Received September 2007
Revised August 2008
Accepted September 2008

Strategic safety management information system for building projects in Singapore

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Abstract

Purpose – The construction industry in Singapore has been recording higher accident rates compared with other industries. As an initiative to reduce occupational accidents, the Building and Construction Authority of Singapore proposed to clients to adopt quality-fee method (QFM) for tender evaluation, departing from the traditional lowest price method. Assessing tenderers' safety proposals is a crucial task for clients' project managers to implement QFM, but it is a difficult and challenging task. This study aims to provide a tool to facilitate this.

Design/methodology/approach – A triple-index model was developed for estimating potential accident risks in building projects, given that a contractor's proposed safety system is in place to combat the accident hazards inherent in the project. The model was then automated as a decision support system (DSS). Case studies were conducted to test the reliability and accuracy of the DSS.

Findings – The DSS produces project accident indices, and it was found in the case studies that values for this index are positively correlated with the number of accidents in building projects. The findings proved that the DSS makes a significant contribution to the state-of-the-art of risk assessment.

Practical implications – The proposed model and its DSS would facilitate the implementation of QFM for tender evaluation and thereby reduce accidents.

Originality/value – The paper presents a novel tool to combat accidents in construction at the early stage of tender evaluation.

Keywords Procurement, Construction industry, Quality, Safety, Decision support systems

Paper type Research paper

Introduction

The construction industry is perceived to be one of the more dangerous industries, which has a poor safety performance record globally. Singapore's construction industry, for only 29 per cent of the total number of industrial workers, accounted for 40 per cent of worksite accidents (Chua and Goh, 2004). Moreover, the latest analysis of worksite accidents by Singapore's Ministry of Manpower revealed that the construction industry recorded the highest accident frequency and severity among all the industries in Singapore (OSHD-MOM, 2006a). Hence, raising safety standards by introducing new laws and frameworks has been a goal, following a series of high profile construction accidents in previous years in Singapore.

The committee of inquiry into the Nicoll Highway collapse recommended that a strict weightage system should form part of the tender evaluation system (Lian, 2005). The weightage system should include non-technical and non-commercial attributes such as safety records and culture of the bidder, and its core or corporate competency.

Engineering, Construction and Architectural Management
Vol. 16 No. 1, 2009
pp. 8-25

0969-9988
DOI 10.1108/09699980910927868

Such a weightage system should apply even if the tenderer is a joint venture or a consortium. It was recommended to clients' project managers to adopt the quality-fee method (QFM) for tender evaluations, departing from the traditional lowest price method (MND, 2005). According to the QFM, tenders are scored based on pre-defined weightings for both price and quality attributes. Quality attributes in a tender include safety management proposal, method statement, resources, programme and innovations. Then, apply a formula approach to combine price scores and quality scores as follows (BCA, 2005):

- the lowest price tender obtains the maximum price-score and the highest quality tender yields the maximum quality-score; and
- the tender with the highest overall score would be selected.

The effective assessment of the safety proposal in a tender is one of the key aspects for project managers to implement the QFM. This study aims at developing a tool to facilitate project managers' task of assessing the safety proposals for building construction projects by means of assessing the potential accident risks given that the proposed safety management system is in place. The objectives of this paper are to:

- identify and explore the factors that lead to accidents in building projects;
- develop a methodology for estimating accident risks in building projects; and
- develop a decision support system (DSS) for automating the methodology above.

The paper discusses the research via various sections in a logical order. First, an extensive literature review on the nature of occupational injuries is presented, followed by an account of hazards in building projects and their assessment parameters. A safety audit roster for building projects is then explored. Subsequently, a triple-index model for estimating accident risks on building sites is proposed, followed by the DSS architecture that automates the triple-index model.

Occupational injuries in construction

Occupational injuries from construction activities in general are defined by Davies and Tomasin (1996) as:

- danger of physical injury and fatality; and
- health problems.

Construction accidents resulting in physical injuries and fatalities can be broadly categorised into the following eight basic groups (Hinze, 2005; Haslam *et al.*, 2005):

(1) *Falling from heights* – involves workers falling from higher floors to lower floors/ground level, and falling from ground level to excavation level.

(2) *Struck by falling objects/moving vehicles* – primarily involves workers being struck by equipment, private vehicles, falling materials, vertically hoisted materials and horizontally transported materials.

(3) *Excavation-related accidents* – encompass cave-in, contact with underground utilities, subsidence of nearby structures, falling of materials/vehicles/objects on to people working in the excavation, fumes, gases, and inrushes of water at the bottom of excavations.

(4) *Accident by operation of machinery/tools* – caused by toppling of machinery, collapse of the parts of machinery, and unsuitable or unsafe hand-held tools.

(5) *Electrocution* – caused by contact with electric current from machines, appliances, light fixtures, faulty electrical equipment and tools, and contact with overhead/underground power lines.

(6) *Fire/explosion* – resulting from the explosion of pressure vessels or gasoline pipes, and fire due to welding/hot works.

(7) *Failure of temporary structures* – involves the failure of formworks and scaffoldings.

(8) *Others* – e.g. slipping on the same level, oxygen deficiency in confined spaces, lightning strike, etc.

Health problems affecting construction workers are shown in Table I.

Abdelhamid and Everett (2000) intensely analysed the root causes of construction accidents. Their work can be summarised by the four clusters as shown in Table II.

