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Towards a better reliability of risk assessment: Development of a qualitative & quantitative risk evaluation model (Q^2REM) for different trades of construction works in Hong Kong

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ABSTRACT

Since the safety professionals are the key decision makers dealing with project safety and risk assessment in the construction industry, their perceptions of safety risk would directly affect the reliability of risk assessment. The safety professionals generally tend to heavily rely on their own past experiences to make subjective decisions on risk assessment without systematic decision making. Indeed, understanding of the underlying principles of risk assessment is significant. In this study, the *qualitative* analysis on the safety professionals' beliefs of risk assessment and their perceptions towards risk assessment, including their recognitions of possible accident causes, the degree of differentiations on their perceptions of risk levels of different trades of works, recognitions of the occurrence of different types of accidents, and their inter-relationships with safety performance in terms of accident rates will be explored in the Stage 1.

At the second stage, the deficiencies of the current general practice for risk assessment can be sorted out firstly. Based on the findings from Stage 1 and the historical accident data from 15 large-scaled construction projects in 3-year average, a risk evaluation model prioritizing the risk levels of different trades of works and which cause different types of site accident due to various accident causes will be developed *quantitatively*. With the suggested systematic accident recording techniques, this model can be implemented in the construction industry at both project level and organizational level. The model (Q^2REM) not only act as a useful supplementary guideline of risk assessment for the construction safety professionals, but also assists them to pinpoint the potential risks on site for the construction workers under respective trades of works through safety trainings and education. It, in turn, arouses their awareness on safety risk. As the Q^2REM can clearly show the potential accident causes leading to different types of accident by trade of works, it helps the concerned safety professionals and parties to plan effective accident prevention measures with reference to the priority of the risk levels.

1. Introduction

It is encouraging that the safety performance in Hong Kong construction industry is improving which can be reflected in the construction accident statistics as published by the Labour Department (2009a,b). The year 2009 recorded a notable drop in the number of site accidents, from 11925 in 2000 to 2755 in 2009, representing a decrease of 76%. The accident rate per 1000 workers in 2009 also dropped by 63% (54.6) when compared with the figure of 2000 (149.8).

However, construction site accidents rates in Hong Kong are still relatively high when compared with most of the neighboring countries, such as Japan and Singapore, despite of the fact that much effort has been made by the HKSAR government, employers, contractors and safety practitioners (Fung, 2010). To some extent, such undesirable situation is attributed by the inert awareness to risk due to the tradition and culture of the workforce.

Assessment of risk level associated with the hazards on site is an essential component in the process of risk management (Trethewy et al., 2003) which is a process of estimating the magnitude of risk and deciding whether the risk is tolerable or not (Occupational Safety and Health Council, 2003). An effective risk assessment can offer a proactive approach to help organizations to avoid incurring losses by preventing the accidents happening in the first place (McGuinness, 1995). According to the Occupational Safety and Health Branch, Labour Department (2008), the following aspects should be taken into account for risk assessment:

- Materials, equipment/plants used for the task/activities.
- Authority for delegation, training and ability to cope in an emergency.

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- Working conditions, like any hazards in the workplace, effect of weather conditions or lighting and hazards from adjacent processes or contractors.
- The working procedures, like examining any potential failures in working methods.

Hurst (1998) revealed that risk assessment is neither subjective nor objective absolutely. Risk assessment will always be subjective, at best to a small degree but possible to a large extent. On the objective measurement, risk estimates make use of data from long periods of experience or consider simple comparisons "before" and "after" safety improvements. In some cases, the objective estimations of risk will match the subjective evaluations which have played some parts in determining the decision makers' perceptions (Cox and Tait, 1998). Nevertheless, the judgment of the risk assessor is important and it is also relevant to consider the historical accident statistics. Indeed, assessments of risks whether they are based on individual attitudes, beliefs within a culture or the models of mathematical risk assessment, necessarily depend upon human judgment.

Effective technical evaluation of risk may be hindered when people in the workplace do not share a common understanding of the nature of risk and its control. Attaining consensus and trust is vital in the risk management decision-making process. Kennedy (1997) indicated that all accidents should be investigated so as to identify causes of accidents, determine the facts, keep records properly, create database for analysis and prevent the accidents from occurring repeatedly. McGuinness (1995) suggested that rough risk assessment can be carried out by gathering available evidence from accident statistics and reports and talking to staff about what they regard as the problem areas. Similar studies are also mentioned at Raafat (1995), Walker and Dempster (1994) and Walker and Cox (1995).

According to the research conducted by Yu et al. (2002), the construction industry of Hong Kong is under-served in occupational safety. Most contractors lack relevant resources, knowledge and willingness to identify hazards in a formal and documented way and the adequacy of the process of 'formal' identification of workplace hazards is problematic (Trethewy et al., 2003). The construction practitioners find it difficult to carry out risk assessment due to an absence of a systematic database for detailed accident recording. As a result, they just rely on partial information, imperfect memories and distorted time perspectives to extrapolate from past experiences into the future (Cox and Tait, 1998).

Through a critical review of the risk assessment (Tung, 2004) provided by 20 leading main construction companies in Hong Kong, it is observed that the formats appear to be too general and subjective to reflect the real situation on site. Different construction companies use diverse procedures and standards in assessing risks of work activities (i.e. using different format of matrix to determine risk level). The results of risk assessment which depend on the data used and even on the biases of the safety professionals under qualitative analyses vary widely. Slovic et al. (1980b) revealed that people tend to rely on what they remember hearing or observing about the risk when there is no relevant statistical evidence on hand. The reliability of the risk assessment, thus, becomes questionable.

2. Literature review

2.1. Attribution of risk

DeJoy (1994) suggests that the attribution of causation is a logical human response to events. People's attribution of risk causation may influence their perceptions on risk control. Besides, attributions of causality are part of analysis of hazards and accidents but many other safety-related attributions should be also considered. In this respect, these attributions need to be better understood if appropriate risk control strategies are to be developed. Perceived control of safety risk acts as an important theme in risk rating judgments of the construction practitioners (Holmes and Gifford, 1997).

2.1.1. Possible errors in risk assessment due to inadequate knowledge

Most of the professionals would tend to accept that 'the best predictor for future behaviour is the past behaviour' (Moore, 1996). However, many risk assessment are generally carried out with reference to the limited available historical accident data but other considerations are ignored.

2.2. Shortcomings of the information and methodology for collection of construction accident statistics

Industry statistics are a useful source of general information about hazards in a particular workplace. However, the accident information and statistics produced by the Labour Department is inadequate in Hong Kong and this demonstrates a lack of understanding of the accident process as criticized by Lingard (1993). The only analysis of construction accidents provided is the types of accident which occurred in one particular year but there is a lack of detailed information of the reasons for the accident. The insufficient safety related data collection and analysis systems of the Labour Department lead to a lack of focus in safety promotions. Rowlinson and Walker (1995) suggested that detailed information on causes of accidents is vital for accident prevention.

Besides, there are some inherent shortcomings of the underlying methodology adopted by Labour Department (HK) in compiling construction industry accident statistics. The importance of accurate data to tackle the common causes for site accidents should be emphasized. In this respect, the Labour Department consulted the members of the Provisional Construction Industry Co-ordination Board to review the current methodology for collating construction safety statistics so as to develop a more reliable mechanism for calculating the site accident rate (Provisional Construction Industry Co-ordination Board, 2003). However, in request at the end of 2009, no information provided by the Board about the proposed mechanism.

It is commonly observed that risk assessments generally contain the determination of risk levels for the works activities on sites in terms of probability and consequence of the accidents based on the safety professionals' own experience. However, each works activities involve various trades of works and their corresponding risk levels, thus, should be also considered thoroughly. Cox and Cox (1996) advocated that job safety analysis is a useful technique in which a particular job is broken down into sub-tasks and each of them has to be investigated for hazard predictions. Although estimation of consequences is complex and in many cases a range of degrees of harm with differing probability can occur, observing accidents and accident rates is regarded useful as a reference to support the prediction of the consequences.

2.3. Risk assessment and accident causes

Risk assessment is considered as the basic approach of modern safety management (Cox and Tait, 1998) but effective accident prevention depends on understanding of causes of accidents (Poon, 2002). To make the risk assessment more reliable, the safety pro-

Table 1
Summary of types of accident causes from previous literatures.

Researchers	Types of accident causes
England (1989), Jannadi (1996), Stranks (1997), Brascamp et al. (1993), Mak (1999) and Frick (1990)	Insufficient management control
England (1989) and Rowlinson (2002)	Unsafe practice
Shield (1994), Jeremy (1994), Jannadi (1996), Rowlinson (1997), Susi, 2000, Haupt and Alexander (2000), Poon (2002) and Rowlinson (2002)	Substandard working condition
England (1989), Shield (1994), Jeremy (1994), Holmes and Gifford (1996), Jannadi (1996), Poon (2002) and Culver et al. (1993)	Personal factor
Rowlinson (2002) and Stranks (1997)	Job factor

fessionals who are the key decision makers to carry out risk assessment have to investigate the possible causes for the accidents through conducting detailed accident reports and reviewing past related accident statistics. Bowers (1994) advocated that the project risk analyzer acts as an intelligent conduit for describing project experience and the information may come from relevant experience of other projects and other organizations, or individuals' knowledge and expertise.

Besides, safety professionals are responsible for investigating discrepancies, distinguishing valuable data, and highlighting the experiences relevant to the current projects. The examples of source of experience are the information from individuals' memories and numerous diverse reports. Vaughan (1997) revealed that the primary methodology of risk identification is the observation of losses resulted from the accidents that had already occurred.

To sum up, the major accident causes can be divided into the 5 broad categories, including insufficient management control, unsafe practice, substandard working condition, personal factors and job factors, as generated from the above stated previous literature which are summarized in Table 1.

Kolluru et al. (1996) pointed out that since quantitative risk assessment requires a significant commitment of a company's resources, a multi-tiered approach can be adopted (Table 2). This approach helps analysts target the areas that should receive the most detailed analysis.

