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INVESTIGATING THE SAFETY COGNITION OF TAIWAN'S CONSTRUCTION PERSONNEL

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Key words: construction personnel, construction accident, safety cognition.

ABSTRACT

A high construction accident rate is related to failures in the implementation of safety management. The rate of occupational injuries of Taiwan construction industry is higher than the ones of the developed counties. Knowledge and reinforcement of safety cognition for construction personnel are critical to improve safety performance in construction. In this study, a safety cognition evaluation scale is developed to measure the safety cognition of construction personnel in Taiwan. The safety cognition of construction personnel was ranked in descending order of safety engineers, contractor-related personnel, and design/audit personnel. The aspect of accident statistics has the smallest cognition differences while the aspect of accident causes has the most inconsistent cognition differences. The investigation of this study provides knowledge of the safety cognition of Taiwan's construction personnel. This information provides safety managers better understanding of Taiwan's construction personnel to enhance the latter's safety cognition and thus safety performance.

I. INTRODUCTION

The construction industry is a high-risk industry with many risky events that can cause damage to multiple contractors or personnel. Against this background, it is not easy to ensure safety in a construction project, especially given each project's particularity and environmental limits. It should be noted that incident causes change over a project lifecycle, in terms of both the goals and individuals' perception of tasks, conditions, and the situation [14]. Mohamed [26] mentioned that construction industry has poor safety records compared to other industries. In the USA, the construction industry accounted for 20% of all occupational fatalities but employed only 5% of the country's workforce [10]. The Occupational Safety and Health Administration (OSHA) classifies construction disasters into several types, including *fall from elevations*, *electric shock*, *collapse*, *struck-by*, *caught-between*, and *others*. During the period 1992-2000, more than 50% of fall-related deaths occurred in construction, far out of proportion to the role of the construction division in the USA [4]. There are similar trends in other countries.

Construction project characteristics play a significant role in causing high accident rates. Work environments such as high-rise SRC buildings, deep excavation areas and heavy traffic roadways are much more hazardous than those encountered in other industries. According to Huang and Hinze [20], there is a close relationship between *falls from elevation* and ladder and scaffold work, exacerbated by insufficient facilities management (defective equipment, openings, scaffold, and working from roofs).

Mohan and Gautam [27] found that two types of accidents occur in highway work zones: the one that involves construction workers and the other that involves motorists outside the construction area. The previous one accounts for 30% of the accidents. During the period 2000-2006, Taiwan had an annual average of 360 workplace accidents, with approximately one death for each accident. Of the 360 annual accidents, 177 (with 180 deaths) occurred in the construction industry, making for about half of all annual accidents [34]. Apparently, the construction industry claims the top spot in terms of accident numbers. Similar to accident trends in other countries, the construction industry in Taiwan is second to the mining and quarrying industry in terms of rates of occupational fatal injuries (ROFI). Among 9,893 average annual injuries, more than 740 disabilities were caused by occupational injuries in Taiwan's construction industry (Table 1). There is an obvious gap between Taiwan and several developed countries (the UK, Japan, and the USA) in terms of construction safety performance (Table 2). The enhancement of Taiwan's construction safety management is urgent.

Although management/supervisors, team leaders, and workers are all responsible for safety, construction personnel often ignore construction safety regulations [33]. Accident rates were related to age in a nonlinear manner, with injuries at first increasing with age, then decreasing [31]. However, older workers exhibit more positive attitudes toward safety than younger workers do. Lingard and Rowlinson [24] tested the

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Table 1. Occupational casualties in Taiwan's construction industry.

Year	Occupational injuries (rate per 1,000 workers)			
	Injured	Disabled	Deaths	Total
2000	10,187 (14.575)	836 (1.196)	206 (0.295)	11,229 (16.066)
2001	10,062 (14.676)	868 (1.266)	185 (0.270)	11,115 (16.212)
2002	9,447 (13.912)	827 (1.218)	165 (0.243)	10,439 (15.373)
2003	9,462 (14.042)	671 (0.996)	171 (0.254)	10,304 (15.292)
2004	10,003 (14.774)	658 (0.972)	122 (0.180)	10,783 (15.926)
2005	9,694 (14.125)	669 (0.975)	165 (0.240)	10,528 (15.341)
2006	10,401 (14.820)	654 (0.932)	167 (0.238)	11,222 (15.989)
Average	9,893.7 (14.418)	740.4 (1.079)	168.7 (0.246)	10,802.8 (15.743)

Note: Traffic incidents are included.

Table 2. Occupational fatal injuries in the construction industry.