Table I. Health problems in construction

Health hazard	Cause
1. Skin diseases	Contact with cement, slaked lime, paint, varnish, thinner, solvents, strong chemicals, grouts, seals and adhesives
2. Hardness of hearing	Noise
3. Respiratory diseases	Inhalation of toxic dusts, vapour and ashes
4. Muscular and bone diseases	High static stress and unnatural working postures
5. Cancer	Carcinogenic materials
6. Mental illness	Stress, inhalation of toxic materials affecting brain and central nervous system
7. Diseases caused by vibration	Vibration

Source: Imriyas *et al.* (2007)

Table II. Root causes of construction accidents

Cluster	Factor
1. Working condition	Type of work Work location Status of tools, equipment and temporary structures Physical layout of the workplace
2. Management failure	Poor housekeeping Violation of workplace safety standards Poor supervision and checking of work progress, tools, equipment and temporary structures
3. Unsafe acts of workers	Disregarding safety rules Horseplay Skill and training
4. Non-human-related events	Unexpected ground conditions/terrain Adverse weather/earthquake/tsunami, etc. on site

The working condition is the inherent work hazard owing to a project's scope and the location. The inherent hazard is managed with a safety management system, which can cause occupational injuries when flaws exist. The negligent attitude of workers to forego safety standards also causes accidents, although it is less quantifiable. Non-human related events are beyond control and prediction. Hence, the estimation of occupational injury risks in construction projects shall assess two factors: the inherent hazard level in the project, and the safety management level. As portrayed in Figure 1, hazards incline the project towards the accident zone while safety pulls it towards the safe zone. When the safety force is at least equal in magnitude to the hazard imposed, the project stays in a neutral zone. Safety below hazard level moves the project towards the accident zone. Hence, the prediction of occupational injuries in a project entails the assessment and comparison of the magnitudes of project hazard and safety.

Assessing project hazards

The combination of work by Davies and Tomasin (1996), and Jannadi and Assaf (1998) produced a list of high hazardous trades in building construction projects for facilitating hazards assessments. The hazardous trades are as follows:

(1) Demolition works.
(2) Excavation works.
(3) Scaffolding and ladder works.
(4) False works (temporary structures).
(5) Roof works.
(6) Erection of structural frameworks.
(7) Crane use.
(8) Construction machinery and tools usage.
(9) Works on contaminated sites.
(10) Welding and cutting works.
(11) Works in confined spaces.

A particular project may have many of these trades and the level of hazard inherent in each trade is determined by its respective risk attributes. An extensive literature review was carried out to identify the significant attributes that contribute to the level of hazard in each of the above hazardous trades. The fishbone diagram in Figure 2 summarises these risk attributes.

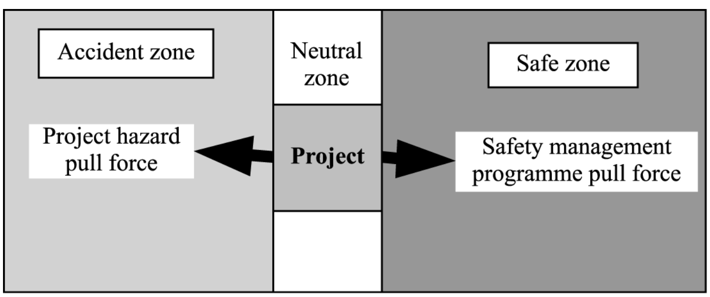

Figure 1.
Hazard vs safety trade-off

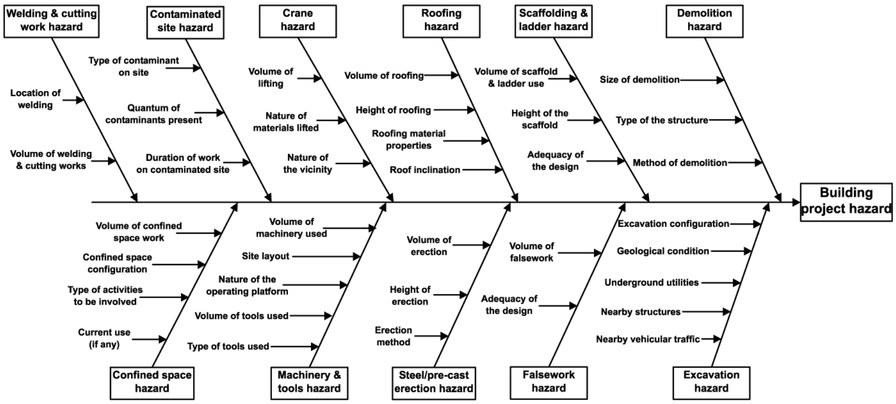

Figure 2.
Fishbone diagram-building hazard attributes

Measuring contractors' safety performance

There are several methods for measuring the safety performance on construction sites:

(1) Applying the concept of profiling that consists of the development of a corporate safety performance standard in a number of categories that are considered important by clients' project managers. Companies are then compared to these categories and a profile is made showing this comparison (Fletcher, 1972).

(2) Conducting a safety audit – a comprehensive audit is a review of the company's safety programme. A properly conducted safety audit will determine the strengths and weaknesses of the current safety programme (Kavianian and Wentz, 1990).

(3) The injury frequency, which is the number of lost-time injuries per million hours of exposure, can also be used to measure the safety performance (Jannadi and Al-Sudairi, 1995).

