CONSTRUCTION INDUSTRY COUNCIL
建造業議會

ELECTRICAL AND MECHANICAL SAFETY IN CONSTRUCTION

RESEARCH SUMMARY

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Published by

Construction Industry Council,
Hong Kong SAR

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FOREWORD

The Construction Industry Council (CIC) Research Fund was established in September 2012 to enhance efficiency and competitiveness of the local construction industry. The CIC Research Fund encourages research and development activities as well as applications of innovative techniques that directly meet the needs of the industry. Moreover, it also promotes establishment of standards and good practices for the construction industry now and into the future.

E&M works are essential in constructing our built environment, involving a wide range of building services trades such as air-conditioning, fire services, plumbing and drainage, electrical wiring and lift installation and maintenance work. Safety hazards exists in installation, testing and commissioning, operation, maintenance and repair stages of E&M works. All E&M accidents should be thoroughly analysed.

The CIC initiated the research by engaging a research team from the Hong Kong Polytechnic University (HKPolyU) to investigate the causes of accidents of E&M works, and to provide recommendations to E&M practitioners and safety professionals for implementing appropriate preventive measures. The research team has successfully identified major factors leading to E&M works related accidents and formulated a series of pragmatic measures for improving the safety of E&M works.

By applying the proposed safety measures in practice, it is envisaged that a safer E&M work environment can be created.

I would like to express my sincere appreciation to the research team at the HKPolyU, and all individuals who contributed in this research.

Ir Albert CHENG
Executive Director of Construction Industry Council

PREFACE

Electrical and Mechanical (E&M) installation was identified as one of the most hazardous trades in the construction industry worldwide. The Hong Kong Federation of Electrical and Mechanical Contractors Limited (HKFEMC), the biggest trade association of E&M works has expressed serious concerns for safety of their practitioners in different occasions. E&M installations involve a considerable proportion of practitioners in the construction industry. A safe E&M work is essential to the success of any construction projects. A comprehensive research on E&M safety is vital to improve the safety performance of E&M works.

In response to such concerns, the Safety Research Group of the Department of Building and Real Estate at the Hong Kong Polytechnic University has successfully carried out a number of tasks, namely, focus group meetings, face-to-face interviews, case studies and questionnaire survey, to identify major factors leading to E&M works related accidents and formulate a series of safety measures for improving the safety of E&M works. This summary report highlights the research methodology and research findings. I hope it provides some insight into the practical and innovative ways to reduce the number of E&M works related accidents. Improvement in safety of E&M works will benefit not only practitioners directly related to E&M works but the industry as a whole as well.

To achieve all of this, I am particularly grateful for the funding support from Construction Industry Council (CIC). I vastly appreciate the strong support from related government departments, E&M specialist contractors, E&M contractor association and E&M trade unions.

It is hoped that the research summary would encourage productive discussions and engender innovative initiatives on this crucial subject of the industry. Safety is a primary consideration at work. The Safety Research Group wishes to contribute to the continuous improvement of the Hong Kong construction industry.

Ir Prof. Albert P.C. CHAN
Head of Department of Building and Real Estate
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RESEARCH HIGHLIGHTS

Electrical and mechanical (E&M) installations are significant to most construction projects regardless of new construction works or repair, maintenance, alteration and addition (RMAA) works. E&M works consist of various specialist trades such as fire services installation, electrical wiring, plumbing and drainage, air-conditioning installation, and lift and escalator installation. As the Hong Kong SAR Government has launched the ten infrastructure projects and the Mandatory Building Inspection Scheme (MBIS), it is foreseeable that the volume of E&M works will be increased continuously. The safety of E&M works has not been given the attention it deserves. Only limited safety research and accident statistics specifically on E&M works could be found.

This research project aims to reveal causes of accidents of E&M works and provide recommendations to improve safety and health of E&M practitioners. There are four specific objectives with this research, including (1) to understand the general practice and procedures in E&M installation; (2) to determine the causes of E&M accidents; (3) to identify effective measures to be implemented in order to reduce E&M accidents on construction sites; and (4) to give recommendations to various stakeholders to enhance E&M installation safety.

