PREDICTING SAFETY LEVELS OF CONSTRUCTION PROJECT SITES

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ABSTRACT

The objective of this paper is to construct a model to predict the safety level of a construction project site. The attributes that govern the safety level of a construction site may be categorized under policy factor, process factor, personnel factor and incentives. Under each factor, many attributes are operationalised. A questionnaire is designed to collect project-specific safety related data from contractors who undertook construction projects in Singapore. The multiple linear regression model to predict construction site safety that is constructed in this study shows that 14 variables may be used to predict construction safety. Based on the results, it is recommended that contractors use the model to assess how safe their construction sites are. In addition, contractors should pay greater attention to personnel factors as these may affect construction safety significantly.

Keywords: site safety, safety policy, Singapore construction industry, site accidents, incentive

INTRODUCTION

In Singapore, safety has been a concern for the construction industry for past decades. Although, the total number of construction accidents has been reduced, fatal accidents are still a problem for the industry. There are 38 cases of construction fatalities reported in 2002 as compared to 27 cases in 2001 (MOM, 2002). In 2002 alone, construction fatal accidents account for 59% of total fatal accidents in all industries over Singapore.

The objectives of this paper are (1) to find explanatory variables that significantly affect the safety level of a construction site, and (2) to construct a model to predict the safety level of a construction site. The first objective is important because contractors will know the important variables that they must pay very close attention to in order that their project sites are safe. The second objective is important because the safety model developed in this study can help contractors predict what the likely safety level of a construction site will be. This is useful because based on the predicted safety level, contractors can decide if they need to improve the safety level further.

The next section is a brief literature review of variables that affect the construction safety on site. The research method is then presented, followed by the results and model construction. A discussion of the model and the factors that may be used to predict construction safety follows, followed by conclusions and recommendations. The projects investigated in this study were building construction projects in Singapore. Both private and public sector projects were investigated.

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LITERATURE REVIEW

The Ministry of Manpower (MOM) in Singapore tracks site safety through several measures. These include frequency rate which is the number of industrial accidents per million man-hours worked; and severity rate, which is the number of industrial man-days lost per million man-hours worked (MOM, 2002). In this study, the safety level of a project is measured on a 5-point scale, where 1= unsafe (fatal accident is likely), 2= Accident that leads to permanent disablement; 3= Accident that leads to temporary disablement; 4= minor injuries and 5= very safe (zero accident).

From the literature based on past safety studies and Singapore Code of Practice for Safety Management System for construction worksites (CP79), the accident contributors may be categorised into five factors: policy, process, personnel, incentive and others. These are further operationalised into attributes, which are now briefly reviewed.

Policy Factors include legislation, codes and regulations relating to safety. Rowlison (1997) explained that legislation forms a framework within which health and safety is regulated and controlled. All construction practitioners have to follow the rules and regulations duly and punishments to be meted out to those who flout them. Lingard and Rowlinson (1994) found that legislation and their enforcement do affect construction job safety to a considerable extent in Hong Kong. As such, safety legislation has to be taken seriously when planning job activities and setting down company policies.

Process factors refer to the process of carrying out works by construction personnel that may eventually be harmful to their well-being and safety. MOM (2002) and Ofori (1997) highlighted that in general, accidents on construction sites in Singapore were caused by: unsafe working conditions at heights, stepping on, striking against or tripping over objects, poor lighting conditions, burial by earth collapse during excavation, collapse of scaffoldings and working platforms, hazards in lifting operations, electrocution, fire hazards, lack of proper access and inadequate education and training. In addition, engagement of poor tools and equipment can also cause accidents (Teo and Chong, 2003; Alistair *et al*., 1997).

Personnel factors refer to issues pertaining to the human aspect of the construction activities, such as the safety behaviour and attitudes of the management and workers within an organisation. The safety behaviour and attitudes represent its safety culture. According to Clarke (1999), safety culture is a subset of organisational culture, where the beliefs and values refer specifically to matters of health and safety. Thus, the safety culture in an organisation is dependent upon its management and workers' level of commitment to its safety promotion and campaign.