Risk-screening (Level 1) approaches are qualitative in nature, providing top-down reviews of the worst-case hazards and risks and prioritizing plant sites or activities that pose the highest risk. Companies usually conduct risk screening by gathering information from facilities and rarely include site inspection at this level of study.

Quantitative risk analyses are intensive in nature and generally require a significant commitment of time and resources. The basic elements for assessment are hazard identification, quantification through consequence analysis, probability or frequency estimation, and risk determination and reporting.

Table 2
Summary of risk assessment tiers.

Level	Risks strategy	Action outcome
Level 1	Screening	Worst-case consequences; assessment for major hazardous materials inventories
Level 2	Survey	Semi-quantitative evaluation of major process hazards, safety management systems, fire-protection/emergency response capabilities
Level 3	Assessment	Full quantification of operational risks

2.4. Reliability and risk

From a statistical standpoint, risk requires a set of occurrences for its calculations according to Turnley (2002). Woodhouse (1993) advocated that estimates of safety-related risks can be taken from global experiences and complex matrices of component probabilities. In many day-to-day decisions that do not warrant a formal risk analysis project, the difficulty of extracting meaningful numbers has therefore prevented adoption of a numerate approach. Many circumstances, like construction sites, are "one-off" and, even if the projections are accurate, one may never know whether the decision is right or not. However, frequent risk exposures can be measured by a quantitative way, conditions that people are capable of articulating subjective impressions of risk (Raftery et al., 2001) and these measurements are useful for the decision makers to carry out risk assessment.

Cox and Tait (1998) revealed that the individual's perception of risk may be different but complementary forms of rationality with their synchronization and personal attitudes should be taken into account in communicating risk. As the safety professionals are the key persons to carry out risk assessment in construction sites, their perceptions of safety risk would directly affect the reliability of risk assessment.

The purpose of this research is to arouse the safety professionals' awareness on the impacts of their perceptions on risk levels of different trades of works, recognitions of accident causes and the occurrence frequency of different types of accidents which may reflect the effectiveness of the risk assessment and, in turn, affect site safety performance. As suggested by McGuinness (1995), accident rate is an indicator for the effectiveness of the risk assessment.

2.5. Importance of historical accident data

The safety professionals usually base upon their knowledge and experiences gained from similar projects. It should be noted that even the most extreme one-off projects may have some connections with past projects and current technologies. The statistics about past site accident in the construction industry can be one of the objective evidences.

It should be noted that the subjective probabilities assigned by different individuals with same experience and information may be very different. The difference in judgmental skills becomes obvious with the degree of knowledge and expertise of the decision makers (Trimpop, 1994). The decision maker's experience, education, values, personality, and perception, as well as preference for a particular event, will be reflected in the subjective probability. In the construction industry, decisions are likely to be determined by subjective probabilities. Since buildings tend to be unique and construction is not a factory line routine repetitive process, decisions are generally generalized from experience and samples using relative frequencies of occurrence. Thus, both of the available objective and subjective evidence should be used in the assignment of subjective probabilities which should reflect the decision maker's beliefs.

Lingard (1993) reported that the accident information such as how, why, when and to whom accidents are happening is extremely important for the development of well-formulated prevention strategies. In the absence of reliable and detailed information, erroneous conclusions concerning accident occurrence can probably be drawn.

According to the study of Simonds and Shafai-Sahrai (1997), the quality of a company's internal accident statistics, followed by top management involvement, is a contributing factor related to accident rate. Andersson and Lagerlof (1983) also stated that the greatest importance of accident information is to 'provide knowledge about risks', to identify risks, evaluate them and find causes. Vaughan (1997) revealed that risk evaluation implies some rankings in terms of importance which suggests measuring some aspects of the factors. Short (1984) argued that "risk acceptability greatly depends on the trust in the institutions presenting the expert rating, and based on the previous failures and success of those institutions." Slovic et al. (1980a) suggested certain methods to improve the understanding, assessment and communication of risk.

2.6. Availability of historical accident statistics

Accessibility and availability of the relevant accident data, resources and references would directly affect one's judgment. The "Five Steps to Risk Assessment" leaflet which is published by the Occupational Safety and Health Branch, Labour Department (2008) gives a general idea of risk assessment to the employers in commercial, service and light industrial sectors. However, it appears to be a dearth of references specifically for the construction industry.

Holmes and Gifford (1996) opined that the employers and employees' understandings of risk in occupational health and safety may influence their view of risk management and have implications on risk control strategies.

According to Flanagan and Norman (1993), objective probabilities are difficult to be obtained in the construction industry as most of them are one-off. However, past experience and extensive historical records are definitely useful. Therefore, the historical accident records, such as different types of accidents and trades of works injured, are crucial for the safety professionals as the background knowledge when carrying out risk assessment.

2.7. Objectives of the research

In this research, the following unexplored issues will be addressed:

- To review the construction safety professionals' current practice on preparation of risk assessment.
- To investigate their recognitions on site accident causes (including unsafe practice, unsafe condition and insufficient management control, personal factors and job factors), the occurrence frequency of different types of accidents and perceptions on risk levels of different trades of works compared with the corresponding published accident statistics.
- To investigate the effect of the respondents' beliefs of risk assessment, recognitions of site accident causes, the occurrence frequency of different types of accidents and perceptions on risk levels of different trades of works on safety performance, respectively.
- To analyze their characteristics and demographical information, and to investigate the possible relationships with the safety professionals' beliefs of the risk assessment, their perceptions on risk levels of different trades of works, recognitions of accident causations and the occurrences frequency of different types of accidents.
- To form a 'Risk Evaluation Model' (Q^2REM) on the basis of the qualitative and quantitative analysis of this research which shows the inter-relationships of different trades of works injured, accident causes and type of accidents in terms of defined risk levels is recommended to implement as a supplementary guideline for risk assessment in construction industry.

3. Research methodology

3.1. Stage (I) Qualitative analysis on risk perception and causes of accidents in risk assessment

In general practice, the construction safety professionals, including safety managers, safety officers, assistant safety officers and assistant safety supervisors, are the key decision makers to carry out risk assessment. Therefore, the accuracy of the risk assessment is subject to their judgment and perceptions of safety risk. In this regard, the safety professionals are selected as the target group in this research.

3.1.1. Rationales behind the safety priority questionnaire setting

There are 2 steps to develop the questionnaire in this stage. In Stage 1A, Delphi technique is employed to gather information about aspects that the construction safety professionals would consider during risk assessment. This technique is traditionally employed in the social science studies to sample the opinions of the experts or informants so that consensus can be obtained (Chan et al., 2001). Therefore, a preliminary questionnaire was firstly drafted and sent to the construction safety professionals who were asked to provide at least five major aspects that they would consider during risk assessment for HK projects. The aspects which conveyed similar meanings were combined and rephrased to avoid duplications.

In Stage 1B, a set of questionnaire about risk perceptions was designed in consultation with the safety professionals and construction practitioners to ensure its readability and clarity. After the pilot study, the questionnaire had been modified by incorporating their valuable comments. Apart from the construction safety professionals, many other stakeholders, such as site agents and project managers would be also involved in risk assessment in general practice. However, the target respondents of this survey are limited to the safety professionals, including safety supervisors, assistant safety officers, safety officers, safety managers and those who are mainly involved in construction safety related tasks on site for at least 1 year so as to ensure the reliability of the survey.

Through the survey, their general perceptions on safety and risk issues can be highlighted. Since the safety professionals are the key decision makers for project safety and risk assessment, the degree of their differentiations on perceptions on risk levels of different trades of works, recognitions of accident causes and the occurrence of different types of accidents would affect the quality of risk assessment. The findings will be analyzed and a risk evaluation model will be developed (in Stage 2) with the formation of priority lists as a set of supplementary guideline for the safety professionals to carry out risk assessment.

In the stage 1B, 250 questionnaires were sent to the safety professionals who worked on 100 various construction sites in the Hong Kong. Only the questionnaires returned from those who are mainly involved in construction safety related tasks on sites for at least 1 year were used in the analysis. Once dubious data were detected, verification with the corresponding respondents would be made by phone. As a result, 74 questionnaires were returned, giving a response rate of about 30%. However, 12 of them were not properly completed and thus 62 returned questionnaires could be used for the analysis.

3.1.2. General practice on preparation risk assessment

After collecting the completed questionnaires from 37 respondents at Stage 1A, frequency of the suggested aspects were calculated and 8 aspects which were suggested by over 50% of the respondents (Table 3) were then selected and rephrased which were used for further structuring the survey questionnaire of this research.

Table 3
8 selected aspects for preparation of risk assessment.

1. Construction workers' past working experience on site	5. Method statement
2. Past accident records from your company	6. Understanding of site condition
3. Understanding of possible risks of different trades of work	7. Safety professionals' understanding of possible accident causes
4. Accident Statistics from Labour Department	8. Involvement of supervisory staff (i.e. engineer, foremen and site agent)

In the designed survey questionnaire, the safety professionals are asked to indicate the priority of 8 selected aspects for preparation of risk assessment. It is intended to determine if their difference of preferences on the aspects affect safety performances.

3.1.3. Recognitions on accidents causes

Identification of accident causations is a crucial process for improvement of safety performance. However, there is a dearth of such information by using past accident statistics which are rarely classified by the real causes (Duff, 2000). The information one can obtain is a series of statistics regarding types of accidents, such as fall of person from height and struck by falling object as published by the Labour Department, HKSAR but statistics about the causes of accidents are unavailable. For this reason, review of safety related literature, previous relevant researches, accident reports were carried out and suggestion of the safety professionals were also obtained for the formation of the survey.

On the basis of the relevant literature as mentioned, the accident causes were classified into 5 categories, including insufficient management control, substandard working conditions, unsafe practice, personal factors and job factors (Fig. 1). 33 possible causes of site accidents were selected in terms of 5 different contributing categories as shown in Table 4 which were randomly listed in the questionnaire so as to minimize the respondents' tendency to make random errors. The safety professionals were asked to indicate their agreement on these aspects and how often they would take these aspects into account during preparation of risk assessment. It is possible that the respondents with high recognition on the possible causes of site accidents may not incorporate such knowledge into the risk assessment.