A mixed method research approach, which employs both qualitative and quantitative research methods, was adopted in this project. Two focus group meetings and ten structured interviews were conducted to identify major causes which contribute to E&M accidents and to help develop a list of practical safety measures. A total of 421 E&M works related accidents were extracted from the “Public Works Programme Construction Site Safety & Environmental Statistics (PCSES)” system, which is an accident database established and maintained by the Development Bureau (DEVB), for the analysis. With the consent of the Coroner’s Court, construction sites fatalities data involving E&M works has been collected and analysed accordingly. The case studies contribute to investigating how and why E&M accidents occur and promulgating preventive measures for E&M accidents. A questionnaire survey was conducted to validate and rank the causes of accidents and strategies for improving safety of E&M works. The preliminary research findings have been disseminated via industry seminars. The engagement of industrial practitioners maximizes the impact of the research in the industry. Positive feedback was received from the seminar participants.

A combination of the results of focus group meetings, interviews, case studies and questionnaire survey, major causes of E&M accidents in new construction works and RMAA works were identified. Accidents related to new E&M works were found to be caused by compressed working schedule, long working hours, complex working environment, manpower shortage and lack of risk assessment. The major causes of E&M accidents in RMAA works include, lack of facilities for safe access or improper design for maintenance, inadequate safety supervision, short construction period with limited safety resources, tremendous pressures on frontline workers and poor safety awareness of workers.

Based on the above findings, recommendations for E&M works' safety were promulgated, and these include: solicit support from developers and main contractors, set up a reasonable project schedule, attract new entrants, develop and implement safety procedures and risk assessment process, extend Pay for Safety Scheme (PFSS) to frontline workers and specific safety measures for electrical works and working at height. Besides, design for safety for E&M maintenance works and new technologies are proposed to reduce the risk of E&M works.

To formulate effective strategies to prevent E&M related accidents in construction, a full investigation into the major causes of accidents and corresponding improvement measures is extremely important. The significance of this research lies in providing a thorough E&M accident analysis in the construction industry. A comprehensive approach with multidisciplinary inputs was adopted to formulate holistic and practical measures to identify the root causes of accidents and their relative degrees of importance; and prevent accidents related to E&M works.

CONTENTS

1 INTRODUCTION

1.1 Background

E&M works is an essential work category in new construction works and repair, maintenance, alteration and addition (RMAA) works. E&M works involve a wide range of building services trades such as air-conditioning, fire services, plumbing and drainage, electrical wiring and lift installation and maintenance works. It plays an important role in the construction industry and involves a considerable number of workers. The number of persons directly engaged in "building services installation and maintenance activities" in 2014 was 66,592, accounting for over 35% of the number of persons directly engaged in "all construction activities" (n=189,454) (Census and Statistics Department, 2015). The gross value of construction works performed (HK$'000 000) increased by 33% from 236,926 in 2012 to 314,916 in 2014 whereas the gross value of building services installation works (HK$'000 000) expanded over 38% from 50,567 in 2012 to 69,972 in 2014 (US$1=HK$7.8). The statistics show that the gross value of building services installation works has continued in an upward trend. The importance of E&M works is expected to increase further. E&M safety is a vital issue in promoting construction safety. Understanding the underlying relationship between E&M works related injuries and factors leading to the injuries are important to enhance the E&M works safety.

Deterioration of fire services system, water pipes and electrical wiring usually occurs in old buildings which lack of proper maintenance. To uphold the ageing building stock properly and enhance public safety in a sustainable way, the Hong Kong SAR government has initiated the Mandatory Building Inspection Scheme (MBIS) in 2012 to stipulate the legal requirements for owners to inspect and repair their ageing buildings on a regular basis. Around 2,000 target buildings would be selected by the government for inspection and for owners to carry out corresponding repair and maintenance works each year. The scope of inspection is not only limited to the structural elements of buildings, but also the fire safety elements and drainage system. Besides, with the rolling out of ten infrastructure projects, it is expected that the volume of E&M works will continue to increase.

With an expanding volume of E&M works, it is foreseeable that the number of E&M accidents will also increase. The Hong Kong Federation of Electrical and Mechanical Contractors Limited (HKFEMC), has long identified E&M safety as key issue to address. E&M installations and maintenance represent a significant proportion of practitioners working in the construction industry. E&M works practitioners are always exposed to the hazards of working at height, with electricity and machinery. It is important to have a better understanding about the causes of E&M works related accidents.

1.2 Aim and Objectives

This research project aims to reveal causes of accidents of E&M works and provide recommendations to improve safety and health of E&M practitioners. To achieve this, four specific research objectives have been set out.

Research Objectives:

i. To understand the general practice and procedures in E&M installation.

ii. To determine the causes of E&M accidents.

iii. To identify effective measures to be implemented in order to reduce E&M accidents on construction sites.

iv. To give recommendations to various stakeholders to enhance E&M installation safety.