Accidents may occur because of poor attitudes and bad behaviours portrayed by workers on construction sites, which are difficult to monitor and control. Hinze (1981) found a positive link between safety performance and workers' attitudes where workers with better safety records relate well with each other. In addition, Dedobbeler and Beland (1991) discovered that negative behaviours and attitudes have prompted most workers not to put on their personal protective equipment whilst working on site. In order for workers to behave safely, they need to possess the correct skills and knowledge for the nature of work and to be motivated (Lindell, 1994).

Previous studies show that there is no concurrence on whether incentives can improve site safety. Some studies in favour of the scheme have proven that a reduction in construction site accidents and injuries has been achieved (Geller, 1999). Other studies showed that safety indices did not improve despite of the introduction of safety incentives (McAfee and Winn, 1989).

The final group of attributes relate to certain measures or programmes that may help to improve site safety. These include having regular group meetings, accident investigation and analysis plans, hazard analysis plans and programmes, emergency preparedness plans and evacuation exercises, movement records of hazardous and flammable substances, safety promotional programmes, and occupational health programmes (Teo and Chong, 2003).

From the literature review, 58 potential variables that may affect the level of safety in the construction sites were identified. These are grouped into five major headings: Policy, Process, Personnel, Incentive and Others. Hitherto, there is no tool to predict how safe a site may be. This study attempts to fill this gap.

RESEARCH METHOD

A questionnaire was designed with the objective of determining the more important variables that affect site safety. In the questionnaire, respondents were requested to provide information relating to safety aspects of one of their most recent completed projects. Respondents were asked to rate the extent to which each of the 58 variables influenced the site safety level of the project, on a five point where 1 represented 'not important at all' and 5 represented 'very important'.

The target population was contractors that are registered with the Singapore's Building and Construction Authority (BCA). The BCA classifies every registered contractor under one of seven categories, depending on their operational and financial capabilities. The lowest category of contractors can bid for projects of value no more than S$500,000 while the highest category of contractors are allowed to bid for projects of any size. The study sampling effort identified 1506 general building contractors. Of these, questionnaires were sent by post to 420 randomly selected contractors in all seven categories. The survey package consisted of a cover letter, the questionnaire and a self-addressed and pre-stamped envelope.

SURVEY RESULTS AND DATA ANALYSIS

61 questionnaires were returned within two months of sending out (see Table 1). Of these, one questionnaire that was not substantially completed was discarded. Data from the remaining 60 (response rate of 14%) usable returned questionnaires were checked, edited, coded and analyzed. The response rate of 14% is not high.

TABLE 1
Distribution of questionnaires and response rate

Contractor financial classification	Sent out	Returned (Usable response)	Percentage
A1	37	12	32.4
A2	28	10	35.7
B1	76	11	14.5
B2	79	7	8.9
C1	66	7	10.6
C2	67	5	7.5
C3	67	4	6
Unknown	-	4	-
Total:	**420**	**60**	**14.29**

The designation of the respondents covered a wide range. 20%, 48% and 17% of the respondents were upper management, middle management and safety personnel respectively. Only 7% of the respondents were junior staff. Upper management respondents comprised managing directors, directors and general managers and senior project managers. The middle management respondents were project managers and assistant general managers. Safety personnel refer to environmental heath and safety officer/ manager, safety officer, safety supervisor and safety auditor. Junior staff refers to site supervisor, site coordinators and clerk-of-works.

The average number of years that respondents have worked in the construction industry is 12 years. The minimum and maximum numbers of years of experience are one and 34 respectively. In addition, 60% of the respondents have more than 10 years of working experience.

The mean response for each attribute is also calculated (see Table 2).

