safety duties of contractors and supervisors in public works, the relevant statutes for most projects need to be revised to raise the effectiveness of the project supervision system.

Although cost, schedule, and quality are the main indicators of construction projects (McKim *et al.* 2000), the safety dimension should be added as one of these standards. As someone with a crucial role in the construction project, the owner dominates the setup of a safe environment to ensure construction safety. The owner should require the contractor to draw up a construction plan and a construction safety evaluation report, analyzing dangers occurring in various stages or operations, evaluating potential risks in operation environments and equipment, and developing construction safety criteria and precautions prior to the commencement of the project. The responsibilities of subcontractors include analyzing construction safety, regulating labor to comply with safety rules at construction sites, and thoroughly monitoring workers to ensure complete safety inspections prior to the commencement of the project.

6. Conclusions and recommendations

This study explores the safety perception of Taiwan's construction jobholders, using SPSS and SEM to develop an evaluation model for their safety perception. The developed model was then used to identify and compare the safety perception levels of Taiwanese construction jobholders. The developed model includes six aspects (HE, SRA, SET, SCF, SIA, and AMA). Six groups of jobholders were investigated including safety managers, contractor managers, public works managers, design and audit managers, owner audit and control managers, and others.

Compared to other groups of Taiwan's construction jobholders, safety managers have the highest safety perception level while owner audit and control managers have the lowest. The safety perception levels of design and audit managers and public works managers were surprisingly low. In particular, design and audit managers play key roles in determining the contents of construction projects. As construction industry professionals, their safety perceptions could be expected to be no worse than those of any other construction professionals, but this is not the case. Public works managers are certified by government authority, and are supposed to not only have a high-level safety-related knowledge, but also consistently emphasize construction safety in all projects. Obviously, this is not the case in Taiwan's construction industry.

Implementation of required health and safety practices and effective training is important to reducing construction accidents (Cheng *et al.* 2010). Comprehensive implementation of construction safety measures and participation by jobholders in management and control are a critical part of a fundamental solution. In particular, construction managers are responsible for enhancing overall construction safety levels by improving safety perception through better practices and safety training. Additionally, reinforcing the safety perception of design and audit managers and public works managers is an urgent task**.** The framework proposed here can be upgraded and we suggest the computation of the relative coefficients for all aspects with paired comparisons be applied to these aspects for further comparison with recalculated scores for all groups' perceptions. Additionally, for assessing construction jobholders' safety perception levels, the sample size should expanded.

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