Nevertheless, conducting a safety audit can give a leading indicator of the safety performance of a contractor whereas the other two methods provide with lagging indicators. Jannadi and Assaf (1998) also recommended that safety auditing is better than other methods to assess the safety performance of contractors.

Teo *et al.* (2004) developed a (3P + I) model for measuring the effectiveness of safety management systems of construction firms in Singapore by assessing policy factors, process factors, personnel factors and incentive factors. Policy factors refer to safety principles and structures that are in place to ensure safety on site. These include relevant codes of practice, and in-house safety rules and regulations. Process factors comprise safety attributes that are directly associated with construction operations. Among the attributes are management of sub-contractors, safe work procedures, communication and information transfer, hazard identification, and housekeeping. Personnel factors refer to key human-related variables that affect site safety such as training and competency, and the structure of the safety committee. Finally, incentive factors are defined as the system that a project has in place to motivate site personnel and sub-contractors to work safely. A roster for a project-specific safety assessment model was derived from the (3P + I) model, the Code of Practice for Safety Management Systems for Construction Sites (SPSB, 1999) and Singapore's new Workplace Safety and Health Act (OSHD-MOM, 2006b). The safety auditing for construction projects has to scrutinise the effectiveness of the aspects listed in Table III.

Triple-index model for estimating accident risks

Based on the findings from the preceding literature reviews, a triple-index model was formulated to predict accident risks in building projects, as shown in Figure 3. As per the proposed model, the estimation of accident risks in a building construction project involves three main phases:

(1) Estimation of a project hazard index (PHI) based on the framework shown in Appendix 1. This framework assesses the degree of hazard in the project. The project is broken down into 11 hazardous trades, as identified in the literature review, and the degree of hazard in each trade is assessed by analysing its hazard driving variables as identified in Figure 2.

(2) Estimation of a project safety index (PSI) exploiting the framework shown in appendix 2. This framework assesses the safety preparedness by analysing eight safety factors with their respective sub-factors that are shown in Table III. The variables that are pertinent to the assessment of safety in each factor were identified through an extensive literature review and arranged in the framework in appropriate orders.

(3) Estimating a project accident index (PAI) by a trade-off analysis between the PHI and the PSI.

Safety element	Audit aspect
1. Project safety organisation	Adequacy of the team and duties and responsibilities
2. Risk assessment and management	Adequacy of the in-house risk assessment system for the project
3. Safe work practices	Application of safe work procedures and codes of practice Permit-to-work systems Personal protective equipment usage
4. Safety training and competency of people	Safety training to management team Certification & safety training of operators In-house safety training to workers
5. Safety inspection	Regular inspection of hazardous activities and the work site Housekeeping
6. Machinery and tools use and maintenance regime	Testing and certification of machinery Inspection systems for machinery and tools Maintenance systems for machinery
7. Sub-contractors' safety systems	Sub-contractors' safety management systems Sub-contractor monitoring
8. Emergency management system	Emergency response plan Emergency response team Emergency response equipment and facilities

Table III.
Project safety auditing roster

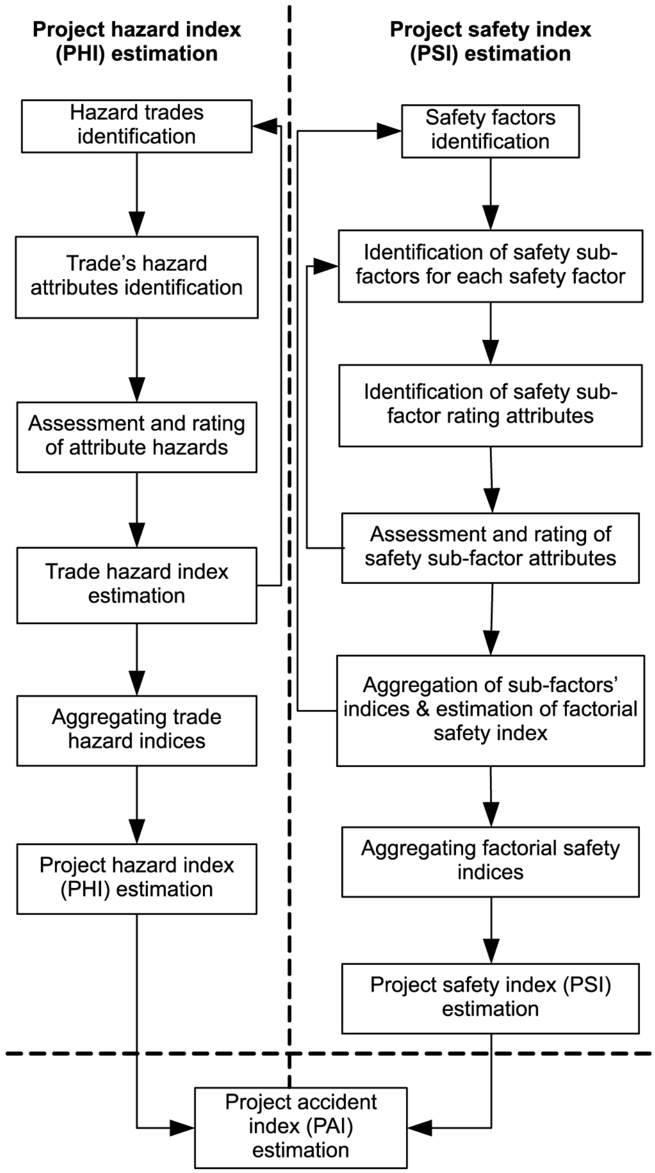

Figure 3.
Triple-index model

The estimation of the PHI entails six steps as described as follows:

(1) Identification of relevant hazardous trades for the project, which are agents for the occurrence of accidents, out of the 11 trades listed in the PHI estimation framework (see appendix 1). That is, when a project is to be hazard-rated, the risk assessor will study the project scope and location, and identify relevant hazardous trades.