TABLE 2
Mean ratings of attributes influencing site safety

Rank	Ref	Attributes influencing site safety	Mean
		POLICY ASPECT	
1	PO1.7	Proper implementation of In-house rules & regulations	4.53
2	PO1.3	Proper implementation of SMS	4.42
3	PO1.6	Understanding of In-house rules & regulations	4.38
4	PO1.2	Understanding of CP79: 1999 (SMS)	4.36
5	PO1.1	Understanding of Factories Act (BOWEC)	4.35
6	PO1.8	Understanding of Permit-to-work system	4.30
7	PO1.9	Proper implementation of Permit-to-work system	4.29
8	PO1.10	Understanding of insurance policies	4.22
9	PO1.4	Understanding of BCA OHSMS	4.03
10	PO1.5	Company's participation in BCA OHSMS	3.85
		PROCESS ASPECT	
1	PR2.9	Identification of unsafe practices on site	4.97
2	PR2.10	Proper implementation of safe practices on site	4.55
3	PR2.5	Familiarity with type & method of construction by safety officers/ supervisors	4.53
3	PR2.8	Proper implementation of safety procedures	4.53
3	PR2.12	Good house-keeping	4.53
6	PR2.13	Proper handling of tools, equipment & plants	4.47
6	PR2.3	Co-ordination, control & management of sub-contractors	4.47
8	PR2.7	Understanding of safety procedures	4.45
9	PR2.6	Communication and information flow	4.43
10	PR2.16	Tight control of hazardous activities on site	4.37
11	PR2.4	Type and method of construction	4.30
11	PR2.11	Identification of hazardous & dangerous activities	4.30
13	PR2.15	Technical competency of specialist sub-contractors	4.22
14	PR2.14	Maintenance regime of tools, equipment & plants	4.08
15	PR2.2	Selection of sub-contractors	4.07
16	PR2.1	Total number of sub-contractors	4.00
		PERSONNEL ASPECT	
1	PE3.3	Adoption of safe work behaviours by workers and supervisors	4.55
1	PE3.2	Attitudes of workers and supervisors towards safe work practices	4.55
3	PE3.11	Management's roles & responsibilities towards safety & health promotion	4.50
4	PE3.12	Management's safety culture	4.40
5	PE3.8	Influence of managers and supervisors over workers	4.39
6	PE3.1	Safety & health training	4.38
7	PE3.9	Safety committee's roles & responsibilities	4.22
8	PE3.10	Understanding of safety committee's aims & objectives by employees	4.13
9	PE3.7	Work experience of workers and supervisors	3.98
10	PE3.6	Workers' language & communication barriers	3.93

Rank	Ref	Attributes influencing site safety	Mean
11	PE3.5	Workers' adaptation to working environment	3.90
12	PE3.4	Workers' cultural backgrounds	3.78
		INCENTIVE ASPECT	
1	IN4.8	Degree, level & type of punishments in terms of fines (Monetary)	4.25
2	IN4.7	Introduction of penalties & punishments	4.07
3	IN4.1	Introduction of incentives	3.95
4	IN4.9	Degree, level & type of punishments in terms of suspension from work	3.93
5	IN4.2	Level & type of incentives in terms of bonus (Monetary)	3.63
6	IN4.6	Level & type of incentives in terms of employee of the month award	3.58
7	IN4.4	Level & type of incentives in terms of certificate of recognition	3.43
8	IN4.5	Level & type of incentives in terms of rewards in kind	3.35
9	IN4.3	Level & type of incentives in terms of promotion (position)	3.32
10	IN4.12	Degree, level & type of punishments in terms of reporting to relevant authorities	3.23
11	IN4.10	Degree, level & type of punishments in terms of demotion (position)	3.15
12	IN4.11	Degree, level & type of punishments in terms of termination of service	3.14
		OTHER ASPECTS	
1	OF5.4	Having regular safety inspections by the safety officer/ safety committee	4.40
2	OF5.1	Having regular group meetings by the management teams and the safety committee (e.g., coordination meetings, safety promotion meetings, etc)	4.17
3	OF5.2	Having thorough accident investigation and analysis plans and regime by the management/ safety committee	4.13
4	OF5.5	Having thorough hazard analysis plans and programmes conducted by the safety officer/ safety committee	4.03
5	OF5.7	Having thorough emergency preparedness plans and evacuation exercises conducted by the management/ safety committee	4.00
6	OF5.6	Having tight control over the movement records and charts of hazardous and flammable substances by the management/ competent personnel	3.98
7	OF5.3	Having safety promotional programmes (e.g., Safety posters, safety slogans, safety contests and competitions, etc)	3.97
8	OF5.8	Emplacing occupational health programmes (e.g., occupational health workshops and talks, regular health screenings, etc)	3.92