1.3 Scope

The research programme lasted for 24 months, from 1 July 2014 to 30 June 2016. The research project provided a full investigation into the major causes of Electrical and Mechanical (E&M) works related accidents and corresponding improvement measures. E&M installations are key activities within new construction works and repair, maintenance, alteration and addition (RMAA) works. E&M works involve various building services trades, includes air-conditioning, fire services, plumbing, electrical wiring and lift & escalator installations. A mixed research methodology, including qualitative and quantitative methods, have been employed. Literature review, case studies, structured interviews and a questionnaire survey have been conducted.

2 RESEARCH METHODOLOGY

A mixed methods research approach which employs both qualitative and quantitative research methods was adopted in this project. The whole research process comprises seven key stages: (1) literature review, (2) focus group meetings, (3) case studies, (4) structured face- to-face interviews, (5) questionnaire survey, (6) data analysis and (7) validation and dissemination. The research framework for the study is shown in Figure 1.

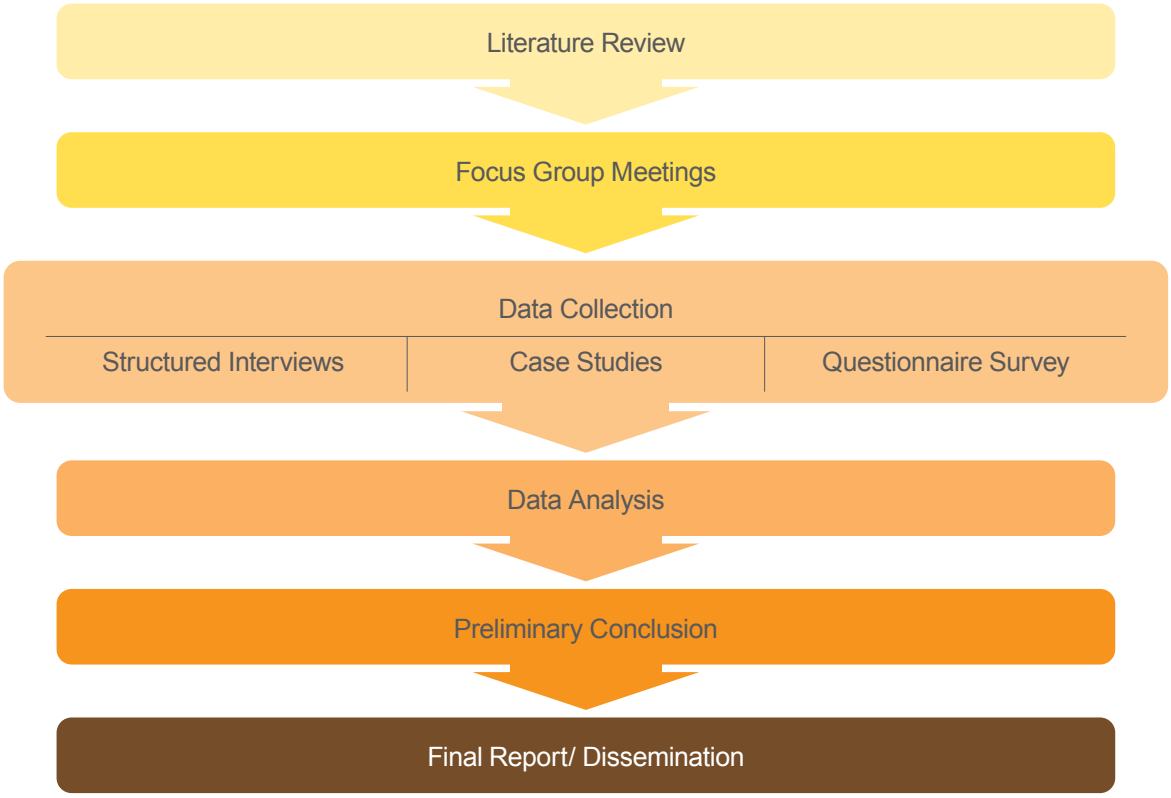

Figure 1 Flowchart of the overall research framework

A combination of qualitative and quantitative methods is adopted to derive the respective benefits of using both approaches. Fellows and Liu (2008) pointed out that the selection of an appropriate research method is dependent on the scope and depth of a research. The following table summarized the research methods used in this study and its achievement.