3.1.4. Perceptions on risk levels of different trades of works

People are different in terms of how they perceive risk (Stranks, 1997). Risk perception is a process of cognitive appraisal which can reflect how people evaluate risk (Cox and Cox, 1996). According to the information provided by the Employment and Earnings Statistics Section in Census and Statistic Department of HKSAR (2008), 20 trades of works which were mainly involved on Hong Kong construction sites are identified. The safety professionals, basing on their own experience and judgment, were asked to indicate the risks levels of the 20 trades of works (Table 5) and the brief job descriptions for the trade of works were attached to the questionnaire (Environment Transport and Works Bureau, 2009).

It is observed that this kind of statistics is not available and published by the Labour Department. The Hong Kong Housing Authority site accident report in January 2001 (Rowlinson, 2002) was only referred as an index to reflect the general trend of the accident by occupation.

The epidemiological approach for descriptive accident analysis is adopted by the researchers, Rowlinson, S.M. and Lingard, H.C., who undertook studies for the Hong Kong Housing Authority (Lingard, 1993). In these studies, the trends of accident occurrence on sites are explored and the typical results are categorised as occupation, time of day, agent involved and accident type (Rowlinson, 1997).

According to the survey conducted by Lingard and Rowlinson (1994), certain trades like carpenter/formworker, labourer and steel fixer/bender are more likely to cause injured than others. According to the Hong Kong Housing Authority site accident reports (Rowlinson, 2002), labourers remain the leading occupation of workers involved in site accidents contributing 24% of accidents. Painters/plasterers are in the second position which contributes 16% of accidents and carpenter injured in Housing Authority site accidents attributed to 14% of accidents. The main cause for accidents was directly due to the workers mishandling equipment and tools. It is suggested that understanding to types of accident and their severity is crucial for the improvement of site safety.

3.1.5. Recognitions of occurrence frequency for different types of site accidents

The safety professionals are asked to indicate the occurrence frequency of the 18 selected types of accidents (Table 6) commonly occurred in the Hong Kong construction industry with reference to the information published by the Labour Department, HKSAR (Labour, 2009).

3.2. Stage (II) Quantitative analysis on historical accident data and the development of Q^2REM

3.2.1. Development of Q^2REM with priority in terms of risk levels by trades of works as a supplementary guideline for risk assessment

McGuinness (1995) suggested that the decision on priorities for risk assessment can be referred to the available evidence gathered from accident statistics and reports. Besides, the Conservation Foundation (1985) revealed that setting priorities for risk assessment is crucial in the process of risk control. In this study, a model would be developed with priority in terms of risk levels by trades of works basing on the qualitative data analyses from Stage 1 and historical accident data obtained from 15 large-scaled sample projects in HK. The created model can be used as a supplementary guideline for the safety professionals to carry out a more reliable risk assessment in Hong Kong construction industry.

4. Data analysis and discussions

4.1. Stage 1A—Gathering information about the aspects of risk assessment by Delphi technique

Delphi technique was employed to develop the questionnaire of this research in Stage 1A and the technique is traditionally employed in the social science studies. After collecting the results from 37 respondents, frequency of the suggested aspects were found and 8 aspects which were suggested by over 50% of the respondents were then selected as shown in Table 7 and rephrased which were used for structuring questionnaire in Stage 1B. The aspects which conveyed similar meanings were combined and rephrased to avoid duplications.

4.2. Stage 1B—Structured questionnaire survey to safety professionals

A total of 62 safety professionals were involved in the structured survey that included safety supervisor (19), assistant safety officer (19), safety officer (18) and safety manager (6). 46 respondents worked for building works whilst the rest worked in the field of civil

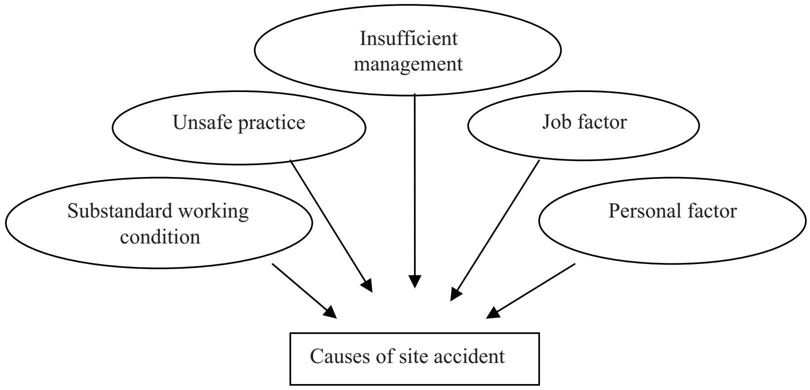

Fig. 1. Different contributing factors to site accident.

Table 4
A summary of 33 possible causes of site accidents in terms of 5 different contributing factors.

Insufficient management control	Unsafe practice	Substandard conditions
Improper or insufficient delegation	Improper use of tools and equipment	Poor housekeeping
Inadequate monitoring of works	Inadequate personal protective equipment	Improper illumination
Inadequate safety training	Improper operating/working speed	Inadequate ventilation
Inadequate supervision/management	Improper handling site materials	Inadequate traffic control
Inadequate specifications	Failure to give warning/secure	Inadequate working space
Poor accident reporting system	Lack of repair/maintenance	Unguarded mechanical/physical hazards
Poor planning for working sequences	Lack of pre-use equipment inspection	Unlabeled or inadequately labeled materials
Inadequate review of safety performance	Use of inherent hazardous method/procedure	
Inadequate accident preventative measures		

Personal factors	Job factors
Inadequate instruction	Inadequate job orientation/induction courses
Poor judgment	Improper storage of materials
Poor coordination/communication	Unrealistic risk assessment
Exposure to unsafe position	Unrealistic hazard analysis
Lack of alertness of the workers	

Table 5
20 trades of works commonly exist on Hong Kong construction sites.

Trades of works	Job descriptions
Bricklayer	To lay bricks and other building blocks, except stones and marble, for construction and repair of walls, partitions, arches, openings and other structures.
Carpenter	To erect and strike timber formwork for building works and construction work related to civil engineering.
Concretor	To mix, place and compact concrete using vibrating machines; to carry out curing, leveling and smoothening of concrete.
Plumber	To assemble, install, repair and maintain pipes, fittings, sanitary fixtures, cold, hot and flush water systems, and soil waste and rain-water drainage systems in buildings.
Electrician	To install, test, commission, maintain, and repair electrical installations and wiring; to fit, assemble, install, test, commission, maintain and repair electrical systems and equipment.
Fitter	To fit, assemble, erect, install, maintain and repair mechanical plants and equipment.
Joiner	To carry out all internal and external woodwork (except formwork and fender) using both hand tools and woodworking machinery.
Labourer	To perform simple duties as directed by the tradesman, general cleaning or minor excavation work.
Painter	To perform painting for surfaces, fittings and fixtures of buildings and other structures for painting.
Plant and equipment operator	To operate construction plant and equipment for material-handling purposes including crawler-mounted mobile crane, wheeled telescopic mobile crane, tower crane, truck-mounted crane, and gantry crane, etc.
Plasterer	To apply coats of plaster to, and to render walls and ceilings to produce finished surfaces, to screed floors, staircases and roofs.
Pneumatic driller	To operate pneumatic or hydraulic drills to make holes and openings or break up concrete, rocks or other hard materials.
Rigger	To set up lifting apparatus and equipment for lifting and lowering of materials.
Bamboo scaffolder	To erect and dismantle bamboo scaffolding required in construction, repair or decoration work, and other forms of structures.
Site supervisory staff/ganger	To supervise, direct and co-ordinate the activities of workers engaged in construction works.
Steel fixer	To cut, bend and fix reinforcement steel bars.
Structural steel erector	To drill, cut and shape steel sections; to assemble structural members and erect steel structures by riveting or bolting; to operate power shears, flame cutting equipment and other tools.
Survey leveller	To read and interpret drawings, to set up job lines and levels and prepare templates.
Truck driver	To drive heavy goods vehicles to transport construction materials, building debris or excavated materials within, into or out of construction sites.
Welder	To carry out welding or cutting work by electric arc, oxy-acetylene flame or other welding processes.

Table 6
18 selected types of accidents commonly occurred in the Hong Kong construction sites.

1. Striking against or struck by moving object	7. Contact with moving machinery or object being machined	13. Striking against fixed or stationary object
2. Injured whilst lifting or carrying	8. Exposure to or contact with harmful substance	14. Contact with hot surface or substance
3. Slip, trip, or fall on same level	9. Contact with electricity or electric discharge	15. Injured by hand tool
4. Fall of person from height	10. Trapped by collapsing or overturning object	16. Exposure to explosion
5. Trapped in or between objects	11. Struck by moving vehicle	17. Injured by fall of ground
6. Stepping on object	12. Struck by falling object	18. Exposure to fire

Table 7
8 aspects which were mostly suggested by the respondents at Stage 1A.

Aspects that the construction safety professionals would consider during risk assessment	% of the respondents who suggested the corresponding aspects
Safety professionals' understanding of possible causes of accident from past working experience	89%
Understanding of possible risks of different trades of works	84%
Accident statistics from Labour Department	78%
Past accident records from company	68%
Construction workers' past working experience	68%
Understanding of site condition	62%
Understanding of method statement	59%
Involvement of supervisory staff	54%

Table 8
Relative importance of different aspects for risk assessment in descending order and the corresponding Pearson correlation coefficients with accident rate.

Aspects	Mean scores^	Pearson correlation coefficient with accident rate
Safety professionals' understanding of possible accident causes from past working experience	6.21	−0.292*
Construction workers' past working experience on site	6.18	0.291*
Understanding of possible risks of different trades of works	6.06	0.003
Understanding of site conditions	6.03	−0.114
Understanding of method statement	5.90	0.029
Involvement of supervisory staff	5.82	−0.020
Accident records in company	5.31	−0.006
Accident statistics from Labour Department	4.35	−0.270*

Note: (^) the mean score is ranged from 1 (least important) to 7 (most important).
*Correlation is significant at 0.05 level (2-tailed).

works. About 77% and 94% respondents have 1–9 years working experience in safety profession and in current company, respectively. Most of the respondents worked for the projects with the employment size greater than 100 employees on sites (81%) and the project size equal to or greater than HK$100 million (92%).