Year	Rates of occupational fatal injuries (ROFI) (per 1,000 workers)				
	Taiwan	Hong Kong (China)	Japan	United Kingdom	USA
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	0.120
2003	0.175	0.390	0.120	0.044	0.127
2004	0.131	0.268	0.120	0.049	0.121
2005	0.172	0.422	0.120	0.035	0.129
2006	0.161	0.303	0.110	0.030	0.117
Average	0.180	0.346	0.119	0.047	0.125

Sources: [34].
Note: Traffic incidents are excluded.

effectiveness of behavior-based methods by applying goal setting and feedback intervention to specific areas of safety performance on Hong Kong Housing Authority construction sites. They found that there is a significant relationship between safety behavior management and workers' attitude. However, it is not easy to realize the relationship between workers' safety attitude and their safety performance.

In recent years, many developed countries have considered safety as one important management issue for construction projects, especially personnel safety. From the viewpoint of construction project management, although there are many ways to reinforce safety management, construction personnel is the key. Neal and Griffin [29] presented a model identifying the linkages between safety climate, safety knowledge, safety motivation, and safety behavior. The results supported the linkages between safety climate (such as general organizational climate, supportive leadership and conscientiousness) and safety behavior. Tsai *et al.* [36] studied the manufacturing workers and found the reinforcement of the safety cognition help reduce accidents. The supports of managers/supervisors to safety management increase effectively manufacturing workers' safety cognition and thus reduce accident rates. Tam *et al.* [33] also found that safety symbols are effective tools to convey safety massages to the construction personnel. These symbols increase the risk perception of the recipients and thus influence their behaviors. Moreover, the awareness and perception of the workers toward safety, health and their working environment are important aspects to enhance the construction to the better condition to the workers themselves [18]. Andi [2] pointed out that the accidents in construction projects, which can range from minor injuries to loss of life, are originated from workers' unsafe acts. The research concluded that good workers' safety cognition build good safety culture, which initiates the reduction of construction accidents.

Taiwan's occupational accidents tend to occur (1) during the worker's first day at the workplace, (2) when the construction project has an excessively low health and safety management, (3) when employer did not provide personal protection equipments to the workers, (4) when personal protection equipment was not correctly used, and (5) when workers failed to adopt safeguards or ignored hazard warning signs in the workplace [5]. These situations relate closely to safety management as well as workers' safety cognition. The studies of the occupational accidents in Taiwan's construction industry most focused on presenting the characteristics of the accidents from the statistical results [5, 6, 9, 34, 37]. Although Kuo *et al.* [23] explored the state of organizational safety culture in practice in Taiwan's construction industry, there has been little investigation of construction personnel's safety cognition. Knowledge of constriction personnel's safety cognition is important in order to improve safety performance.

II. BUILDING THE COGNITION SCALE

1. Questionnaire Development and Distribution

Personal cognition means that the person selects, organizes, and explains information from external sources and internalizes meaningful conclusions. Individual cognition varies with different external environments, personal characteristics, and individual conditions [22]. Consumers' cognition of products for manufacturing and service industries can be evaluated easily. However, jobholders' cognition of safety for construction industry cannot be evaluated easily. It is important to select variables correlated with disastrous events when investigating construction jobholders' cognition.

Table 3. Summary of research topics of different journals.

Journal	No. of articles extracted	Publication time	Research topics of selected articles
ASCE Journal of Construction Engineering and Management (JCEM)	17	1998-2006	Safety design, labor safety, fall supervision and control, crane accidents, excavation safety, accidents, risk management model, safety climate management and performance, safety management, quantity and quality performance, occupational safety and health policies, human error, construction safety act, accident causes, owner safety management, owner safety rule.
Construction Management and Economics (CME)	5	1999-2004	Safety and accident, worker cognition, perception and risk control, safety resources.
International Journal of Project Management (IJPM)	3	2000-2004	Human risk, safety management, safety rule.
Journal of Construction Innovation (JCI)	1	2004	Safety management method.
Journal of Safety Research (JSR)	1	2004	Safety supervises and control.
Journal of Construction Research (JCR)	2	2003	Safety performance index, safety control.
Engineering, Construction and Architectural Management (EC&AM)	1	1999	Human error.
Automation in Construction (AIC)	1	2006	Improve worker safety.
Safety Science (SS)	2	1997, 2008	Serious accidents, worker perception.
Journal of Occupational Safety and Health (JOSH) (in Chinese)	1	2000	Falls from elevation accidents.
Journal of Chinese Institute of Civil Hydraulic Engineering (JCICHE) (in Chinese)	1	2005	Safety and schedule.
Total	35	-	-

We extracted 234 construction safety cognition items (CSCIs) from 11 construction-related journals (published from 1997 to 2008) and Taiwan's construction safety accident data. Table 3 summarizes the research topics of the 35 articles selected from these journals. Five construction professionals, with more than 20 years working experience, were invited to screen the 234 CSCIs. The 234 CSCIs were summarized in 43 variables and were further classified into seven categories based on their attributes (Table 4). The 43 variables were integrated and reduced to 36 on the basis of the results of interviewing 15 experienced construction practitioners.