(2) Once relevant hazardous trades are identified, the next step is to identify the hazard-rating attributes from the PHI estimation framework for each trade.

(3) Performing a detailed study on the scope and location of the work for the identified hazardous trade, and rating the level of hazard posed by each attribute, based on the PHI estimation framework.

(4) Aggregating the attribute hazard ratings, normalising the ratings and computing a trade hazard index so that $0 \leq$ trade hazard index ≤ 1.00. Reiterating the process for all the hazardous trades in the project.

(5) Aggregating the estimated trade hazard indices and normalising them based on a suitable trade hazard weightage. Each trade is considered to have the same influence over the total project hazard because accidents can happen in any trade and therefore equal scrutiny is essential to avoid venues for mishaps. Thus, a hazard weightage of $1/m$ is suggested for each trade to normalise the trade hazard indices, where m is the number of hazardous trades that are applicable to the project.

(6) Finally, aggregating the normalised hazard trade indices and deriving a PHI.

The estimation of the PSI involves seven steps as described as follows:

(1) Identification of the factors that are to be safety-rated in a project and their pertinent sub-factors, as per the PSI estimation framework in appendix 2. The parameters for safety auditing of each factor were identified in the literature and listed in here.

(2) Upon the identification of the safety factors and sub-factors, the next step is to identify the safety attributes for each sub-factor from the PSI estimation framework.

(3) Studying the safety management system in place as opposed to the hazards in the project, and rating the adequacy of safety attributes for each sub-factor. That is, when a project is to be safety-rated, the risk assessor will assess the suitability and adequacy of the safety management for each attribute in each safety sub-factor, and rate it based on the PSI estimation framework.

(4) Aggregating the attribute safety ratings for each sub-factor and normalising the ratings to compute the sub-factor safety index so that $0 \leq$ sub-factor safety index ≤ 1.00. Reiterating the process for all the sub-factors.

(5) Aggregating the sub-factor safety indices of the safety factor and normalising them to compute the factorial safety index. Reiterating the process for all the safety factors in the PSI estimation framework.

(6) Aggregating the factorial safety indices and normalising them with a suitable safety weightage. Each safety factor is considered to have the same bearing towards the PSI, and therefore a safety weightage of $1/n$ is suggested for normalising factorial safety indices, where n is the number of safety factors that are applicable to the project.

(7) Finally, aggregating the normalised factorial safety indices, and deriving a PSI.

Decision support system (DSS) architecture

The DSS architecture that automates the proposed triple-index model is depicted in Figure 4. The proposed DSS consists of two major components: graphical user interface (GUI) and processing unit (PU). The GUI consists of three major interfaces to interact with the user:

(1) The interface for keying-in of values for project hazard attributes to compute the PHI.

(2) The interface for feeding-in of values for project safety attributes to compute the PSI.

(3) The interface for displaying the final output – the PAI.

The PU contains three sub-components namely, PHI computer, PSI computer and PAI computer, and their respective functions are described below.

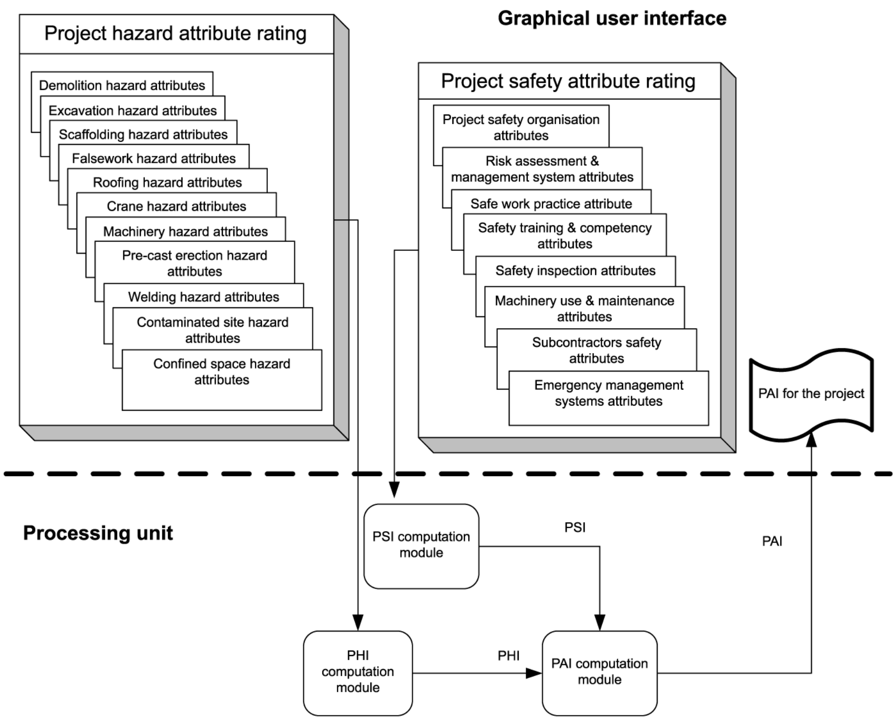

Figure 4.
DSS architecture

PHI computer

The PHI computer estimates the project hazard level via the PHI, based on the framework in Appendix 1. Hence, the PHI is derived by the following normalised formula:

$$PHI = \frac{1}{m}\left[\begin{array}{l} DMH_{score} + EXH_{score} + SLH_{score} + FLH_{score} RFH_{score} + ERH_{score} \\ + CRH_{score} + MTH_{score} + CsiteH_{score} + WCH_{score} + CspaceH_{score} \end{array}\right] \quad (1)$$

where: $0 < m \leq 11$

DMH_{score} = Degree of hazard contributed by demolition works.