4.2.1. The respondents' perceptions on importance of aspects for risk assessment

The relative importance of different aspects for risk assessment was measured in terms of mean score as shown in Table 8. From the table, it was found that 'safety professionals' understanding of possible accident causes from past working experience' was the most important aspect for risk assessment with negative and significant correlations between this aspect and accident rates* ($r = -0.292$, $p = 0.021$) under the Pearson Correlation Test. 'Construction workers' past working experience on site' was considered as the second important aspect for risk assessment with positive and significant correlations with accident rates ($r = 0.291$, $p = 0.022$). 'Accident statistics from the Labour Department' was considered as the least important aspects but the correlation with accident rate was significantly negative ($r = -0.270$, $p = 0.034$).

*Accident rate (in this study) = average monthly accident rates per 1000 workers of their projects in accordance with the following formulae as provided in the questionnaire:

$$\frac{\text{Average monthly accident rate}}{\text{1000 workers}} = \frac{\text{Sum of no. of reported accidents up to latest reported month/no. of reported month}}{\text{Sum of no. of manual workers employed monthly up to latest reported month/no. of reported month}} \times 1000.$$

4.2.2. The respondents' perceptions on importance of the aspects for risk assessment by accident rate group

For easy comparison, if the accident rate of the sampled projects is equal to or above 70/1000 workers (average accident rate for the whole construction industry in HK, 2006–2008), it is classified as high accident rate and the respondents working on the corresponding site would be classified as high accident rate group whereas if the accident rate of the sampled project is below 70/1000 workers, it is classified as low accident rate and the respondents working on the corresponding site would be classified as low accident rate group.

The extent of differences of the respondents' perceptions on importance of aspects for risk assessment was examined under low and high accident rate groups. With reference to the defined accident rate grouping, the relative importance of aspects for the respondents under high and low accident rate groups are presented in Table 9 accordingly. It was found that the mean scores of each aspect for both groups were above average (>4.00). It meant that they generally thought that these aspects were important for risk assessment.

Among the 8 aspects, the most important aspects for risk assessment as perceived by the low accident rate group and high accident rate group were 'safety professionals' understanding of possible causes of accidents from past working experience' and 'construction workers' past working experience on site', respectively.

Table 9
Comparison of different perceptions on importance of aspects for different respondent groups.

Aspects	Mean scores for the low accident rate group (<70)	Rank	Mean scores for the high accident rate group (>70)	Rank
Safety professionals' understanding of possible accident causes from past working experience	6.44	1	5.97	3
Construction workers working experience on site	5.94	4	6.43	1
Understanding of method statement	5.88	5	5.93	4
Understanding of site conditions	6.16	2	5.90	5
Understanding of possible risks of different trades of works	6.06	3	6.07	2
Involvement of supervisory staff	5.84	6	5.80	6
Accident records in company	5.31	7	5.30	7
Accident statistics from Labour Department	4.63	8	4.07	8

The difference of two groups' perceptions on 'safety professionals' understanding of possible accident causes from past working experience', 'construction workers' past working experience on site' and 'accident statistics from the Labour Department' were statistically significant by Levene's test and Independent Sample *t*-Test as shown in Table 10.

With reference to Table 10, there was significant positive correlation between 'construction workers' past working experience on site' and accident rates whereas significant negative correlations were found in the aspects of 'safety professionals' understanding of possible accident causes from past working experience' and 'accident statistics from the Labour Department' with accident rate. It reinforced that emphasis placed on safety professionals' understanding of possible causes of accident and awareness of accident statistics from the Labour Department would help to improve safety performance whilst emphasis placed on 'construction workers' past working experience on site' may have negative effect.

Although 'accident statistics from Labour Department' was considered as the least important aspect, significant difference existed between two groups for this aspect by Independent Sample *t*-Test (Table 15), and significant negative correlation was also found (Pearson correlation coefficient = −0.270, P = 0.034). Thus, it has positive effect on improvement of safety performance.

4.2.3. Reliability test

As it was about measurement of the respondents' perceptions on causes of accident, the reliability of the measuring instrument had to be considered firstly. The reliabilities of the variables for each category of accident causes were examined before carrying out data analysis.

Referring to Table 11, it was observed that the original reliabilities for each type of accident causes were high with the reliability coefficient (α) ranging from 0.6841 to 0.8519 and the overall reliability was 0.9476. However, the reliability level is acceptable when α equals or greater than 0.7 (Nunually, 1978 and Foster, 2001). In order to obtain higher reliability for the 'personal factor' type, 'exposure to unsafe position' variable was extracted and the reliability became 0.7096. As a result, 32 variables were left for further analysis and the overall reliability became 0.9458.

After the reliability analysis, the respondents' recognitions on different types of accident causes were examined. From Table 12, the mean scores of the 5 types of accident rates were above average scores of 4.00. The highest mean score was 5.34 for the 'personal factor' whereas the lowest mean score was 4.54 for the 'job factor' (Table 13).

The findings reflected that the respondents tended to attribute accident causes to 'personal factor' such as inadequate instruction, lack of alertness of the workers and poor coordination and com-

Table 10
Differences of the respondents' perceptions on importance of aspects for risk assessment by accident rate groups under Levene's Test and Independent Sample *t*-Test.

		Levene's Test for equality of variances		*t*-Test for equality of means			
		F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference
Construction workers' past working experience on site	Equal variances assumed	.060	.808	−2.35 3	60	.022	−.50
	Equal variances not assumed			−2.363	59.785	.021	−.50
Method statement	Equal variances assumed	10.985	.002	−.223	60	.824	−.06
	Equal variances not assumed			−.227	51.176	.821	−.06
Accident records in company	Equal variances assumed	1.046	.310	.043	60	.966	.01
	Equal variances not assumed			.043	58.871	.966	.01
Understanding of site conditions	Equal variances assumed	2.882	.095	.891	60	.3 77	.26
	Equal variances not assumed			.879	49.556	.3 84	.26
Understanding of possible risks of different trades of works	Equal variances assumed	1.671	.201	−.023	60	.982	.00
	Equal variances not assumed			−.022	57.153	.982	.00
Safety professionals' understanding of possible accident causes from past working experience	Equal variances assumed	1.846	.179	2.364	60	.021	.47
	Equal variances not assumed			2.335	50.087	.024	.47
Accident statistics from Labour Department	Equal variances assumed	.450	.5 05	2.172	60	.034	.56
	Equal variances not assumed			2.177	59.997	.033	.56
Involvement of supervisory staff	Equal variances assumed	5.315	.025	.154	60	.878	.04
	Equal variances not assumed			.156	51.192	.876	.04

Table 11
Reliabilities analysis for the variables under different causes of accident by categories.

Variables for 'insufficient management control'	Variables for 'unsafe practice'	Variables for 'substandard working condition'	Variables for 'personal factor'	Variables for 'job factor'
Improper or insufficient delegation	Improper use of tools and equipment	Inadequate traffic control	Exposure to unsafe position	Improper storage of materials
Inadequate monitoring of works	Inadequate personal protective equipment	Poor housekeeping	Inadequate instruction	Unrealistic risk assessment
Inadequate safety training	Improper operating/working speed	Unguarded mechanical/physical hazards	Lack of alertness of the workers	Unrealistic hazard analysis
Inadequate supervision/management	Improper handling site materials	Inadequate working space	Poor coordination/communication	Inadequate job orientation/induction course
Inadequate specifications	Failing to give warning/secure	Inadequate ventilation	Poor judgment	
Inadequate accident preventative measures	Lack of repair/maintenance	Unlabelled or inadequately labeled materials		
Inadequate review of safety performance	Lack of pre-use equipment inspection	Improper illumination		
Poor planning for working sequence	Use of inherent hazardous method/procedure			
Poor accident reporting system				
$\alpha = 0.7818$	$\alpha = 0.7837$	$\alpha = 0.8214$	$\alpha = 0.7096$	$\alpha = 0.8519$

Table 12
The respondents' recognitions of different categories of accident causes in terms of the mean scores and the corresponding Pearson correlation coefficients with accident rate.

Type of accident causes	Mean scores^	Pearson correlation coefficient with accident rate
Personal factors	5.34	−0.210
Insufficient management control	5.02	−0.271*
Unsafe practice	4.86	−0.194
Substandard conditions	4.84	−0.319*
Job factors	4.54	−0.326*

Note: (^) the mean score is ranged from 1 (least agree) to 7 (strongly agree).
*Correlation is significant at 0.05 level (2-tailed).
It was found that average scores for the 5 categories of accident causes were negatively correlated with accident rates (Table 13). It proved that the respondents with higher recognitions of accident causes would help to improve safety performance in terms accident rates.

munication. Lau (1996) also revealed that site accidents are mainly due to personal mistakes made by the construction practitioners. The results were in line with the findings of Tse's study (1997) that construction workers are usually the victims of accidents due to a lack of safety and risk awareness.

From Table 12, the respondents had the lowest recognitions on the 'job factor', such as inadequate job orientation/induction course, unrealistic risk assessment and hazard analysis, among 5 categories of accident causes. It should be noted that the respondents are the safety professionals who are mainly involved in these tasks. Actually there are two possibilities leading to the results. One is that they are confident in their works and seldom make mistakes. Thus they may think that accidents are less likely caused by their own faults. Another possibility is that they ignore this factor but simply attribute accident causes to factors, such as personal factor. If the latter is true, it would probably be an obstacle for improvement of safety performance. As an effective risk assessment involves analysis and evaluation of risk is a proactive process to prevent accidents occurred repeatedly and, in turn, improve safety performance (Cox and Cox, 1996), it is necessary to investigate the actual reasons in further studies.

4.2.4. *Risk levels for different trades of works*

In the survey, the respondents were asked to indicate the risk level of different trades of works according to their experience and professional judgment. The results were listed according to different accident rate groups in Table 14.