The 36 variables serve as the basis of the questionnaire for evaluating the safety cognition of construction personnel. Each variable represents one question in the initial questionnaire. With a Likert seven-point scale adopted in the initial questionnaire, the options were divided into several categories of importance from "very important" (seven points) to "very unimportant" (one point). This study's initial questionnaire was distributed to construction jobholders for pretest and 110 valid questionnaires were collected.

Reliability analysis of the valid questionnaires indicated that Cronbach's α was 0.960; correlations of variables were between medium and high (0.423-0.728), and variables were extracted using principal component analysis (extracted values greater than 0.5). Because the 36 variables' extracted values were between 0.543 and 0.781, all 36 variables remained and were incorporated into the final questionnaire.

We 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, subcontractor foremen, and supervisors), government officers and scholars (e.g., occupational safety officers, junior engineers, engineering audit and control managers, and purchasing agents), and others (owners and engineers). Of the 385 respondents, 364 were valid so there were more than 10 times as many responses as investigated variables.

2. Factor Analysis and Labeling

Factor analysis (FA) uses a few dimensions to represent the data structure and retain most of the original data. FA is a series of methods used to identify clusters of related variables and, hence, is an ideal technique for reducing numerous variables into an easily understood framework. The sample size for FA must be 2-20 times greater than the number of variables to be analyzed, and at least five observations for each variable are indispensable for development of a reliable factor framework [32]. The first stage of FA involves the determination of the strength of relationships among variables measured by correlation coefficients for each pair of variables.

Derived from four stages of FA, the Bartlett test of sphericity is 5934.854 and the associated significance level is 0.000,

Table 4. Selected initial variables.

Categories	No. of variables	Variables	Literature
Human error	6	Unfamiliarity with work, hurry working hours, lack of innovative technique/experience, defective equipment or inappropriate use, judgment mistakes, distracting actions.	[16, 20, 38]
Safety performance	5	Rates of accident while working, cost of accident, lost time and worker absence, safety inspection and culture, first aid injuries.	[12, 19, 37]
Accident causes	7	Unsafe site conditions, poor supervision, lack of safety training, lack of safety equipment or tools, unsafe methods or sequencing, violation of labor laws, external factors.	[3, 20, 25]
Risk and perception	6	Insufficient risk perception, insufficient risk evaluation, risk of design factors, education level, company and government policy, safety equipment and material.	[11, 15, 28, 35]
Management actions	7	Investment in safety resources, regulation enforcement, cooperation and communication, safety education, jobsite safety inspections, subcontractor management, site safety environment.	[7, 8, 12, 13, 17, 26]
Safety management and control	6	Safety audit, up-to-date safety policies, emergency response system, punishment of violations, site safety meetings, urgent response system, tender risk evaluation.	[1, 12, 13, 21]
Accident statistics	6	Rate of occupational injuries, medium and category of accident, annual accident case, relating category and activity, high rates accident activity, definition severe accident.	[9, 16, 28]
Total	43	-	-

indicating that the population correlation matrix is not an identity matrix. All 36 variables were incorporated into the FA. Seven (SC16, SC17, SC19, SC20, SC18, SC2, and SC3) were deleted and 29 variables were extracted, with factor loading values exceeding 0.5 via Principal Component Analysis, after the four stages of FA. No variable is double loaded in any factor. Additionally, the value of the Kaiser-Meyer-Olkin measure of sampling accuracy is 0.932, which clearly exceeds 0.5, and hence is highly acceptable. These test results show that the sample data collected by the study are suitable for FA.

Based on the statistics generated by SPSS 12.0, six factors with eigenvalues > 1 were extracted (Table 5). Each variable weighed heavily on only one factor. The loadings and the interpretation of the variables extracted were generally reasonably consistent. From Table 6, the six factors explained up to 64.5% of the accumulated interpretation variance with a Cronbach's α of 0.946 and hence all six factors are acceptable. Labeled in accordance with variable attributes under them, the six factors were named Human error (HE), Safety performance (SP), Accident causes (AC), Management actions and risk (MAR), Safety management and control (SMC), and Accident statistics (AS).