MULTIVARIATE ANALYSIS

In this study, multivariate regression analysis was used to develop a model to determine the statistical relationship between site safety level (response variable) and the explanatory variables (for example total number of sub-contractors in the project, see Table 2). The model was developed using traditional regression techniques with the help of the Statistical Package for Social Sciences software (SPSS).

In this research, the independent/predictor variables are the attributes relating to the policy, process, personnel and incentive aspects of the project listed in Table 2. For each model, the dependent variable is the site safety level.

MODEL DEVELOPMENT

Given the large number of predictor variables and the limited sample size, there was a need to reduce the number of predictor variables, before embarking on regression modelling. In Step 1, predictor variables that correlate significantly ($p \leq 0.05$) to the safety level were identified through Spearman's correlation analysis. The other independent variables that displayed weak associations ($p > 0.05$) with the performance metric were eliminated, and therefore, the number of predictor variables was reduced. The predictor variables that are significantly correlated to a dependent variable were then used to construct a multiple linear regression model.

Regression modelling is an iterative process. The details of the site safety and related features of the 60 projects were input into the SPSS software and 14 possible models were produced. The predictive power of the model is judged through the coefficient of determination (R^2), which is a measure of the goodness of fit for the model. R^2 is used to measure the strength of the correlation when more than two variables are being analyzed. The R^2 gives the proportion of the variance of Y, which is explained by the independent variables, reflecting the aptness of the model. However, when more independent variables are introduced into the model, R^2 automatically increases. A better estimate of the model's goodness of fit is *adjusted* R^2. Unlike R^2, it does not inevitably increase as the number of included explanatory/independent variables increases.

The optimum model is Model 14 is selected through accepted regression modelling practices. The regression analysis techniques include maximizing the R^2 value ($R^2 = 0.996$, adjusted $R^2 = 0.990$), minimizing model variances, and only including variables in the model that have been proven to be statistically significant through t-tests (see Table 3), F-tests (F statistic = 154.441, $p = 0.000$), and stepwise selection procedures.

TABLE 3
Coefficients for dependent variable 'site safety'

Model 14	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	4.918	.291		16.914	.000
PO1.5	-.783	.027	-1.155	-29.061	.000
IN4.1	.499	.036	.508	13.756	.000
PO1.10	-.769	.039	-.694	-19.484	.000
IN4.9	-.255	.036	-.276	-7.052	.000
PE3.1	1.080	.077	.689	13.975	.000
PE3.7	.653	.047	.451	13.885	.000
PE3.6	-.465	.047	-.435	-9.793	.000
PE3.9	-.454	.047	-.376	-9.705	.000
PE3.12	.696	.071	.584	9.817	.000
IN4.7	-.190	.036	-.175	-5.230	.001
OF5.7	-.240	.038	-.250	-6.340	.000
OF5.1	.285	.043	.285	6.703	.000
PR2.8	-.355	.103	-.245	-3.451	.009
IN4.11	-6.246E-02	.026	-.107	-2.429	.041

MODEL ESTIMATION AND DISCUSSION

This section discusses the model that was developed. The discussion highlights significant attributes that affect site safety. By knowing the attributes, practitioners could go about controlling and managing them so as to achieve a higher level of project success.