It should be stressed that the ranking exercise is based on perception, not an objective assessment. A subjective assessment of the ranking results is made to analyze the perceived relative importance of factors. The fact is that this subjective assessment does not provide any absolute value on the ranking position. Emphasis is given only to factors that are perceived to be the most important and the least important (Chan and Yeong, 1994).

With reference to the scale given in the questionnaire, the risk levels were classified into three categories: 'low' for mean scores less than 4.00, 'moderate' for mean scores between 4.00 and 4.99 and 'high' for mean scores equal to or greater than 5.00–7.00. It was observed that the risk levels for different trades of works as perceived by different accident rate groups were the similar and there was no significant difference in the perceptions between high and low accident rate groups by Levene's Test and Independent Sample *t*-Test.

From Table 14, the risk level of 'bamboo scaffolder', 'structural steel erector', 'carpenter', steel fixer' and 'fitter' were considered as high (mean score > 5.00) whereas 'painter', 'survey leveller', 'plant operator', 'truck driver' and 'site supervisory staff' were relatively

Table 13
Correlations between average scores for the 5 categories of accident causes and accident rates.

		Yearly accident rate/1000 workers	Average scores of 5 categories of accident causes
Yearly accident rate/1000 workers	Pearson Correlation	1	−.320*
	Sig. (2-tailed)		.011
	N	62	62
Average scores of 5 categories of accident causes	Pearson Correlation	−.320*	1
	Sig. (2-tailed)	011	
	N	62	62

Table 14
Risk levels of different trades of works perceived by different accident rate groups.

Trades of works	Overall		Low accident rate group (yearly accident rate <70)		High accident rate group (yearly accident rate >70)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Bamboo scaffolder	6.13	0.996	6.31	0.859	5.93	1.048
Structural steel erector	5.65	1.073	5.94	0.878	5.33	1.184
Carpenter	5.61	1.092	5.59	1.012	5.63	1.189
Steel fixer	5.19	1.006	5.22	0.792	5.17	1.206
Fitter	5.18	1.017	5.13	0.660	5.23	1.305
Electrician	4.89	0.907	4.91	0.856	4.87	0.973
Labourer	4.87	1.248	4.91	1.400	4.83	1.085
Joiner	4.74	1.159	4.88	1.129	4.60	1.192
Rigger	4.66	1.130	4.50	0.984	4.83	1.262
Welder	4.47	1.302	4.66	0.937	4.27	1.596
Pneumatic driller	4.44	1.363	4.47	1.077	4.40	1.632
Concretor	4.24	1.250	4.38	1.289	4.10	1.213
Plasterer	4.23	1.372	4.22	1.263	4.23	1.501
Plumber	4.15	1.053	4.28	0.888	4.00	1.203
Bricklayer	4.15	0.743	4.16	0.677	4.07	0.819
Painter	3.92	1.309	3.91	1.228	3.93	1.413
Survey leveller	3.58	1.313	3.50	1.164	3.67	1.470
Plant and equipment operator	3.56	1.288	3.38	0.751	3.77	1.675
Truck driver	3.48	1.576	3.41	1.365	3.57	1.794
Site supervisory staff/ganger	3.47	1.468	3.28	1.143	3.67	1.749

low (mean score < 4.00). The risk levels of the rest of trades of works as listed in the table were medium as perceived by the respondents in both high and low accident rate groups.

4.2.5. Rank agreement factor, percentage agreement and disagreement

It should be stressed again that the ranking exercise is based on perception, not an objective assessment. A subjective assessment of the ranking results is made to analyze the perceived relative importance of factors (Chan and Yeong, 1994). With reference to the scale given in the questionnaire, the frequencies were classified into three broad categories: 'low' for mean scores less than 4.00, 'moderate' for mean scores between 4.00 and 4.99 and 'high' for mean scores equal to or greater than 5.00–7.00. For the ease of comparison, the actual occurrence frequencies from 2006 to 2008 (Occupational Safety and Health Council, 2009) were also divided into 3 broad categories in terms with the percentage of each accident type occupied: 'low' (<1% of total accidents), 'moderate' (between 1% and 10% of total accidents) and 'high' (>10% of total accidents).

The categories were further ranked as '1' for high frequency, '2' for moderate frequency and '3' for low frequency. The comparison of the occurrence frequency by the three categories and ranks for different types of accidents was listed in Table 15.

Table 16 showed the bias of the respondents in judged occurrence frequency of different types of accidents compared with the published statistics from 2006 to 2008 (Occupational Safety and Health Council, 2009). The occurrence frequencies of 'stepping by hand tool', 'injured by hand tool' and 'injured by fall of ground' were overestimated but each of them just occupied below 5% according to the published statistics from 2006 to 2008. On the other hand, they underestimated the occurrence frequencies of 'injured whilst lifting or carrying', 'striking against fixed or stationary object', 'striking against or struck by moving object', 'trapped in or between objects', and 'contact with moving machinery or object being machined'.

According to the published statistics from 2006 to 2008, the former three types of accidents occupied over 12% whereas the latter two occupied below 7%. The results showed that the respondents' recognitions of the recent trend of occurrence frequencies of different types of accidents were fairly low which leaded to about 44% misjudgment.

4.2.6. Comparison of RAF, PA and PD by accident rate groups

To test the degree of agreement in ranking between different groups, cross comparison was carried out. The rank agreement factors (RAFs) were computed using the formula, $\mathrm{RAF} = (\sum_{i=1}^{N}\left|R_{i1} - R_{i2}\right|)/N$ for the two groups, assuming the ranks of the ith item in group 1 be R_{i1} and in group 2 be R_{i2} and the absolute difference (D_i) becomes $D_i = \left|R_{i1} - R_{i2}\right|$ where $i = 1, 2, \ldots\ldots\ldots N$ items, as adopted in the study of Okpala and Aniekwu (1988). The RAF is ranged from 0 which indicates perfect agreement whilst the degree of disagreement would be increased with the value of RAF. In this study, the degree of disagreement and RAF was used to reflect the extent of difference in ranks of occurrence frequency of different types of accidents between the published accident statistics from 2006 to 2008 and the mean scores of the respondents.

The percentage agreement and percentage disagreement can also be calculated accordingly. As mentioned before, it is a matter of subjective assessment, the exact ranks for the types of accidents are not necessary for analysis. Instead, the broad ranks from 1 to 3 were employed to represent the extent occurrence frequencies of different types of accidents (1 = the lowest frequency, 2 = moderate frequency and 3 = the highest frequency) for calculations. In this way, the absolute maximum difference ($D_{\max}$) becomes $D_{\max} = \left|R_{x1} - R_{y2}\right|$ and the percentage disagreement, $\mathrm{PD} = 100\% \times (\sum_{i=1}^{N}\left|R_{i1} - R_{i2}\right| / \sum_{i=1}^{N} D_{\max i})$, can be calculated where $i = 1, 2, \ldots\ldots\ldots N$ items, x and y are represented the item ranks in accordance with the published accident statistics from 2006 to 2008 and the mean score of the respondents, respectively (if $x = 1$ or 3, $y = 2$ and if $x = 2$, $y = 1$). The percentage agreement (PA) becomes 100% − PD.

Table 17 shows the results of average RAF, PA and PD for different group pairs. The average percentage agreement of 58% and rank agreement factor of 0.70 for the respondents and the accident statistics reflected that the construction practitioners did not fully recognize the recent trend of different types of accidents with respect to the occurrence frequency.

Table 15
The relative rankings of different types of accident between the accident statistics from 2006 to 2008 (Occupational Safety and Health Council, 2009) and the respondents under 'low accident rate' and 'high accident rate' groups.

Type of accident	Mean scores for 'low accident rate' group (rank)	Mean scores for 'high accident rate group (rank)	Average mean scores for all respondents (rank)	% of total number of accident derived from accident statistics from 2006 to 2008 (rank)
Slip, trip or fall on same level	5.41 (1)	4.87 (2)	5.15 (1)	18.8% (1)
Stepping on object	4.94 (2)	5.27 (1)	5.10 (1)	1.5% (2)
Injured by hand tool	4.91 (2)	5.20 (1)	5.05 (1)	4.9% (2)
Injured whilst lifting or carrying	4.84 (2)	4.73 (2)	4.79 (2)	15.4% (1)
Fall of person from height	4.72 (2)	4.73 (2)	4.73 (2)	8.9% (2)
Striking against or struck by moving object	4.75 (2)	4.27 (2)	4.52 (2)	22.9% (1)
Struck by falling object	3.81 (3)	4.80 (2)	4.29 (2)	3.6% (2)
Injured by fall of ground	4.13 (2)	4.13 (2)	4.13 (2)	0.1% (3)
Striking against fixed or stationary object	3.94 (3)	3.97 (3)	3.95 (3)	12.4% (1)
Trapped in or between objects	4.09 (2)	3.70 (3)	3.90 (3)	1.9% (2)
Exposure to or contact with harmful substance	3.41 (3)	4.13 (2)	3.76 (3)	0.7% (3)
Contact with electricity or electric discharge	3.13 (3)	4.17 (2)	3.63 (3)	0.3% (3)
Trapped by collapsing or overturning object	2.91 (3)	4.13 (2)	3.50 (3)	0.4% (3)
Contact with moving machinery or object being machined	3.31 (3)	3.77 (3)	3.53 (3)	6.1% (2)
Contact with hot surface or substance	3.19 (3)	3.27 (3)	3.23 (3)	0.9% (3)
Struck by moving vehicle	2.53 (3)	2.97 (3)	2.74 (3)	0.4% (3)
Exposure to fire	2.50 (3)	2.83 (3)	2.66 (3)	0.3% (3)
Exposure to explosion	2.13 (3)	2.63 (3)	2.37 (3)	0.1% (3)

Note: Rank '1' for occurrence frequency > 10% or >5.00 of mean score.
Rank '2' for 1% < occurrence frequency < 10%.
or for 4.00 mean score < occurrence frequency < 5.00 of mean score.
Rank '3' for occurrence frequency by type of accident < 1% or <4.00 of mean score.