According to Tsai *et al.* [36], workers' safety cognition is related to accident rate, occupational hazards survey, management level, workers themselves, and management and facility. Table 7 summarizes the reasons for extracting the six factors and 29 variables. Factor 1 (HE) includes four variables (unfamiliarity with work, defective equipment or inappropriate use, judgment mistakes, and distracting actions). Factor 2 (SP) includes five variables (rates of accident while working, cost of accident, safety inspection and culture, and first aid injuries). Factor 3 (AC) includes four variables (poor supervision, lack of safety training, lack of safety equipment or tools, and unsafe methods or sequencing). Factor 4 (MAR) includes four variables (investment in safety resources, regulation enforcement, cooperation and communication, and safety education). Factor 5 (SMC) includes seven variables (jobsite safety inspections, subcontractor management, site safety environment, safety audit, up-to-date safety policies, emergency response system, and punishment for violation). Factor 6 (AS) includes five variables (medium and category of accidents, annual accident cases, related category and activity, high accidental activity, and definition of severe accident). The six factors were renamed as six aspects based on Tsai *et al.* [36] and Yang and Peng [39]. Fig. 1 shows the evaluation framework for the safety cognition scale.

III. APPLYING THE COGNITION SCALE

1. Practice Evaluation

A cognition evaluation scale, consisting of two parts, was designed to assess jobholder's safety cognition. Part I collects the respondent's background, and Part II includes 29 questions corresponding to all variables regarding occupational safety regulations, statistics for construction accidents, and development of the current status of construction safety in Taiwan.

Table 5. Factors of matrix after varimax rotation.

Variables	Factor[a]					
	1	2	3	4	5	6
SC33 Per year accident rates	0.809					
SC36 Definition of severe accident	0.799					
SC35 High accidental activity	0.794					
SC34 Relate category and activity	0.790					
SC32 Medium and category of accidents	0.724					
SC28 Safety audit		0.685				
SC27 Site safety environment		0.662				
SC29 Up-to-date safety policies		0.626				
SC26 Subcontractor management		0.595				
SC25 Jobsite safety inspections		0.578				
SC31 Punishment for rule violation		0.564				
SC30 Emergency response system		0.535				
SC9 Safety inspection and culture			0.687			
SC8 Lost cost of accident			0.640			
SC7 Rates of accident while working			0.598			
SC10 First aid injuries			0.570			
SC11 Unsafe site conditions			0.562			
SC14 Lack of safety equipment or tools				0.752		
SC13 Lack of safety training				0.736		
SC15 Unsafe methods or sequencing				0.664		
SC12 Poor supervision				0.579		
SC1 Unfamiliarity with work					0.749	
SC4 Defective equipment or inappropriate use					0.719	
SC6 Distracting actions					0.657	
SC5 Judgment mistakes					0.652	
SC23 Cooperation and communication						0.688
SC24 Safety education						0.668
SC22 Regulation enforcement						0.651
SC21 Investment in safety resources						0.615

Extraction method: principal component analysis.
Rotation method: varimax with Kaiser normalization.
[a] Rotation converged in 7 iterations.

Table 6. Summary information of principal component analysis.

Factor	Initial eigenvalues			Rotation sums of squared loadings		
	Eigenvalues	% of variance	Cumulative %	Eigenvalues	% of variance	Cumulative %
1	11.355	39.157	39.157	4.525	15.605	15.605
2	2.441	8.417	47.574	3.552	12.248	27.853
3	1.464	5.047	52.621	2.879	9.927	37.779
4	1.303	4.494	57.116	2.612	9.008	46.787
5	1.098	3.785	60.901	2.575	8.880	55.667
6	1.045	3.605	64.505	2.563	8.839	64.505

For instance, the question in SC5 (judgment mistakes) is: What kinds of task judgment mistakes on a construction site have the highest accident frequency? Five options (elevator, dump truck, roller, backhoe, crane) were provided. The Likert seven-point scale designed for the 29 corresponding questions in the cognition evaluation scale is classified as seven points for complete agreement, five-six points for near agreement, and one point for strong disagreement. The suitability of these questions was verified by five experienced professionals.

The evaluation scale was distributed to 110 construction jobholders including safety engineers (30 subjects), design/audit-related personnel (40 subjects), and contractor-related personnel (40 subjects). Table 8 shows that 73 valid copies were retrieved (66.36% returned rate), among which 15 (20.55%)

Table 7. Interpretation of clusters.