Table 1 Achievement of different research tools

Research Strategies	Purpose
Literature Review	• To capture abundant knowledge on construction safety on E&M works. • To collect accident statistical data in Hong Kong. • To identify major causes of E&M works accidents and good practices in E&M installation work. • To develop templates for structured interviews and questionnaire surveys.
Focus Group Meetings	• To collect large amount of information through two focus group meetings with E&M works practitioners. • To identify the safety problems, major causes of E&M accidents and possible preventive strategies. • To develop templates for structured interviews and questionnaire surveys.
Case Studies	• To examine how and why E&M accidents occur and promulgate preventive measures for E&M accidents for public sector projects. • To review the sequence of event and major causes leading to the E&M fatal accidents from the Coroner's Court. • To develop templates for structured interviews and questionnaire surveys.
Structured Interviews	• To collect opinions from key E&M installation trades at different levels from frontline workers to senior government officials through series of in-depth structured interviews. • To identify the major causes and possible safety measure for E&M works. • To develop templates for questionnaire surveys.
Questionnaire Survey	• To prioritize the causes of E&M accidents and possible recommendations. • To identify any significant differences in perceptions between group of respondents, management staff and frontline staff.

Literature Review

The research began by updating an extensive review of safety research on E&M works from textbooks, professional journals, conference proceedings, refereed publications, research monographs, workshop seminars, and internet materials across different countries including the United Kingdom, Australia and Hong Kong. Sources of information include academic journals, industry reports, guidance notes, etc. Hong Kong accident statistics data have been obtained from relevant government departments (including the Electrical and Mechanical Services Department, Architectural Services Department and Census and Statistics Department, etc.) and the patterns, nature and volume of E&M accidents were examined and categorised. This review focused on identifying the factors leading to accidents of E&M works and good E&M works practices.

Focus Group Meetings

Two focus group meetings were conducted with (1) trade unions' representatives and frontline tradesmen, and (2) representatives from the Hong Kong Federation of Electrical and Mechanical Contractors Limited (FEMC) in 28th October and 8th December 2014 respectively. A total of 19 E&M practitioners were participated in the two focus group meetings. The focus group meeting participants were invited through related E&M trade unions and associations. It aims to examine the safety problems and the major causes of accidents. The research team facilitated both sessions. After a short briefing about the background of this project by the research team, the participants were invited to provide their expert knowledge on safety issues of E&M works, the root causes of E&M accidents and preventive strategies and measures.

Case Studies

Both fatal and non-fatal E&M accidents were retrieved and reviewed in this project. Services of the Architectural Services Department (ArchSD) and the Electrical and Mechanical Services Department (EMSD) contribute to a significant portion of government's E&M related works. An accident database entitled "Public Works Programme Construction Site Safety & Environmental Statistics" (PCSES) system is established and maintained by the Development Bureau (DEVB) for recording the accident statistics of public works contracts. A total of 421 sets of accident cases related to E&M works for the period between 2001 and 2015 were provided by the EMSD and the ArchSD of the Hong Kong Government from the PCSES system for analysis. Based on the injury report form, an EXCEL file with 18 variables describing the characteristics of the accident was developed for data input. The 18 variables include: (1) Gender; (2) Age; (3) Day of week; (4) Season; (5) Type of accident; (6) Type of E&M works; (7) Type of works; (8) Imported labourer; (9) Length of experience; (10) No. of month on site; (11) Body part injured; (12) Injury nature; (13) Severity of injury; (14) Period of incapacity; (15) Agent involved; (16) Unsafe action; (17) Unsafe condition and (18) Personal factor.

The Coroner's Court has the power to inquire into the causes and circumstances of any unnatural deaths. Case files from the Coroner's Court have been used as an important source of primary information. With the consent of the Coroner's Court, the case files of E&M works related fatalities between January 2010 and July 2013 were collected for in-depth analysis. Excluding cases which are being processed, there were 13 case files that were related to E&M works in this period. A rich set of information was obtained from the coroner's death investigation case file. The case files typically consisted of an autopsy report, toxicology report, medical report for that particular accident, medical report for medical history, investigation report by the Labour Department and other relevant government departments (e.g. Electrical and Mechanical Services Department), death report (Form 16) and death investigation report (Form 17) compiled by the Police and the Coroner's Court respectively. The death report includes a set of witness statements reports (employer, co-workers, family or friends, accident witnesses) and an investigation report concerning the fatal accident.