EXH_{score} = Degree of hazard contributed by excavation works.

SLH_{score} = Degree of hazard contributed by scaffolding and ladder use.

FLH_{score} = Degree of hazard contributed by false works.

RFH_{score} = Degree of hazard contributed by roof works.

ERH_{score} = Degree of hazard contributed by erection works.

CRH_{score} = Degree of hazard contributed by crane use.

MTH_{score} = Degree of hazard contributed by machinery and tools use.

$CsiteH_{score}$ = Degree of hazard contributed by works on contaminated sites.

WCH_{score} = Degree of hazard contributed by welding and cutting works.

$CspaceH_{score}$ = Degree of hazard contributed by works in confined spaces.

However, not every hazard trade may be applicable to a given project. Relevant trades need to be chosen and hazard-rated. Hence, the PHI computation will exploit the following algorithm:

$$\begin{array}{c} \text{IF demolition hazard} = \text{true THEN} \\ DMH_{score} = \frac{1}{3} \times \frac{1}{5} \sum_{a=1}^{3} \text{Demolition hazard attribute score}_a \\ ELSE\ DMH_{score} = 0 \\ ENDIF \end{array} \quad (2)$$

The coefficients of 1/3 and 1/5 are included because the hazard score for demolition works is computed by equally assessing three obligatory attributes on a 1-5 scale, and then the score is normalised to 1.00. A similar approach is pursued to compute other hazardous trade scores too.

PSI computer

The PSI computer estimates the effectiveness of the project safety management system via the PSI, based on the framework in appendix 2. Hence, the PSI is derived based on the following normalised formula:

$$PSI = \frac{1}{n}\{PSO_{score} + RAM_{score} + SWP_{score} + STC_{score} + SI_{score} + SMT_{score} + SM_{score} + EM_{score}\} \quad (3)$$

where: $0 < n \leq 8$

PSO_{score} = Adequacy score for project safety organisation.

RAM_{score} = Adequacy score for risk assessment and management system.

SWP_{score} = Adequacy score for safe work practices.

STC_{score} = Adequacy score for safety training and competency of people involved.

SI_{score} = Adequacy score for safety inspection system.

SMT_{score} = Adequacy score for safe use and maintenance of machinery and tools regime.

SM_{score} = Adequacy score for sub-contractors' safety systems.

EM_{score} = Adequacy score for emergency management system.

For each safety factor the score is the sum of the attribute scores divided by the number of obligatory attributes, and divided again by the range of the scoring system. For example, PSO_{score} is computed by equally assessing three obligatory attributes of the factor on a 1-5 scale. Therefore, the PSO_{score} is calculated as per formula (4). A similar method is adopted to calculate the scores for the other safety factors too:

$$PSO_{score} = \frac{1}{3} \times \frac{1}{5} \sum_{a=1}^{3} PSO\, attribure\, score_a$$

PAI computer

The PAI computer peruses a trade-off between the PHI and the PSI, and derives a PAI value for the project based on the following algorithm:

$$\begin{gathered} If\ PSI < PHI \\ Then\ PAI = 1 - (PSI/PHI)\ Else\ PAI = 0 \\ Endif \end{gathered} \quad (5)$$

DSS implementation and validation

The proposed DSS was prototyped using VBA™ and MS Access™. Subsequently, an empirical study was conducted to ascertain the accuracy and reliability of the proposed triple-index model and the DSS. Five building projects, which are nearing completion, were chosen for a predictive verification of the DSS. Accident data on these projects were first collected. Then, hazards and safety assessments were carried out, in collaboration with site safety officers, using the proposed model. The assessment data were then keyed into the prototype DSS and the PAI value for each project was derived. The results are shown in Table IV. A graph was plotted, as depicted in Figure 5, to observe the relationship between the PAI values and the number of accidents. It showed a strong correlation between the computed PAI values and the actual number of accidents. That is, the higher the PAI value, the higher the frequency of accidents.

Conclusion

As part of its strategies to improve safety standards in construction projects, Singapore conceptualises the implementation of the QFM for tender evaluation, departing from the traditional lowest price method. Under the QFM, tenders are scored based on both price and quality attributes. Safety management proposal is one of the key quality attributes. The effective assessment and scoring of tenderers' safety proposals is therefore a crucial task for clients' project managers.

It is hypothesised that the effectiveness or flaw of the proposed safety proposal can be assessed by establishing the potential accident risks given that the proposed safety system is in place. This study therefore proposes a triple-index model for estimating accident risks in building construction projects. The model firstly assesses the degree of hazards in a given project and then measures the safety preparedness of the contractor to arrest the hazards that cause accidents. Subsequently, it performs a trade-off analysis between hazard and safety preparedness to derive an accident index, which reveals the potential accident risks in the project. Subsequently, the model was automated as a DSS exploiting MS Access™ and VBA™, tested empirically and found to be reliable.