Factors	Contents of variable	Comments
Human error (HE)	SC1 Unfamiliarity with work SC4 Defective equipment or inappropriate use SC5 Judgment mistakes SC6 Distracting actions	The four variables are critical to construction engineering human error. According to Huang and Hinze [20], the four variables are suitable to be included in the investigation of human error on construction sites.
Safety performance (SP)	SC7 Rates of accident while working SC8 Lost cost of accident SC9 Safety inspection and culture CS10 First aid injuries CS11 Unsafe site conditions	Based on Wang *et al.* [37], these variables are important for construction safety cognition evaluation in Taiwan.
Accident causes (AC)	CS12 Poor supervision CS13 Lack of safety training CS14 Lack of safety equipment or tools CS15 Unsafe methods or sequencing	The four variables are the primary reasons for project accidents proposed by Arboleda and Abraham [3].
Management actions and risk (MAR)	CS21 Investment in safety resources CS22 Regulation enforcement CS23 Cooperation and communication CS24 Safety education	Compared with Cheng *et al.* [7], the four variables are important for construction safety. The four variables are thus included to evaluate cognition of safety.
Safety management and control (SMC)	CS25 Jobsite safety inspections CS26 Subcontractor management CS27 Site safety environment CS28 Safety audit CS29 Up-to-date safety policies CS30 Emergency response system CS31 Punishment for rule violation	According to Fang *et al.* [12, 13], the seven variables are suitable to identify safety cognition.
Accident statistics (AS)	CS32 Medium and category of accidents CS33 Per year accident cases CS34 Relate category and activity CS35 High accidental activity CS36 Definition of severe accident	In accordance with Gyi *et al.* [16], the four variables are useful for assessing construction accidents.

were from safety engineers, 26 (35.61%) were from design/audit-related personnel, and 32 (43.84%) were from contractor-related personnel. Nearly half of the respondents were working in contractor-related fields. More than 70% of the respondents had been working in the construction industry for 5-20 years. About a quarter of the respondents were equipped with professional licenses such as Professional Engineer and Architect, which were authorized by the Taiwanese government.

2. Group Cognition Comparison

Referring to Table 9, the safety cognition levels for the three groups of jobholders are different. For safety engineers, the sample mean scores (S_i) are between 4.47 and 7.0, and most S_i (15 samples) exceed 6.0. For design/audit-related personnel, S_i (26 samples) are between 2.54 and 6.73, and most S_i are lower than 6.20. For G3, S_i (32 samples) are between 4.03 and 7.0, and most S_i are between 5 and 6 for contractor-related personnel.

Additionally, in the comparisons of the three groups' cognition levels for all variables via the *t*-test, there is no significant difference observed in the three groups for 15 variables (e.g., SC7). On the other hand, significant differences in cognition level are normally limited to one or two groups except for SC34 (accident-related category and activity), for which all three groups have different cognition levels. While investigating all the groups' cognition for each factor's detailed differences, we did not detect significant difference in the three groups' cognition for the variables under the aspect of accident statistics, expect for the variable of SC34. On the other hand, we find the most inconsistent cognition in the three out of four variables under the aspect of accident causes in which the three groups have discrepancies.

Nine and 10 variables were significantly different in terms of group comparisons for G1-G2 and G2-G3, respectively. Only four of the 29 variables were significantly different in terms of group comparison for G1-G3. Against this, we concluded that the least cognition difference occurs between G1 and G3. Additionally, among three groups, the least cognition difference and the most cognition difference belong to safety

Table 8. Questionnaire classification.

Profession	Item	Safety engineers	Design/audit-related personnel	Contractor-related personnel		
	No.	15	26	32		
	%	20.55	35.62	43.83		
Sub-profession	Item	Site supervision	Project management	Quality engineers	Occupational safety	Technician
	No.	23	3	21	15	11
	%	31.51	4.11	28.77	20.55	15.06
Working experience (yrs)	Item	< 5	5-10	10-20	21-30	> 30
	No.	14	24	28	5	2
	%	19.2	32.9	38.4	6.8	2.7
Professional license	Item	Professional engineers	Architect	None		
	No.	12	4	57		
	%	16.44	5.48	78.08		