Table 16
Bias of the respondents in judged occurrence frequency of different types of accidents.

Overestimated types of accidents	Underestimated types of accidents
Stepping on object	Striking against or struck by moving object
Injured by hand tool	Injured whilst lifting or carrying
Injured by fall of ground	Striking against fixed or stationary object
	Trapped in or between objects
	Contact with moving machinery or object being machined

4.3. Stage 2—Development of a 'Risk Evaluation Model' (Q^2REM)

Basing on the results of the Stage 1, the general deficiencies of local practice for risk assessment were found:

1. Respondents tend to attribute accidents causes to personal factors (i.e. lack of alertness of the workers, poor judgment, poor communication/coordination). No relevant historical statistics to reflect the actual proportions of different types of accident causes.
2. Respondents used to evaluate risk in terms of works activities instead of trades of works (analysis for risk assessment not detailed enough).
3. Respondents had fairly low recognition on the recent trend of occurrence frequency of different types of accidents (44% misjudgement compared with the actual and published statistics).

Due to the deficiencies of the general practice through investigation of the safety professionals' perceptions on risk and in order to improve the reliability of risk assessment, a "Risk Evaluation Model" (Q^2REM) is proposed.

The correctness of the chosen level of risk can be experienced and assessed by its consequences over time (Trimpop, 1994). Historical accident records, such as accident causes and types of accident by trades of works, are the examples. Systematic documented procedures can assist in identifying work related hazards and developing controls to minimize/eliminate those hazards as suggested by Trethewy (2003). In spite of the importance of risk assessment, precise estimate of risk may not be required (Jannadi and Almishari, 2003). Instead, a reliable tool to measure the extent of the potential risk is essential.

The decision on priorities for risk assessment can be based on the available evidence gathered from accident statistics and reports (McGuinness, 1995) and setting of priorities for risk assessment is essential in the process of risk control (The Conservation Foundation, 1985). In light of this, a model with priority in terms of the quantitative risk estimates is developed with reference to the restructured historical data of 15 large scaled construction projects. The historical accident data (from January 2006 to December 2008) by trades of works, types of accident and accident causes was available for the 15 sample projects and it was summarized in Table 18 and the meanings of abbreviations used for types of accident and accident causes were tabulated in Tables 19 and 20.

Measurement of risk involves probability and severity of all hazards of each work activity. In this research, the risk levels 'R' by trades of works and types of accidents were determined in terms of the probability of accidents occurred and severity of the accidents. The occurrence frequencies of different combinations of accident

Table 17
Average rank agreement factor (RAF), percentage agreement (PA) and percentage disagreement (PD) on occurrence frequency of different types of accidents.

Group	Average rank agreement factor (RAF)	Average percentage agreement (PA)	Average percentage disagreement (PD)
Low accident rate group and statistics from 2006 to 2008	0.56	67%	33%
High accident rate group and statistics from 2006 to 2008	0.84	49%	51%
All respondents and statistics from 2006 to 2008	0.70	58%	42%

Table 18
Summary of the historical accident data by trades of works, types of accident and accident causes restructured from the 15 large-scaled sample projects (in 3-year average).

Trades of works (numbers of accidents)	Probability (P)	Severity (S)	Risk level (S)	Type of accident (number of accident)	Probability (P)	Severity (S)	Risk level (S)	Causes of accidents (numbers of accidents)	Occurrence frequency by %
Labourer (86)	0.46	4.14	1.90	Kl (32)	0.17	4.53	0.77	MSP (26)	14.0%
Steel Fixer (16)	0.09	4.88	0.44	K4 (27)	0.15	5.11	0.77	SJP (20)	10.8%
Carpenter (16)	0.09	4.69	0.42	Kll (26)	0.14	4.38	0.61	CSJP (18)	9.7%
Site supervisory staff (12)	0.06	4.42	0.27	K2 (26)	0.14	4.35	0.61	MCSP (17)	9.1%
Plant Operator (12)	0.06	4.42	0.27	K3 (21)	0.11	4.52	0.50	SP (17)	9.1%
Welder (5)	0.03	6.40	0.19	K5 (20)	0.11	4.25	0.47	MCSJ (10)	5.4%
Pneumatic Driller (6)	0.03	5.12	0.15	K6 (9)	0.05	4.33	0.22	CSP (10)	5.4%
Surveyor levellor (8)	0.04	3.63	0.15	K17 (9)	0.05	3.56	0.18	MCS (8)	4.3%
Rigger (6)	0.03	4.33	0.13	K10 (5)	0.03	4.80	0.14	CSJ (7)	3.8%
Truck driver (1)	0.01	6.00	0.06	K15 (3)	0.02	4.67	0.09	MS (7)	3.8%
Drainlayer (3)	0.01	5.33	0.05	K13 (3)	0.02	3.33	0.07	SJ (6)	3.2%
Electrician (2)	0.01	3.00	0.03	K8 (l)	0.01	5.00	0.05	CS (5)	2.7%
Concretor (1)	0.01	3.00	0.03	K12 (l)	0.01	5.00	0.05	MSJP (4)	2.2%
Plasterer (1)	0.01	4.00	0.02	K16 (l)	0.01	3.00	0.03	CJP (4)	2.2%
Others (11) (including site investigation worker, pile worker, banksman, technician	0.06	4.73	0.28	K7 (2)	0.01	2.50	0.03	MP (4)	2.2%
				K9 (0)				S (4)	2.2%
				K14 (0)				JP (3)	1.6%
				K18 (0)				MC (3)	1.6%
								MCSJP (2)	1.1%
								MCP (2)	1.1%
								MJ (2)	1.1%
								C (2)	1.1%
								MCJP (1)	0.5%
								MSJ (1)	0.5%
								MJP (1)	0.5%
								CJ (1)	0.5%
								P (1)	0.5%

causes are presented by percentages. For the values of 'P', it is generated from the number of site accidents occurred divided by the updated total numbers of site accidents and types of accidents whilst for the values of 'S', it is referred to the average mandays lost due to the accidents. The values of 'R' can then be obtained from the products of 'P' and 'S' ($P \times S = R$) which are classified as low ($0 < R < 1.32$), moderate ($1.32 < R < 3.30$) and high ($3.30 < R < 7.00$), respectively. For the detailed definitions and classifications of 'P', 'S' and 'R' can be referred to Tables 21 and 22.

However, the discrete historical accident data as shown in Table 18 may not be representative enough because it fails to show the interrelationships among trades of works injured, types of accidents and accident causes. In this regard, the historical data was re-examined and rearranged in terms of the risk levels of different trades of works injured caused by different types of accidents by different accident causes and they are summarized in Table 23.

According to the above shown restructured historical data, a 'Risk Evaluation Model' (named as *Q*^{2}*REM* hereafter) is then developed. For clear demonstration of the *Q*^{2}*REM*, some abbreviations are employed for identifications of types of accidents and accident causes. The *Q*^{2}*REM* shows the inter-relationships among trades of works injured, types of accidents in terms of risk levels and accident causes which is presented in Fig. 2.

The *Q*^{2}*REM* contains accidents causes which are categorized into 5 broad types, insufficient management control (M), unsafe practice (S), substandard working condition (C), personal factor (P) and job factor (J) with sub-groups remarked in the model. Taking 'labourer' as an example, 16% of the accidents lead to labourer struck by falling object (K11) and 21.4% of them are due to insufficient management control, unsafe practice, and personal factor. The insufficient management control includes 'inadequate specifications' and 'poor planning for working sequence' whilst the unsafe practice includes 'inadequate personal protective equipment' and 'failure to give warning/secure'. The personal factor includes 'lack of alertness of the workers' and 'poor judgment'.

It should be noted the elements and the priority of accident data listed in the ***Q*^{2}*REM*** can be varied from case to case which depends on the historical accident data recorded in the construction projects. For example, the priorities of different trades of works in terms of risk levels may be different on the basis of the past safety performance of the corresponding construction projects. Besides, the information about the accident causes are obtained from the accident investigation and its quality and accuracy is subject to the safety professionals' judgment.

In this model, the available accident data from the large-scaled sample project was referred to and restructured. Besides, for the ease of demonstration, the trades of works listed in the model are not complete (only 9 trades of works shown in the *Q*^{2}*REM*)

Table 19
Meanings of the abbreviations for types of accidents.

Type of accident	
K1: Trapped in or between objects	K10: Trapped by collapsing or overturning object
K2: Injured whilst lifting or carrying	K11: Struck by falling object
K3: Slip, trip or fall on same level	K12: Struck by moving vehicle
K4: Fall of person from height	K13: Contact with moving machinery or object being machined
K5 Striking against fixed or stationary object	K14: Contact with hot surface or substance
K6: Striking against or struck by moving object	K15: Exposure to fire
K7: Stepping on object	K16: Exposure to explosion
K8: Exposure to or contact with harmful substance	K17: Injured by hand tool
K9: Contact with electricity or electric discharge	K18: Injured by fall of ground

Table 20
Meanings of the abbreviations for accident causes.

Accident causes		
M: Insufficient management control	S: Unsafe practice	C: Substandard working condition
M^1: Improper or insufficient delegation	S^1: Improper use of tools and equipment	C^1: Inadequate traffic control
M^2: Inadequate monitoring of works	S^2: Inadequate personal protective equipment	C^2: Poor housekeeping
M^3: Inadequate safety training	S^3: improper operating/working speed	C^3: Unguarded mechanical/physical hazards
M^4: Inadequate supervision/management	S^4: Improper handling site materials	C^4: Inadequate working space
M^5: Inadequate specifications	S^5: Failure to give warning/secure	C^5: Inadequate ventilation
M^6: Inadequate accident preventative measures	S^6: Lack of repair/maintenance	C^6: Unlabelled or inadequately labeled materials
M^7: Inadequate review of safety performance	S^7: Lack of pre-use equipment inspection	C^7: Improper illumination
M^8: Poor planning for working sequence	S^8: Use of inherent hazardous method/procedure	
M^9: Poor accident reporting system		
P: Personal factor	J: Job factor	
P^1: Exposure to unsafe position	J^1: Improper storage of materials	
P^2: Inadequate instruction	J^2: Unrealistic risk assessment	
P^3: Lack of alertness of the workers	J^3: Unrealistic hazard analysis	
P^4: Poor coordination/communication	J^4: Inadequate job orientation/induction course	
P^5: Poor judgment		

Table 21
Definitions of '*P*', '*S*' and '*R*'.