Structured Interviews

Ten structured interviews were conducted with key trades of E&M installations, including air-conditioning, fire services, plumbing, and electrical works. Interviewees include representatives from the government, quasi-government organizations, professional institutes, contractors' associations, and trade unions. Interview questions were compiled based on the literature review and also the results of the focus group meetings. It was designed to identify the causes leading to common E&M accidents and strategies for improving safety of E&M work practitioners.

Questionnaire Survey

A questionnaire survey was designed based on literature and findings from the case studies and structured interviews. The previous qualitative interviews can be used as an exploratory step before designing the questionnaire. Respondents were requested to prioritize the causes of E&M accidents and importance of recommendations for enhancing E&M works safety. Two sets of questionnaires were developed for management staffs and frontline staffs respectively. 371 completed questionnaires were collected. Questionnaires were dispatched via industry forums and presentations. The advantages of conducting questionnaire survey in this way are that respondents can get immediate assistance from investigators of the proposed studies and thus improving quality of their responses. Also, respondents attending the industry forum have interests in E&M safety. They are more likely to give reliable and informed responses based on their working experience and expertise.

3 RESEARCH FINDINGS AND DISCUSSION

Further to the two rounds of focus group meetings and ten structured interviews, a questionnaire survey was conducted to solicit the opinions of E&M practitioners on E&M works' safety. The survey can be regarded as a supplement to provide quantitative data providing more insights to the team to formulate a more complete and effective safety measures for E&M works. Based on the combined findings from the focus group meeting, interviews, case studies and the questionnaire survey, the key research results and discussions are reported in this section.

Characteristics of E&M Works

Both E&M works and general builders' works may cause fatal accidents. As various trades, regardless of E&M works or builders' works, have their own characteristics, the major causes of accidents would be different. For E&M works, the key hazards are identified in activities that involve working at height, electricity, confined space, lifting, machinery (for lift and escalator), welding, and using handheld tools, etc. Some hazards in E&M works are quite particular as per the E&M work processes like lifting of chiller or generators, electrical hazard at switch gear works, and confined space hazards at water tank, etc. Compared with general builders' works, E&M works often require working at height. Over 80% of air-conditioning and fire services installation works involve working at height. This greatly increases the likelihood of fall of person from height.

Generally, E&M sub-contractor is selected and appointed by the clients as a Nominated Sub-contractor (NSC) in new construction projects. In this kind of subcontract, there is a direct contractual relationship between the client and the NSC. On the other hand, domestic subcontractors are selected and appointed by the main contractor. The main contractor pays more attention to their domestic subcontractors. Thus, the planning of works and safety of NSC may sometimes be ignored. Some interviewees expressed that the safety assessment and supervision system of E&M works are less comprehensive than building works.

Most of the E&M installation works need to follow some buildings activities, say for example conceal conduit is only allowed to start after completion of the first layer re-bar but should completed before laying of second re-bars by builder. It makes E&M works always be put in a passive position. In another words, the degree of E&M risk at works nearly relies completely on the management of the builders. The new construction works of previous trades may be delayed that lead to the formation a domino (i.e. knock-on) effect. However, no extra time provision will be allowed for the E&M installation works. They need to strictly follow a master programme. With a tight working schedule and long working hours, workers may neglect the safety procedures and overlook the hazardous of working environments. Most of the E&M installation works is always being put at the last construction stage. Multi building service trades are concurrently working at the same location more or less at the same time under a compressed working schedule that will substantially increase the safety risk of the E&M workers.

General Safety Image of E&M Works Industry

Generally, the safety image of the E&M industry is not well-developed. Some interviewees expressed that safety culture is not fully established within the E&M industry. A good safety culture within the industry or working environment is essential for stimulating safety behaviour of workers. The safety awareness of E&M workers is inadequate. However, the general safety attitude of workers is improving recently as different safety campaigns such as safety carnival and safety seminars have been organized regularly to uplift the safety knowledge and safety awareness. The accident rate of E&M works is still not good enough and it can be further improved.

Electrical installation works are high risk activities on site. The workers realise that the working environment is dangerous and they have also acquired adequate safety knowledge. In the actual working situation, the workers may neglect the safety procedures and overlook the hazardous working environments due to rush working schedule, heavy workload and long working hours. Some workers expect to have fluke, underestimate the risk of works and disregard the importance of Personal Protective Equipment (PPE) and safety precautions. Over-confidence of experienced worker fails to isolate electricity source for electrical wiring and maintenance work for electrical installations. Without isolating the electricity source, the worker would be vulnerable to electrocution.