The model to predict construction site safety, extracted from Table 3 is presented below.

$$Y = -.783(PO1.5) + .499(IN4.1) - .769(PO1.10) - .255(IN4.9) + 1.080(PE3.1) + .653(PE3.7) - .465(PE3.6) - .454(PE3.9) + .696(PE3.12) - .190(IN4.7) - .240(OF5.7) + .285(OF5.1) - .355(PR2.8) - 0.06246(IN4.11) \quad (1)$$

Where:

Y is the safety level of the site, measured on a 5-point scale, where 1= unsafe (fatal accident is likely), 2= Accident that leads to permanent disablement; 3= Accident that leads to temporary disablement; 4= minor injuries and 5= very safe (zero accident).

The other variables are as defined in Table 2, and measured on a 5-point scale, where 1= not important or not emphasized; and 5= very much emphasized or very important.

To use the model, contractors should input the relevant ratings for the 14 variables and then calculate the safety level of the project (Y).

Under *policy factor*, two predictor variables are identified: company's participation in safety certification scheme (PO1.5); and understanding of insurance policies taken up for the project (PO1.10). Both these attributes have negative β coefficients, indicating that when there is higher participation or understanding, the site safety level may decrease.

A company's participation in safety certification scheme may be through the Occupational Health and Safety Management System (OHSMS) certification. To achieve this, firms need to fulfil the requirements of the Occupational Health and Safety Assessment Scheme (OHSAS) 18001. While the safety certification is meant to encourage and enhance safety awareness, promote safe work practices and raise the safety standards of the Singapore construction industry, the results show that high levels of this may affect safety negatively (Pol_5). One possible explanation is that employees may be too preoccupied with documentation and paperwork, and neglect the actual safety aspects on site.

The Workmen's Compensation policy and the Contractor's All Risk Liability policy are necessary insurance obligations the contractor has to fulfil before any construction work commences. The results show that deeper understanding of insurance policies may lead to lower site safety (PO1.10). This is consistent with Lingard and Rowlinson's (1994) study which found that contractors who rely more on insurance may tend to shift the liability for compensation to insurance companies, and in so doing, disregard the adequate provision of proper site safety training and supervision for the workers (Lingard and Rowlinson, 1994).

Under *process factor*, only one variable affects site safety directly: proper implementation of safety procedures (PR2.8). The negative β coefficient shows that when more safety procedures are implemented, safety level may decrease. One possible explanation is that workers who work in construction sites which have many safety procedures may become complacent about safety. Dedobbeler and Beland (1991) found that some organisations or individuals had in fact, committed an unsafe act unknowingly while carrying out their tasks and jobs. As a result of their ignorance, they are subjecting themselves and others to potential dangers and injuries.

Personnel factor has the highest number of variables (five) that affect site safety. These are: safety and health training for employees (PE3.1); workers' language and communication barriers (PE3.6); level of work experience within an employee's specific trade (PE3.7); roles and responsibilities of the safety committee (PE3.9); and safety culture displayed by the management (PE3.12).

The results show that when there is more safety and health training for employees (PE3.1), site safety level will become higher. This is consistent with other studies (Heberle, 1998). Lingard's (2001) study on the effect of first aid training on Australian construction workers revealed that training has a positive preventive effect on workers to avoid injury. Similarly, McKenna and Hale (1981) found workplace injuries are reduced when workers received first aid training.

The negative β coefficient for workers' language and communication barriers (PE3.6) indicate that when barriers are high, site safety will be lowered. Studies have shown that having effective communication and information transfer will yield better safety standards and enhance the achievement of safety policies (Holt, 2001). The type and nature of information transfer varies from the use of different means (for example; verbally, written, gesture, etc) and will greatly affect the effectiveness of such transferring mediums.

When workers and supervisors' experience (PE3.7) is high, the site safety will also improve. Work experience will lead to higher job performance and this is also translated into lower safety violations. More job experience leads to higher job performance because job experience enables individuals to acquire skills, techniques, methods, and habits that directly produce improvements in performance capabilities (Schmidt *et al*., 1986).