	Calculations
P (by trades of works)	Nos. of site accidents occurred for the particular trades of works Updated total nos. of site accidents
P (by types of accidents)	Nos. of the particular type of accidents updated total nos. of site accidents
S (by trades of works)	The average mandays lost due to the accidents for the particular trades of works according to defined index (1 = 0–3 days; 2 = 3–7 days (1 week); 3 = 8–30 days (1 month); 4 = 31–90 mandays (3 months); 5 = 91–183 mandays (6 months); 6 = 184–365 mandays (1 year) and 7 = 366 days or above (over 1 year) or mortality)
S (by types of accidents)	The average mandays lost due to the particular types of accidents according to defined index (1 = 0–3 days; 2 = 3–7 days (1 week); 3 = 8–30 days (1 month); 4 = 31–90 mandays (3 months); 5 = 91–183 mandays (6 months); 6 = 184–365 mandays (1 year) and 7 = 366 days or above (over 1 year) or mortality)
R (by trades of works)	*P* (by trades of works) × *S* (by trades of works)
R (by types of accidents)	*P* (by types of accidents) × *S* (by types of accidents)

and. only types of accidents with the top three ranked risk levels and the corresponding accident causes ranked in the top three in terms of occurrence frequency are shown in the Q^2REM. From the sampled projects, it was found that there are some other trades of works which encountered relatively low probability of accident on site, such as site investigation worker, pile worker, banksman, technician and site clerk. It would not be meaningful to get the discrete probability, severity and risk levels for these trades of works, respectively. Thus, they were grouped and classified as "others" trade of works and the combined probability, severity and risk level became 0.06, 4.73 and 0.28 accordingly with reference to Fig. 2.

Table 22
Classifications of '*P*', '*S*' and '*R*'.

Probability (*P*)	Severity (*S*)	Risk level
$0 < P < 0.33$ (Low)	$0 < S < 4.00$ (Low)	$0 < R < 1.32$ (Low)
$0.33 < P < 0.66$ (Moderate)	$4.00 < S < 5.00$ (Moderate)	$1.32 < R < 3.30$ (Moderate)
$0.66 < P < 1.00$ (High)	$5.00 < S < 7.00$ (High)	$3.30 < R < 7.00$ (High)

Nevertheless, all of the accident data have to be included to reflect the real picture of the safety performance in actual practice. Most importantly, great care must also be taken to select data which are relevant to the situation under consideration if realistic risk assessment is to be made.

4.3.1. Benefits of implementation of the 'Q^2REM'

In general practice, the construction safety professionals tend to rely heavily on their own past experience to make subjective decisions on risk assessment. However, Flanagan and George (1993) advocated that both objective and subjective evidence available currently should be used to assess the probabilities. Besides, subjective probabilities should not be formed by an individual or a group but they should acquire abundant desirable properties of objective probabilities. The model Q^2REM is served as a platform to ensure all construction personnel share a common understanding of its application. Stahl et al. (2001) revealed that effective risk communication can help the practitioners being kept informed of the methodologies and analysis techniques so that the data shown in the model does not come from 'black-box science'. Indeed, the model provides objective evidence to assess the probabilities and severities which clearly shows the distributions of different combinations of accidents causes resulting in different types of accidents for different trades of works.

At project level, the implementation of the Q^2REM benefits the safety professionals to communicate effectively with the workers from different trades of works about their corresponding potential risk which would probably cause different types of accidents due to different accident causes on the basis of the objective statistics shown in the model. It helps to arouse their attentions for accident prevention through safety trainings. It also facilitates communication for identification and control of risk. The safety professionals can also make easy reference to allocate relevant safety precautions with reference to the systematic and historical accident data in a more effective manner.

At organization level, the senior management can obtain an overall picture about the risk levels by trades of works from all their construction projects. They can also easily spot out which trades of works generally are ranked at relatively high risk level so that they can easily find out the possible accident causes and types of accidents with reference to the relevant historical data shown in the Q^2REM. The information is vital for them to make proper decisions for risk reduction of the corresponding trades of works.

Special attention should be paid because the model is not unique and the safety professionals can modify and add some information that they consider as useful for risk assessment. Parts of injury and

Table 23
Summary of historical accident data in terms of risk levels by trades of works due to different causes of accident causing different types of accidents.

Trades of works (number of accident)	Probability	Severity	Risk level	Type of accident (number of accident)	Probability	Severity	Risk level	Accident causes (number of accident)	%
Labourer (86)	0.46	4.14	1.90	K1 (12)	0.14	3.92	0.55	$C^3S^1J^{2,4}$ (2)	16.7
								$S^{1,5}J^{1,2}P^{3,5}$ (3)	25.0
								$M^{3,5,6,8}S^{3,4}P^{3,4}$ (4)	33.3
								$M^6S^{1,5,8}P^{3,5}$ (2)	16.7
								$M^8C^4S^1J^3$ (1)	8.3
				K2 (14)	0.16	3.79	0.61	$S^{1,4,8}J^{2,3}$ (3)	21.4
								$S^{1,3,4}J^{2,3}P^{3,5}$ (4)	28.6
								$M^{5,8}S^1$ (2)	14.3
								J^2P^5 (1)	7.1
								$M^{5,8}S^{3,4}J^{2,3}P^3$ (2)	14.3
								$M^8J^3P^3$ (1)	7.1
								$M^4S^2P^3$ (1)	7.1
				K3 (9)	0.10	4.56	0.46	$M^8S^1J^1P^5$ (1)	11.1
								$C^3S^5J^3$ (1)	11.1
								$C^{2,4}S^{4,5}P^3$ (2)	22 2
								$C^2S^5J^2P^5$ (2)	22 2
								$M^8C^2S^5$ (1)	n.i
								$M^8S^3P^3$ (1)	n.i
								S^5 (1)	n.i
				K4 (10)	0.12	5.30	0.64	$M^9C^2S^5J^2$ (1)	10.0
								$C^3S^4J^{2,3}P^3$ (1)	10.0
								$C^3S^5P^2$ (1)	10.0
								$M^6C^2S^{4,5}P^3$ (1)	10.0
								M^3P^3 (1)	10.0
								$S^{1,8}P^{3,5}$ (2)	20.0
								$M^6S^5J^4$ (1)	10.0
								$M^{5,8}C^3S^5$ (2)	20.0
				K5 (7)	0.08	4.71	0.38	S^5J^2 (1)	14.3
								$C^2S^4J^3$ (1)	14.3
								$M^9C^2S^{4,5}P^3$ (1)	14.3
								$M^5S^8P^5$ (1)	14.3
								$S^5J^2P^5$ (1)	14.3
								$M^8C^2S^5$ (1)	14.3
								C^1 (1)	14.3
				K6 (4)	0.05	3.75	0.19	$M^3S^1P^3$ (1)	25.0
								$C^3S^{1,2}P^2$ (1)	25.0
								$S^{1,2}$ (1)	25.0
								M^8P^1 (1)	25.0
				K7 (2)	0.02	2.50	0.05	$C^3S^4P^2$ (1)	50.0
								C^3S^3 (1)	50.0
				K8 (1)	0.01	5.00	0.05	$C^2S^3J^2$ (1)	100.0
				K10 (2)	0.02	4.50	0.09	$C^4S^8J^1P^3$ (1)	50.0
								$M^{5,8}C^2J^{2,4,5}P^1$ (1)	50.0
				K11 (14)	0.16	4.21	0.67	$M^8C^2S^4$ (1)	7.1
								$M^{5,8}S^{2,5}P^{3,5}$ (3)	21.4
								M^8C^3 (1)	7.1
								$M^{3,5,8}S^{1,4,7}$ (2)	14.3
								$M^3C^2S^4P^4$ (1)	7.1
								$C^3S^8J^2P^5$ (1)	7.1
								$M^{3,8}C^{2,3}S^{4,5}J^2$ (2)	14.3
								$S^1P^{3,5}$ (1)	7.1
								$S^{1,4,8}J^{1,2,3}P^{3,4}$ (2)	14.3
				K13 (3)	0.03	3.33	0.10	$M^8C^3S^4J^2P^3$ (1)	33.3
								$M^8S^1P^2$ (1)	33.3
								$S^{1,7}J^2P^3$ (1)	33.3
				K15 (2)	0.02	3.50	0.07	$M^8S^{4,6,7}P^3$ (1)	50.0
								S^1P^3 (1)	50.0
				K16 (1)	0.01	3.00	0.03	S^7 (1)	100.0
				K17 (5)	0.06	3.20	0.19	$M^3S^{2,8}P^3$ (2)	40.0
								$M^3C^4S^5J^3$ (1)	20.0
								C^2S^5 (1)	20.0
								$S^1J^{2,3}P^3$ (1)	20.0

Table 23 (*Continued*)