The interviewee pointed out that E&M workers can be divided into two types, i.e. new construction works and RMAA works. The safety awareness of these two types of E&M workers is different. In RMAA works, the safety awareness of workers is poor. Some workers even are not aware that their Green Cards have expired. They often underestimate the risk of non-capital works and disregard the importance of Personal Protective Equipment (PPE) e.g. safety helmet. The E&M workers of new construction works in general have higher safety awareness. The condition of new construction site is generally untidy with more unforeseeable situation. Multi building service trades are concurrently working at the same location. The workers realise that the working environment is dangerous, so their safety awareness will be raised. In addition, safety officers or safety managers will conduct surprise inspection for each new construction site to monitor the safety of workers. On-site safety training for workers will be held regularly. It also effectively increases the safety awareness of workers and prevents any unsafe act of them.

Multi-layer subcontracting system is widely used within the Hong Kong construction industry. Generally, E&M sub-contractor is appointed trade sub-contractor in new construction projects. The execution of safety procedures for the subcontracted workers may be deviated. Sometimes, the communication problem between main contractor workers and subcontracted workers may greatly increase the likelihood of E&M accidents. As lack of supervision on subcontracted workers, the safety awareness of subcontracted workers is poor.

Given that fast track construction is a distinguishing feature of property development in Hong Kong, workers are usually engaged in the dilemma between progress of works and safety at works. Despite knowing of the hazards associated with their works, some workers still select scarifying safe operation for the convenience of works.

Major Categories of E&M Works Related Accidents

Based on the results of the structured interviewees, major categories of E&M accidents were summarized in Table 2. The major types of accidents related to E&M works are fall of person from height and electrocution.

The major type of accidents related to air-conditioning works in both new construction works and RMAA works is fall of person from height. Air-conditioning works comprise of work at height outside the external wall and use of ladder inside the building. Use of ladder is very frequent in new air-conditioning works and maintenance works. Trapped in or between objects and injured by moving machinery, striking against fixed or stationary object and struck by falling object would be commonly occurred in lift installation and maintenance works. The major types of accidents related to fire services installation works are fall of person from height, injured whilst lifting or carrying, contact with moving machinery and hazardous energy. As most of the plumbing works are mainly located at height, working platform cannot be used due to the limited size of working area. Only ladder can be used to carry workers for works at height, fall accidents may easily happen. When replacing of drainage pipes and other plumbing work, workers may cut by the sharp edge of a pipe or injure by hand tool. A worker may be injured by fragments when welding and cutting pipes without suitable protective measures. Struck-by accidents may happen when the pipes are not fixed or anchored properly when lifting or unload. Demolition of pipe and drainage works would be dangerous for workers. Sludge in pipe may contain hazardous gases which may cause suffocation. The major type of accidents related to electric wiring works include fall of person from height, contact with electricity or electric discharge and injured whilst lifting or carrying. Electrocution is a major type of E&M related accident. For electrical wiring works, the E&M workers are vulnerable to electric shock hazard whilst working on the conductive parts of the electrical cable which has not been properly isolated from the power source.

Some interviewees also indicated that the accident rate of RMAA works is substantially higher than new construction works. The major types of accidents related to E&M RMAA works are fall of person from height (i.e. from ladder or working platform), electrocution and cut during the working process. Although the type of accidents of RMAA works is limited, the occurrence is frequent. It may due to the fact that RMAA works generally last for a short construction period with less safety resources, equipment and inadequate safety supervision.

Table 2 Major categories of accidents

Major categories of accidents	Air-conditioning	Lift/ escalator	Fire service	Plumbing & drainage	Electrical Wiring
Fall of person from height (e.g. ladder, working platform)	X	X	X	X	X
Electrocution	X	X			X
Cut during the working process				X	
Slip and fall on same level		X			
Trapped or injured by moving machines		X	X		
Injured whilst lifting or carrying			X		X
Struck by falling object		X		X	
Laceration by sharp edges or tools				X	
Suffocation in confined space				X	
Striking against fixed or stationary object		X			
Contact with hazardous energy			X		

Major Causes of E&M Accidents

Due to the differences in job nature and working environment of new construction E&M works and RMAA E&M works, the major causes of E&M works related accidents are also different. Based on the results of focus group meetings, case studies, structured interviews, questionnaire surveys, the major causes of E&M accidents in new construction works and RMAA works are summarized respectively.