This study shows that when the safety committee has many important roles and responsibilities, the safety level on site may in fact reduce (PE3.9). This is a peculiar result because if all the positive actions will lead to a decline in performance they appear to have no effective use. One possible reason is the reliance on this committee to ensure site safety, instead of making safety everybody's business.

The positive β coefficient safety culture displayed by the management (PE3.12) means that higher safety culture displayed lead to higher site safety. This is in accord with the findings of Mattila *et al*. (1994) that the reduction in accidents would be achieved when the top management take an active interest and are dedicated to safety enhancement as well as maintaining good safety standards.

Four attributes under *incentives* affect site safety: incentives to employees for motivating them towards maintaining good safety standards on site (IN4.1); penalties and punishments for offenders/ repeat offenders (IN4.7); suspension from work (IN4.9); and termination of service when violating safety rules and regulations (IN4.11).

This study found that incentives lead to higher site safety (IN4.1). The finding therefore agrees with Geller (1999). The other three variables relating to disincentives in the form of penalties (IN4.7), suspension from work (IN4.9) and termination of service (IN4.11) all have negative β coefficients; indicating that the less these are used, the higher the site safety will be. The reasons may be that these measures are drastic and should only be considered when the violator has committed a serious safety and health offence or is a repeat offender. This is consistent with Hislop (1999) who argued that discipline should be the last recourse to reinforce the application of safe work practices when all else (training, guidance and encouragement) failed.

Two *other variables* that may be used to predict construction safety are: having regular group meetings by the management teams and the safety committee (OF5.1) and having thorough emergency preparedness plans and evacuation exercises conducted by the management/ safety committee (OF5.7).

Having regular group meetings by the management teams and the safety committee (OF5.1) indicates a healthy safety culture, which brings about positive effects on construction sites, as previously discussed. Baxendale and Jones (2000) discovered that the safety commitment of the management is determinant upon the various means of communication and information transfer to all levels of the construction project. The negative β coefficient for having thorough emergency preparedness plans and evacuation exercises conducted by the management/ safety committee (OF5.7) may mean too much time and effort spent in these exercises, to the extent that actual site works and safety aspects are neglected.

The findings in this study suffer have some limitations. The first limitation is that only 60 project data sets were used to construct the models, which appeared to be small. The second is the possible presence of multicollinearity in the model. When multicollinearity is present, the variances of the estimated coefficients will be exaggerated and thus the predictability of the regression models becomes less satisfying. The second limitation is that the model has not been validated. This could be a possible further research on this model.

CONCLUSION

The essence of this study is that significant variables that affect construction safety were identified in Table 3, thus achieving the first objective. Site safety level can be predicted, thus fulfilling the second objective of this study. The prediction can be made through the model shown in Table 3 or Equation 1. The model has high R^2 and the regression coefficients are significant.

The multiple linear regression model to predict construction site safety that is constructed in this study shows that 14 variables may be used to predict construction safety. Under *policy factor*, two predictor variables are identified: company's participation in safety certification scheme; and understanding of insurance policies taken up for the project. Under *process factor*, only one variable affect site safety directly: proper implementation of safety procedures. *Personnel factor* has the most variables (five) that affect site safety. These are: safety and health training for employees; workers' language and communication barriers; level of work experience within an employee's specific trade; roles and responsibilities of the safety committee; and safety culture displayed by the management. Four attributes under *incentives* affect site safety: incentives to employees for motivating them towards maintaining good safety standards on site; penalties and punishments for offenders/ repeat offenders; suspension from work and termination of service when violating safety rules and regulations. Two other variables that may be used to predict construction safety are: having regular group meetings by the management teams and the safety committee; and having thorough emergency preparedness plans and evacuation exercises conducted by the management/ safety committee.

The model developed in this study can be used to predict the project's likely safety level. The practical application of this research finding for contractors is that in order to ensure their projects have high safety standards, they should concentrate on the important attributes which can be used to site safety.

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