Trades of works (number of accident)	Probability	Severity	Risk level	Type of accident (number of accident)	Probability	Severity	Risk level	Accident causes (number of accident)	%
Steel Fixer (16)	0.09	4.88	0.44	K1 (5)	0.31	5.20	1.61	$M^3P^{1,5}$ (1)	20.00
								$S^5J^2P^5$ (1)	20.00
								$M^3S^3P^3$ (1)	20.00
								$C^3S^5P^3$ (1)	20.00
								$S^4P^{1,5}$ (1)	20.00
				K2 (3)	0.19	5.00	0.95	J^2P^5 (1)	33.33
								$C^4J^2P^5$ (1)	33.33
								$M^{7,8}S^8$ (1)	33.33
				K3 (1)	0.06	6.00	0.36	$M^3C^2S^5P^3$ (1)	100.00
				K4 (2)	0.13	3.50	0.46	$S^5P^{3,5}$ (1)	50.00
								$M^6S^5P^5$ (1)	50.00
				K5 (2)	0.13	4.00	0.52	$S^5P^{3,5}$ (1)	50.00
								$P^{3,5}$ (1)	50.00
				K6 (2)	0.13	5.00	0.65	$S^{3,4}P^{3,5}$ (2)	100.00
				K10 (1)	0.06	6.00	0.36	C^2S^4 (1)	100.00
Carpenter (16)	0.09	4.69	0.42	K1 (2)	0.13	4.50	0.59	$C^3J^2P^5$ (1)	50.00
								$M^4C^3S^1J^1$ (1)	50.00
				K2 (1)	0.06	5.00	0.30	J^2P^6 (1)	100.00
				K3 (1)	0.06	4.00	0.24	$C^2S^5J^2P^5$ (1)	100.00
				K4 (3)	0.19	5.00	0.95	$C^3S^8P^{4,5}$ (1)	33.33
								$M^{3,8}S^4$ (1)	33.33
								$S^4P^{3,5}$ (1)	33.33
				K5 (3)	0.19	5.00	0.95	$C^3S^4J^2P^5$ (1)	33.33
								$M^2S^5J^3P^5$ (1)	33.33
								$M^6C^2S^4$ (1)	33.33
				K6 (1)	0.06	3.00	0.18	$C^4S^4J^3P^3$ (1)	100.00
				K11 (2)	0.13	5.50	0.72	$M^{2,8}C^3S^4J^4$ (1)	50.00
								$C^2S^5P^{3,5}$ (1)	50.00
				K17 (3)	0.19	4.33	0.82	$S^5P^{3,5}$ (1)	33.33
								$M^8S^8P^5$ (2)	66.67
Drainlayer (3)	0.01	5.33	0.05	K1 (1)	0.33	5.00	1.65	$M^5C^4S^{5,7}P^4$ (1)	100.00
				K2 (1)	0.33	4.00	1.32	$M^{5,8}J^4$ (1)	100.00
				K5 (1)	0.33	7.00	2.31	M^6S^5 (1)	100.00
Plasterer (1)	0.01	4.00	0.02	K2 (1)	1.00	4.00	4.00	$S^4J^3P^3$ (1)	100.00
Electrician (2)	0.01	3.00	0.03	K3 (1)	0.50	4.00	2.00	S^5 (1)	100.00
				K11 (1)	0.50	2.00	1.00	$M^5C^3S^4J^3$ (1)	100.00

agents involved are examples that can be added to the suggested model to make it more informative and comprehensive.

As the model can provide qualitative assessment of risks levels for different trades of works causing different types of accidents in accordance with the determined quantitative calculations based on the historical accident data only, the follow up actions the safety professionals would take are out of the scope of this research. The tasks, instead, should be rested on them to make by their professional judgment so as to suit their site conditions. The important thing is that they can take a grip on these relatively objective statistics and utilize them appropriately so as to make a more reliable risk assessment by implementation of the *Q²REM*.

5. Conclusion and recommendations

After a series of analyses of the findings, the deficiencies of the current general practice for risk assessment were pinpointed, such as a lack of comprehensive system recording accident causes for different trades of works resulting in different types of accidents. Indeed, it was essential for the safety professionals to learn and apply the appropriate statistical techniques to handle the accident data for the ease of their preparation on reliable risk assessment. In this regard, the *Q²REM* with priority in terms of risk levels by trades of works was developed and demonstrated on the basis of the historical accident data from 15 large-scaled sample projects in Hong Kong construction industry.

By determining the mechanisms for calculations of the risk levels in terms of probability and severity of accidents, the risk levels by trades of works and accident causes could be prioritized. One of the benefits was that the safety professionals were able to obtain relatively objective accident statistics through combination of the quantitative and qualitative methods for determining the risk levels. It could be employed by the safety professionals as a useful supplementary guideline of risk assessment in the construction industry.

After all, effective safety management depends on how the risks are assessed and how coherent decisions to reduce and control them (Cagno et al., 2000). Successful safety management system requires a systematic risk assessment process and a continuous improvement approach which can support the concerned safety professionals and parties in planning effective prevention measures. Risk assessment is holistic and largely qualitative. To identify an effective risk assessment methodology, it is vital to

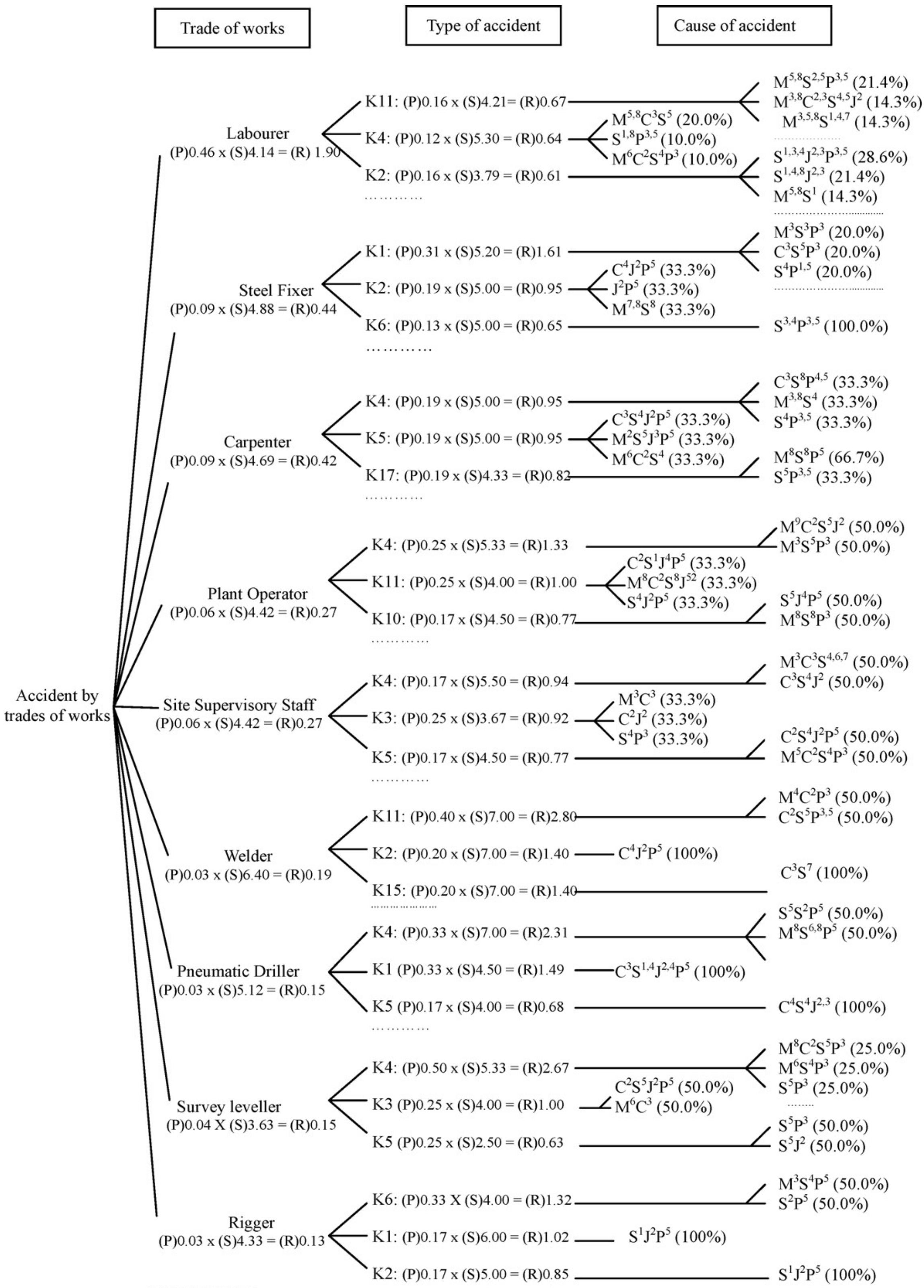

Fig. 2. Formation of 'Risk Evaluation Model' Q^2REM for showing the inter-relationship among trades of works being injured, types and causes of accidents with reference to the accident data from 15 project samples.

define the risk model to reduce subjectivity and misinterpretation in estimating risk and its causes. The Q^2REM developed in this study is an example which integrates the contribution to risk given by different types of accidents so that the overall risk evaluation can be derived by trades of works.

To ensure the construction safety professionals capability of risk assessment to up standard, legislated mandatory 'risk assessment' courses is recommended to them and the techniques of analyses by accident causes, types of accidents and trades of works should also be incorporated into the courses which can help to improve their safety risk perceptions. The implementation of the Q^2REM would then become informative and applicable.

For determination of the probability of accident encountered by trades of works (P), there is an alternative method for calculations which is shown as follows:

$$P(\text{trades of works}) = \frac{\text{No. of accident encountered by the particular trades of works}}{\text{No. of mandays for the particular trades of works}}.$$

As the number of workers for different trades of works would be greatly different, it would affect the accuracy for calculations of the probability to some extent. For example, if one accident is encountered by the site investigation workers and there are only 3 workers working for this trades of works, the probability would be smaller by using the original defined definition as shown in Table 21 due to the relatively small population for this trades of works. However, since there is absence of the records of mandays for different trades of works, there is no way to carry out the probability by using the proposed formula. Nevertheless, it highly recommended that the safety professionals to use it so as to get more realistic data for risk assessment.

In this study, the focus is to analyze the safety professionals' perceptions to risk assessment by means of accident rate group. However, it is possible to analyze the findings in further studies in terms of the other possible respondent groupings, like 'education level', level of safety training' and 'safety attitudes and awareness', to see the extent of these effects on the safety professionals' risk perceptions.

Learning from past experience is worthy for accident prevention. The safety professionals who gained different experience from each unique project are encouraged to sharing their experience and information. Through the available advanced computer network system, they can share the safety related statistics among different construction companies with the implementation of the model as developed in this study. This encourages exchanging useful information on safety issues and share their safety knowledge and experience among the safety professionals. This is the ultimate goal which all construction practitioners expect to reach.

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