3.1. New Construction Works

Compressed Working Schedule

Based on focus group meetings, interviews and questionnaire survey results, compressed working schedule was regarded as the most significant causes of E&M accidents in new construction works. As the installation of E&M works needs to follow the general builder's works, it makes E&M installation works always be put in a passive position at the last construction stage. The delay of previous construction works would carry on to the E&M works. Even though E&M works are postponed due to delay of completion of the general builder's works, E&M contractors still need to strictly follow the master programme and no extra time provision is being allowed. An unreasonable project schedule may bring about safety problems, adversely affect the safety performance of E&M works and prone to accidents.

Long Working Hours

"Long working hours of E&M workers" was regarded as one of the major causes of E&M accidents in the results of focus group meeting and interviews. It was also ranked as the second top major causes of E&M related accidents in construction by the questionnaire respondents. The interviewees pointed out that the execution of safety procedures for the workers may be deviated due to the pressure of rush working schedule, heavy workload and long working hours. Tight project schedule involving long working hours may result in fatigue of workers and reduce their concentration and increase errors in judgment.

Complex Working Environment

As construction is always risky due to its complexity and continuously changing working environment as well as the associated hazardous characteristics of E&M works, E&M workers who are less familiar with the site and working environment are more prone to accidents. The site condition of new construction works is generally untidy with inadequate working space. Sometimes, the working area is occupied with construction materials. With limited working area, the E&M workers can only use "A" ladders instead of working platforms for their work. It highly increases the risk of working at height. Moreover, multi building service trades are concurrently working in the same location simultaneously. Under a crowed and messy working environment, workers may be prone to accidents. The housekeeping or orderliness also influences workers' exposure to slip, trip or fall hazards. Carrying out E&M works on slippery or uneven floor may cause slip, trip or fall accidents when workers are not fully concentrated on their works.

Manpower Shortage

The questionnaire survey respondents were divided into two groups for comparison (i.e. management staffs and frontline/site staffs) who are two primary parties involved in E&M works. Significant differences in the ranking between group respondent groups were found in this Item “Manpower shortage”. The frontline/ site staffs ranked this item as the third major causes of E&M accidents whereas the management staffs ranked it as the tenth. This result indicated that the frontline staffs considered manpower shortage for E&M works as a serious problem whiles the management staffs did not treat this as a critical issue. With the rolling out of major infrastructure projects and considerable housing development projects, the construction industry faces the pressure of manpower shortage. As most of the E&M workers are skilled workers with special training, the manpower shortage problem is particularly serious in E&M industry. The manpower shortage issue poses challenges to the work progress as well as the E&M works safety.

Lack of Risk Assessment and Safety Plan

E&M installation works are regarded as high-risk operations in construction process. Due to the tight working schedule of E&M works in new construction works, the process of risk assessment may be neglected. Lack of risk assessment at the workplace may lead to E&M accidents. It is important to carry out appropriate risk assessment by a competent person to ensure safety and health of workers. An appropriate risk assessment may include an effective safety plan with appropriate safety procedures and measures.

3.2. Repair, Maintenance, Alteration and Addition (RMAA) Works

Lack of Facilities for Safe Access or Improper Design for Maintenance

The participants of focus group meeting and interviews revealed that the lacks of facilities for safe access or improper building design are the main causes of E&M accident in RMAA works. The interviewees expressed that safety component design for public housing was better than private buildings. The PNAP (ADV-14 Facilities for External Inspection and Maintenance of Buildings) was issued by the Buildings Department for advising the Authorized Persons (APs) and Registered Structural Engineers (RSEs) to consider incorporating facilities for safe access to the external walls of buildings. However, some developers or architects considered that building appearance would take priority over safety of building maintenance and neglected the accessibility for building maintenance. Different accessibility problems such as inadequate space for installing three anchor bolts for truss-out bamboo scaffold or thick decorative external wall tiles would be discovered during the building maintenance. These adverse working environments greatly increase the risk of E&M RMAA works. Some unfavorable design for E&M works which revealed by interviewees are summarized as follows.

(a) Unfavorable Design for Air-conditioning Works

Some interviewees pointed out that accidents related to air-conditioning installations works are mainly due to buildings are being designed without consideration of repair and maintenance activities and incorporation with proper facilities for safe access to the workplace.

Most of the maintenance activities for air-conditioning need to be carried out at height outside the external wall of a building. Many buildings are not incorporated with permanent suspended access system, anchorages and alternative permanent features (such as hooks, holes or platforms) at suitable locations for anchorage of scaffoldings or safety belt and lack of sufficient space for properly erection of truss-out scaffold. Sometimes, mobile fall arresting equipment is also impracticable.