The proposed triple-index model and its DSS address one of the current challenges faced by clients' project managers in the implementation of the QFM for tender evaluations. The study also reveals a systematic approach for predicting accident risks in

Project	Number of accidents	PAI value
A	26	0.450
B	5	0.110
C	15	0.375
D	39	0.570
E	24	0.430

Table IV. Empirical test results

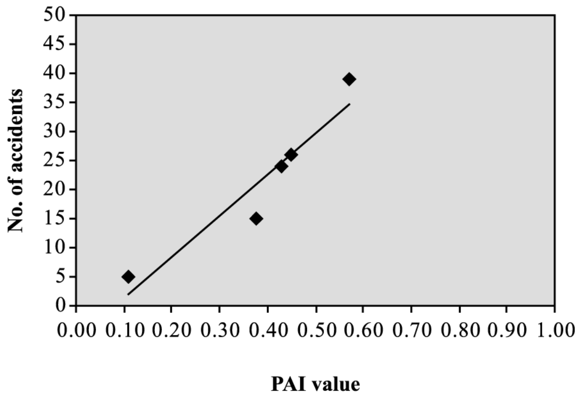

Figure 5. PAI vs number of accidents

building projects. Nevertheless, the proposed model covers only building projects. It could be extended in future research efforts to accommodate any type of construction projects.

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Appendix 1

Estimating project hazards	Low				High
1. Demolition works					
Rate the level of hazard posed by the following parameters in demolition works in this project					
Volume/size of demolition	1	2	3	4	5
Type of structure	1	2	3	4	5
Method of demolition	1	2	3	4	5
Trade score					
2. Excavation works					
Rate the level of hazard posed by the following parameters in excavation works in this project					
Excavation configuration (depth, width and length)	1	2	3	4	5
Geological condition (soil type, water table, etc.)	1	2	3	4	5
Underground utilities (electrical, water and sewer lines)	1	2	3	4	5
Nearby vehicular traffic (vibration and surcharge)	1	2	3	4	5
Nearby structures	1	2	3	4	5
Trade score					
3. Scaffolding and ladder usage					
Rate the level of hazard posed by the following parameters in scaffolding and ladder usage in this project					
Volume of scaffolding and ladder usage	1	2	3	4	5
Height of the scaffold/ladder that is to be used	1	2	3	4	5
Adequacy of design (type of material, member size, bracing, guardrails, platform size, toe board)	1	2	3	4	5
Trade score					
4. False works (temporary structures)					
Rate the level of hazard posed by the following parameters in false works in this project					
Volume of false work involved in the project	1	2	3	4	5
Adequacy of design (material, member size, bracing, guardrails, platform size, toe board)	1	2	3	4	5
Trade score					
5. Roof works					
Rate the level of hazard posed by the following parameters in roof works in this project					
Volume of roofing involved	1	2	3	4	5
Height of the roof	1	2	3	4	5
Roofing material property such as slippery, brittleness, asbestos etc.	1	2	3	4	5
Inclination of the roof	1	2	3	4	5
Trade score					
6. Erection of steel/pre-cast concrete structures					
Rate the level of hazard posed by the following parameters in erection of steel/pre-cast concrete structures in this project					
Volume of erection work	1	2	3	4	5
Height of erection work	1	2	3	4	5

(*continued*)

Table AI. Framework for estimating PHI

Estimating project hazards	Low				High
Erection method (partial/full erection at height, labour involvement level)	1	2	3	4	5
Trade score					
7. Crane use					
Rate the level of hazard posed by the following parameters in lifting and crane use in this project					
Volume of lifting involved	1	2	3	4	5
Nature of materials lifted	1	2	3	4	5
Operating platform	1	2	3	4	5
Nature of site vicinity (nearby structures, overhead cables, etc.)	1	2	3	4	5
Trade score					
8. Construction tools and machinery use					
Rate the level of hazard posed by the following parameters in plant and tools use in this project					
Volume of plant and machinery used	1	2	3	4	5
Operating platform of plant and machinery (i.e. slope etc.)	1	2	3	4	5
Site layout	1	2	3	4	5
Volume of tools used	1	2	3	4	5
Type of tools used	1	2	3	4	5
Trade score					
9. Works on contaminated sites					
Rate the level of hazard posed by the following parameters in working on contaminated site in this project					
Type of contaminants on the site	1	2	3	4	5
Quantity of contaminants present	1	2	3	4	5
Duration of work on contaminated site	1	2	3	4	5
Trade score					
10. Welding and hot works					
Rate the level of hazard posed by the following parameters in welding and hot works in this project.					
The volume of welding and hot works	1	2	3	4	5
Location of welding (confined space, underground, on ladders etc.)	1	2	3	4	5
Trade score					
11. Works in confined spaces					
Rate the level of hazard posed by the following parameters in confined space works in this project					
The volume of confined space works	1	2	3	4	5
Confined space configuration	1	2	3	4	5
Type of activity to be involved (e.g. welding, waterproofing etc.)	1	2	3	4	5
Current usage of the confined space (if any)	1	2	3	4	5
Trade score					
Total project score (PHI)					

Table AI.