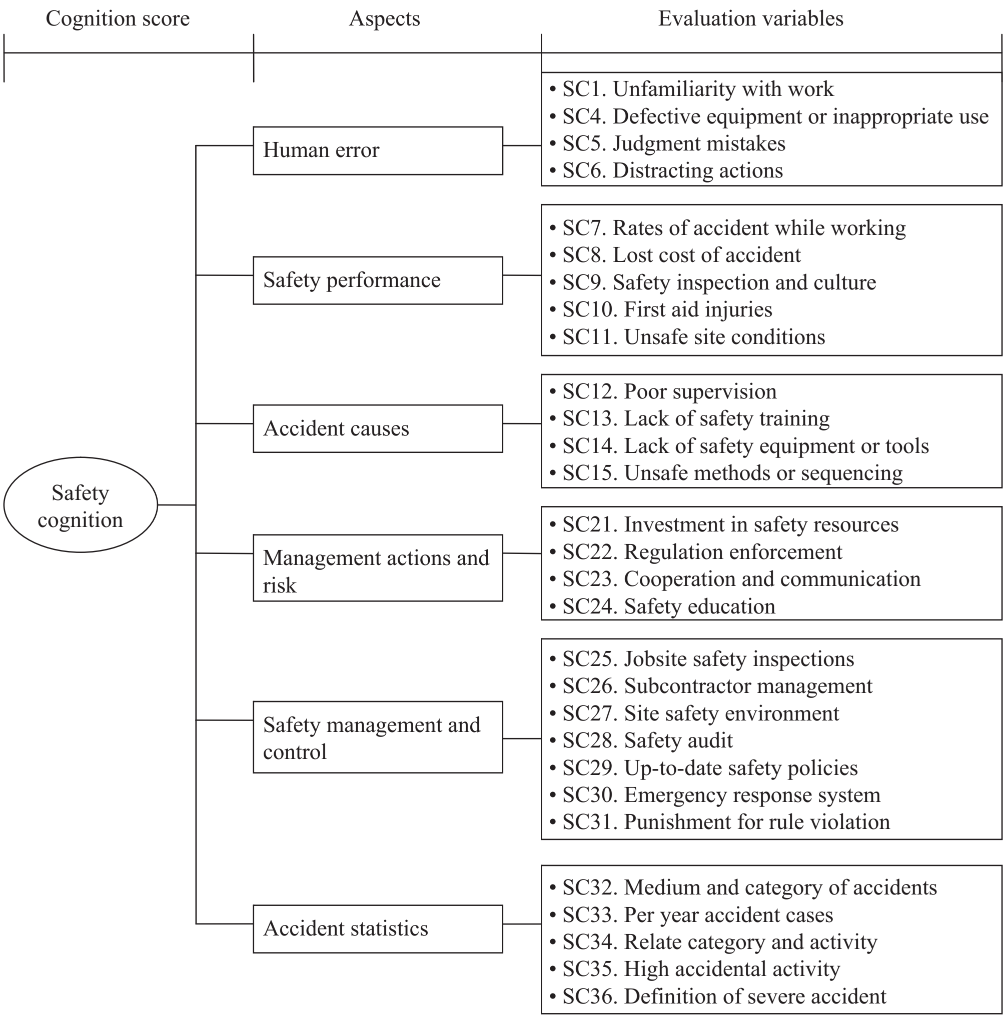

Fig. 1. Evaluation framework for cognition scale.

management and control, and accident causes, respectively. Furthermore, "accident causes" show the most significant differences in terms of group comparison.

As shown in Fig. 1, the S_i from the cognition questions are accumulated to the related aspects. The cumulative scores from all aspects are added to become a total cognition score as

Table 9. Cognition scores of groups.