Appendix 2

Estimating the Project Safety Index						
A) Project safety organisation						
Please rate the adequacy of the duties and responsibilities of the following personnel/team in the project safety organisation.	Low…………………………...High					
1. Workplace safety and health coordinator	1	2	3	4	5	
2. Workplace safety and health auditor	1	2	3	4	5	
3. Workplace safety and health committee	1	2	3	4	5	
Section score						
B) Risk assessments and management system						
Please rate the adequacy of the following aspects of the risk assessment and management system in the project.	Low…………………………...High					
1. Risk assessment team and responsibilities	1	2	3	4	5	
2. Risk assessment procedures	1	2	3	4	5	
3. Reporting procedures to workers of identified risks	1	2	3	4	5	
4. Control measures for risks identified	1	2	3	4	5	
Section score						
C) Safe work practices						
C.1) Work procedures: Please rate the effectiveness of the work methods and procedures for the following trades.	Low……………………………..High					
1. Concrete works	1	2	3	4	5	NA
2. Structural steel and pre-cast assembly	1	2	3	4	5	NA
3. Erection and dismantling of scaffolds and false works	1	2	3	4	5	NA
4. Works at heights	1	2	3	4	5	NA
5. Demolition works	1	2	3	4	5	NA
6. Excavation works	1	2	3	4	5	NA
7. Piling operations	1	2	3	4	5	NA
8. Welding and cutting works	1	2	3	4	5	NA
9. Works in confined spaces	1	2	3	4	5	NA
10. Works in toxic/contaminated environments	1	2	3	4	5	NA
11. Use of construction plant such as excavators, trucks, etc.	1	2	3	4	5	NA
12. Use of cranes	1	2	3	4	5	NA
13. Electrical installation and use	1	2	3	4	5	NA
Sub-section score						
C.2) Permit-to-work (PTW) systems: Please rate the effectiveness of the PTW systems for the following trades.	Low……………………………..High					
1. Working at heights	1	2	3	4	5	NA
2. Excavation works	1	2	3	4	5	NA
3. Working in confined spaces	1	2	3	4	5	NA
4. Welding and cutting works	1	2	3	4	5	NA
5. Demolition works	1	2	3	4	5	NA
6. Working in toxic/contaminated environments	1	2	3	4	5	NA
Sub-section score						
C.3) Personal protective equipment(PPE) use: Please rate the adequacy of the PPE use for the following trades.	Low…………………………..….High					
1. Concrete works	1	2	3	4	5	NA
2. Structural steel and pre-cast assembly	1	2	3	4	5	NA
3. Erection & dismantling of scaffolds & false works	1	2	3	4	5	NA
4. Works at heights	1	2	3	4	5	NA
5. Demolition works	1	2	3	4	5	NA
6. Excavation works	1	2	3	4	5	NA
7. Piling operations	1	2	3	4	5	NA
8. Welding and cutting works	1	2	3	4	5	NA
9. Works in confined spaces	1	2	3	4	5	NA
10. Works in toxic/contaminated environments	1	2	3	4	5	NA
11. Use of machinery such as excavators, trucks, etc.	1	2	3	4	5	NA
12. Use of cranes	1	2	3	4	5	NA
13. Electrical installation and use	1	2	3	4	5	NA
Sub-section score						
Section score						
D) Safety training and competency of people involved						
D.1) Safety training to management team: Please rate the adequacy of the safety training to the following personnel in the project.	Low……………………….……High					

(continued)

Figure A1.
Framework for estimating PSI

Estimating the Project Safety Index						
1. Demolition supervisor(s)	1	2	3	4	5	NA
2. Excavation supervisor(s)	1	2	3	4	5	NA
3. Piling supervisor(s)	1	2	3	4	5	NA
4. Lifting supervisor(s)	1	2	3	4	5	NA
5. Scaffold and/or suspended scaffold supervisor(s)	1	2	3	4	5	NA
6. False work supervisor(s)	1	2	3	4	5	NA
7. Welding & cutting supervisor(s)	1	2	3	4	5	NA
8. Confined space work supervisor(s)	1	2	3	4	5	NA
9. Toxic/contaminated environment work supervisor(s)	1	2	3	4	5	NA
10. Project management team members	1	2	3	4	5	NA
Sub-section score						
D.2) Certification & safety training of operators: Please rate the adequacy of the certification & safety training of the following operators in the project.	Low……………………………..…High					
1. Crane erector(s)	1	2	3	4	5	NA
2. Crane operator(s)	1	2	3	4	5	NA
3. Riggers(s)	1	2	3	4	5	NA
4. Signal men	1	2	3	4	5	NA
5. Scaffold erector(s) and/or suspended scaffold rigger(s)	1	2	3	4	5	NA
6. Erectors of hoists and lifts	1	2	3	4	5	NA
7. Operators of hoists and lifts	1	2	3	4	5	NA
8. Operators of plant like excavators, bull dozer, etc.	1	2	3	4	5	NA
9. Construction vehicle drivers	1	2	3	4	5	NA
Sub-section score						
D.3) In-house safety training to workers: Please rate the adequacy of the following modules of the in-house safety training to workers in the project.	Low…………..………………..…High					
1. Site rules & regulations, and proper use of PPE	1	2	3	4	5	
2. Emergency response for various possible incidents	1	2	3	4	5	
3. First aid procedures	1	2	3	4	5	
4. Safe handling of tools and equipment	1	2	3	4	5	
Sub-section score						
Section score						
E) Safety inspection system						
E.1) Inspection of worksite: Please rate the adequacy of the inspection system for the following items in the project.	Low………..…………...High					
1. Excavations by a competent person on a daily basis and after hazardous events (e.g. inclement weather)	1	2	3	4	5	NA
2. Scaffolding by a scaffold supervisor on a weekly basis and after inclement weather	1	2	3	4	5	NA
3. False works by a PE or other competent person before, during and after casting and after inclement weather	1	2	3	4	5	NA
4. Demolition by a competent person on a daily basis and after inclement weather	1	2	3	4	5	NA
5. Material loading platform by a competent person on a regular basis and after inclement weather	1	2	3	4	5	NA
6. Temporary structures such as site office, canteen, site hoardings & concrete batching plant on a regular basis	1	2	3	4	5	NA
7. Specialised structures or operations like use of customised shoring systems by a competent person	1	2	3	4	5	NA
8. General site by a safety personnel or the site manager	1	2	3	4	5	NA
Sub-section score						
E.2) Housekeeping: Please rate the adequacy of the housekeeping for the following locations/items in the project.	Low…....……………….High					
1. Construction worksite	1	2	3	4	5	NA
2. Workers' quarters	1	2	3	4	5	NA
3. Toilets and washing facilities	1	2	3	4	5	NA
4. Canteen or eating places	1	2	3	4	5	NA
5. Site offices	1	2	3	4	5	NA
6. Storages for materials, tools & wastes	1	2	3	4	5	NA
Sub-section score						
Section score						
F) Machinery and tools use and maintenance regime						
F.1) Testing & certification of machinery: Please rate the adequacy of the testing & certification of the following machinery in the project.	Low…………………….High					
1. Lifting gears (12 monthly)	1	2	3	4	5	NA
2. Lifting appliances (12 monthly)	1	2	3	4	5	NA
3. Lifting machines (12 monthly)	1	2	3	4	5	NA
4. Hoists and lifts (6 monthly)	1	2	3	4	5	NA
5. Air receivers (24 monthly)	1	2	3	4	5	NA