Aspect	Variables	Sample mean score (S_i)			*T*-test significance (*p* value; 2-tailed)		
		G1 (N = 15)	G2 (N = 26)	G3 (N = 32)	Groups 1-2	Groups 1-3	Groups 2-3
Human error, HE	SC1	5.73	4.42	5.94	0.061	0.588	**0.002**
	SC4	6.47	3.62	6.38	**0.000**	0.914	**0.000**
	SC5	5.93	6.73	6.53	0.034	0.117	0.357
	SC6	5.93	5.31	6.09	0.286	0.612	0.038
Safety performance, SP	SC7	6.73	6.12	6.13	0.136	0.206	0.980
	SC8	7.00	6.62	7.00	0.083	1.000	**0.009**
	SC9	6.07	4.54	5.94	**0.016**	0.902	**0.001**
	SC10	6.40	4.92	5.78	0.101	0.305	0.189
	SC11	6.80	5.54	5.53	**0.021**	**0.003**	0.988
Accident causes, AC	SC12	7.00	6.19	6.91	0.033	0.514	**0.008**
	SC13	5.27	2.65	4.47	**0.000**	0.248	**0.002**
	SC14	6.07	4.12	4.03	**0.001**	**0.000**	0.832
	SC15	5.20	5.00	4.75	0.909	0.615	0.607
Management actions and risk, MAR	SC21	4.47	4.00	4.31	0.227	0.892	0.228
	SC22	6.60	6.50	6.28	0.895	0.582	0.616
	SC23	4.40	2.54	4.94	**0.021**	0.741	**0.001**
	SC24	6.13	5.04	6.25	0.087	0.700	**0.005**
Safety management and control, SMC	SC25	6.73	6.73	6.66	0.935	0.766	0.670
	SC26	6.07	6.08	6.03	0.869	0.934	0.882
	SC27	6.53	6.38	6.38	0.512	0.517	0.973
	SC28	7.00	5.85	6.47	**0.017**	0.081	0.100
	SC29	5.60	4.85	4.53	0.071	**0.009**	0.190
	SC30	6.00	6.42	6.50	0.240	0.137	0.815
	SC31	6.87	5.92	6.72	**0.003**	0.627	**0.004**
Accident statistics, AS	SC32	6.73	6.31	5.81	0.373	0.100	0.278
	SC33	4.60	3.50	4.59	0.107	0.935	0.034
	SC34	6.93	4.50	5.88	**0.000**	**0.025**	**0.010**
	SC35	5.40	4.65	4.06	0.218	0.219	0.134
	SC36	6.13	6.15	6.22	0.966	0.812	0.797

Note: G1: Safety engineers; G2: Design/audit-related personnel; G3: Contractor-related personnel; *p* value with bold means difference.

the basis to compare all groups' cognition levels. Table 10 shows the cognition score for Group 1, sample #1. Investigating outcomes of cognition analysis for each group's samples shown in Appendix 1, we perceive the order regarding evaluated safety cognition as: safety engineers, contractor-related personnel, and design/audit-related personnel. With the cumulative cognition scores for the 2-tailed *t*-test of significance, $p = 0.000$ for safety engineers to design/audit-related personnel and design/audit-related personnel to contractor-related personnel, and $p = 0.0289$ for safety engineers to contractor-related personnel. Significant differences exist in cognition scores between safety engineers and design/audit-related personnel and between design/audit-related personnel and contractor-related personnel. However, the difference between the cognition scores of safety engineers and contractor-related personnel is smaller.

3. Results Analysis

Appendix 1 shows that the cognition scores of safety engineers involved in construction safety are much higher than those of design/audit-related personnel or contractor-related personnel. For example, the difference between cognition scores of safety engineers and design/audit-related personnel is 25.6 points (= 176.8 – 151.2). With the mean cognition score of each group divided by the total cognition score (29 × 7 = 203), the ratio is 87.09% (= 176.8 ÷ 203) for safety engineers, 82.3% (= 167.1 ÷ 203) for contractor-related personnel, and 74.5% (= 151.2 ÷ 203) for design/audit-related personnel. In this regard, design/audit-related personnel equipped with low safety cognition levels (< 75%) may cause more accidents while engaged in safety control at a construction site compared with safety engineers and contractor-related personnel, who are both equipped with much higher safety cognition levels（≧ 80%).

In line with the dissimilar overall cognition scores among the three groups, the cognition for all aspects' variables are quite different (Table 9). The smallest cognition difference among the three groups is in the aspect of accident statistics;

Table 10. Cognition score of examples.

Evaluation ΣΣ (S_i)	Aspect score	Variables	G1, sample #1 score (S_i)	Aspect score (ΣS_i)	Aspect averaged score
Cognition score, CS (Σ = 161)	Human error, HE	SC1	7	22	5.5
		SC4	4		
		SC5	7		
		SC6	4		
	Safety performance, SP	SC7	7	20	4.0
		SC8	7		
		SC9	1		
		SC0	1		
		SC11	4		
	Accident causes, AC	SC12	7	20	5.0
		SC13	2		
		SC14	4		
		SC15	7		
	Management actions and risk, MAR	SC21	4	25	6.25
		SC22	7		
		SC23	7		
		SC24	7		
	Safety management and control, SMC	SC25	7	46	6.57
		SC26	7		
		SC27	7		
		SC28	7		
		SC29	7		
		SC30	4		
		SC31	7		
	Accident statistics, AS	SC32	7	28	5.6
		SC33	7		
		SC34	7		
		SC35	3		
		SC36	4		

the biggest cognition difference is in the aspect of accident causes. Of the 29 variables, nine were significantly different between safety engineers and design/audit-related personnel, and 10 between design/audit-related personnel and contractor-related personnel. Only four variables were identified with little difference between safety engineers and contractor-related personnel. The results indicate that different cognition for all aspects' variables exists between design/audit-related personnel and safety engineers, design/audit-related personnel and contractor-related personnel.