(*continued*)

Figure A1.

Estimating the Project Safety Index						
6. Explosive power tools (36 monthly)	1	2	3	4	5	NA
Sub-section score						
F.2) Inspection of machinery & tools: Please rate the adequacy of the inspection system for the following machinery in the project.	Low……………………High					
1. Cranes by crane operators on a daily basis	1	2	3	4	5	NA
2. Electrical distribution board by a competent person on a daily basis	1	2	3	4	5	NA
3. Electrical equipment and tools by a competent person on a regular basis (weekly/more frequent)	1	2	3	4	5	NA
4. Construction vehicles like trucks, forklift, bull dozer, etc. by drivers or a designated person on a daily basis	1	2	3	4	5	NA
5. Temporary electrical installation by a licensed electrical worker	1	2	3	4	5	NA
6. Specialised equipment by a competent person	1	2	3	4	5	NA
Sub-section score						
F.3) Maintenance of machinery: Please rate the adequacy of the maintenance regime for the following machinery in the project.	Low……..………………High					
1. Tower crane(s)	1	2	3	4	5	NA
2. Mobile crane(s)	1	2	3	4	5	NA
3. Gondola(s)	1	2	3	4	5	NA
4. Piling machine(s)	1	2	3	4	5	NA
5. Passenger hoist(s)	1	2	3	4	5	NA
6. Mobile working platform(s)	1	2	3	4	5	NA
7. Construction vehicles like truck, forklift, bulldozer, etc.	1	2	3	4	5	NA
Sub-section score						
Section score						
G) Sub-contractors' safety systems						
Please rate the adequacy of the following items of sub-contractors in the project.	Low…………..…………..High					
1. Safe work procedures	1	2	3	4	5	
2. Safe use of plant, machinery and tools	1	2	3	4	5	
3. Safety inspection systems	1	2	3	4	5	
4. Trained operatives and supervisors	1	2	3	4	5	
5. Adherence to safety requirements during construction	1	2	3	4	5	
Section score						
H) Emergency management system						
H.1) Emergency response plan: Please rate the adequacy of the emergency response plan for the following emergency scenarios in the project.	Low…………..…………..High					
1. Fire & explosion	1	2	3	4	5	
2. Failure & collapse of structures/temporary supports	1	2	3	4	5	
3. Failure & collapse of heavy machinery & equipment	1	2	3	4	5	
4. Leakage of hazardous substances	1	2	3	4	5	
5. Adverse weather & flooding	1	2	3	4	5	
Sub-section score						
H.2) Emergency response team: Please rate the adequacy, competency and set-responsibilities of the following emergency response team members for various emergency scenarios in the project.	Low………......…………….High					
1. Emergency coordinator(s)	1	2	3	4	5	
2. Site safety personnel	1	2	3	4	5	
3. Designated rescuer(s)	1	2	3	4	5	
4. First-aider(s)	1	2	3	4	5	
5. Specialist operators(s)	1	2	3	4	5	
Sub-section score						
H.3) Emergency equipment: Please rate the adequacy of the emergency response equipment and facilities for the following emergency scenarios in the project.	Low…………..…………….High					
1. Fire & explosion	1	2	3	4	5	
2. Failure & collapse of structures/temporary supports	1	2	3	4	5	
3. Failure & collapse of heavy machinery & equipment	1	2	3	4	5	
4. Leakage of hazardous substances	1	2	3	4	5	
5. Adverse weather & flooding	1	2	3	4	5	
Sub-section score						
Section score						
Total project score (PSI)						

Figure A1.

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