Identified by the study, the low safety cognition levels of design/audit-related personnel show that the supervision system in Taiwan's construction industry is not substantially satisfied (except the public works' supervision system) because architects fail to reach a consensus for construction safety supervision [30]. Satisfying the construction supervision system is obviously a critical issue in Taiwan for the improvement of construction safety. In fact, the *Guidelines for Occupational Safety and Health Management for Public Works* in Taiwan explicitly regulates related construction safety activities taken by contractors and supervisors for public works. However, there is a need for revision of regulations for private projects.

The performance of construction safety should be managed and controlled by the jobholders at various levels for construction projects. The three-level safety-management approach was promoted to improve construction safety management in Taiwan [30]. The hierarchy approach includes: contractor's safety self-management (Level 1), designer's safety supervision and inspection (Level 2), and owner's safety management (Level 3). Construction jobholders should strengthen their safety cognition to raise their safety performance via occupational safety practice and educational training.

IV. CONCLUSIONS AND SUGGESTIONS

To collect safety cognition variables from construction jobholders, we designed a cognition questionnaire consisting of six aspects (human error, safety performance, accident causes, management actions and risk, safety management and control, accident statistics) and 29 cognition evaluation questions. A safety cognition evaluation scale was developed and used to investigate the safety cognition of three groups of construction personnel in Taiwan.

The safety cognition ranking for construction personnel (in descending order) is: safety engineers, contractor-related personnel, and design/audit-related personnel, respectively. Based on the *t*-test of safety cognition, it was found that significant differences exist between safety engineers and design/audit-related personnel, and between design/audit-related personnel and contractor-related personnel, while no significant differences was found between safety engineers and contractor-related personnel. We concluded that there are significant differences among the three groups in terms of overall cognition and individual variables. According to the difference analysis in terms of the six aspects, the accident statistics aspect shows the smallest cognition difference while the accident causes aspect shows the most inconsistent cognition difference. Based on variables difference analysis, there are nine (the highest among the three groups) variables with significant differences between safety engineers and design/audit-related personnel, and 10 between design/audit-related personnel and contractor-related personnel. There are only four variables with significant differences between safety engineers and contractor-related personnel, the lowest among the three groups of construction jobholders. The low safety cognition level of design/audit-related personnel reveals that the supervision system in Taiwan's construction industry is not substantially satisfied; especially, architects of private projects fail to reach a consensus for construction supervision. The *Guidelines for Occupational Safety and Health Management for Public Works* in Taiwan explicitly regulates related construction safety activities taken by construction and supervisors for public works. There is a need for revision of regulations for private projects.

There has been little investigation of Taiwan's construction personnel's safety cognition. The investigation of this study provides knowledge of the safety cognition of Taiwan's construction personnel. This information provides safety managers better understanding of Taiwan's construction personnel to enhance the latter's safety cognition and thus safety performance. In addition, safety management should become an important focus for construction projects, which traditionally concentrate on schedule management, cost and quality. For future research, we suggest incorporating the safety cognition of other construction jobholders (such as owners, contractors, administrators, public works staff, subcontractors, and researchers) and expanding the samples of the study. Using the confirmatory Structural Equation Modeling (SEM), an evaluation model comparing different groups' construction safety cognition should be considered as well.

APPENDIX 1 GROUPS SAMPLE COGNITION SCORES

Sample (No.)	Cognition score, CS		
	Safety engineers (Group 1)	Design/audit-related personnel (Group 2)	Contractor-related personnel (Group 3)
1	161	156	178
2	153	169	138
3	176	156	167
4	175	149	178
5	191	162	149
6	192	135	165
7	185	162	177
8	197	172	184
9	199	160	169
10	179	136	162
11	167	149	171
12	167	145	178
13	162	144	172
14	162	137	176
15	186	142	166
16		146	166
17		152	172
18		159	159
19		161	162
20		132	184
21		165	151
22		134	157
23		137	171
24		154	170
25		166	162
26		151	161
27			165
28			167
29			167
30			161
31			173
32			169
Mean	176.8	151.2	167.1
Std. Deviation	14.5	11.8	9.8
T-test	Groups 1-2	Groups 1-3	Groups 2-3
Significance (*p* value; 2-tailed)	0.000	0.0289	0.000

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