Some buildings are incorporated with a working platform for maintenance. Due to limited working space, only one technician can be allowed to work at the working platform. The technician would be easily injured when moving large machinery parts of the air-conditioning.

Figure 2 Limited area that may not be sufficient to install scaffolding for maintenance

Figure 3 No safe access for air-conditioning maintenance

Figure 4 The access to air-conditioning system is obstructed by louver
Photos (Fig. 2, 3 & 4) are provided by the interviewee

(b) Unfavorable Design for Lift Repair and Maintenance Works

E&M accidents of lift installation works are usually caused by a variety of factors such as lack of safety access to lift pit, inappropriate location of cat ladder in lift pit, inadequate lighting and poor ventilation. The workers are in danger when access the lift pit. Fall accidents may easily happen. Some lift systems are being designed without consideration of repair and maintenance works. Some elevators without a machine room for high-rise buildings are designed without considering repair and maintenance activities. The lift machine is mounted within the hoist-way. There is lack of a firm working platform for carrying out repair and maintenance works. This design is only appropriate for low-rise buildings (e.g. shopping centre). When there is no separations in common lift well, E&M workers may be injured by moving machinery. Moreover, a cat ladder is commonly used to access the lift machine room. It would be dangerous for workers to climb up the cat ladder with heavy tools, equipment or materials.

(c) Unfavorable Design for Fire Services Maintenance Works

In order to reduce the construction costs, some firefighting pump rooms in some buildings were designed with inadequate space. Therefore, the pump was unable to be moved out for maintenance.

Inadequate Safety Supervision

The safety awareness of workers in RMAA works are weak. Usually, the RMAA works are conducted by only one or two workers without any supervision. Some interviewees advocated that inadequate safety supervision was one of the factors leading to E&M RMAA accidents. Safety supervision is difficult to conduct as the locations of RMAA works are widely scattered, particularly for those term contract works. Besides, RMAA works usually being carry out in a short period of time without employment of site safety personnel, that is, there is no competent person fully designated for safety supervision.

Short Construction Period with Less Safety Resources

The working condition of new construction works is better than RMAA works. New construction works last for a longer period with more resources (erection of scaffolding and provision of working platform) and more safety supervision (e.g. employment of safety officer or supervisor). RMAA works generally last for a short construction period with less safety resources, equipment and inadequate safety supervision. Most of the E&M RMAA works are carried out by small and medium enterprises (SMEs) with limited safety resources. In order to reduce construction time, cost and interference of users, the E&M workers may use “A” ladders instead of working platforms for working at height.

Tremendous Pressures on Frontline Workers

For the E&M maintenance works, there are tremendous pressures on frontline workers because property management companies are often unwilling to suspend the electricity supply or lift services for a long period of time. Without isolating the electricity source, the workers have to work on a live circuit and would be vulnerable to electrical hazards including electric shock, electrical flashover and short circuit. The situation of insufficient number of qualified engineering personnel to carrying out the maintenance works is not uncommon in the industry. In many circumstances, there is only one engineering personnel to work alone without any supervision or working partner. It substantially increases the risk of E&M works.

Poor Safety Awareness of Workers

The results of questionnaire survey indicated that there was a noticeable discrepancy between the ranking of management staffs and frontline/site staffs on the item “Poor safety awareness of workers”, ranked as second by management staffs and thirteenth by frontline staffs. The safety awareness of workers is weak from the viewpoint of management staffs whereas the frontline staffs perceive as adequate. Some interviewees pointed out that the safety awareness of workers in RMAA is particularly inadequate. As the RMAA works is not as complex as new construction works, some RMAA workers expect to have fluke, underestimate the risk of works and disregard the importance of safety measures e.g. Personal Protective Equipment (PPE) and safety procedures. Some workers may forget to post warning notices at the working area. Prone to accidents when a worker is carrying out repair and maintenance works without placing warning sign.

3.3 Analysis of Accident Cases from the PCSES

An accident database entitled “Public Works Programme Construction Site Safety & Environmental Statistics” (PCSES) system is established and maintained by the Development Bureau (DEVB) for recording the accident statistics of public works contracts. All dangerous occurrences and reportable accidents resulting in death, serious bodily injury and injury with incapacity for more than 3 days should be included in the PCSES system (DEVB, 2008). According to the chapter 9 of the Construction Site Safety Manual (DEVB, 2008), the safety officers or site agents of principal contractors should complete the injury report form (version 2001) and submit to the Departmental Safety and Environmental Advisory Unit within seven days on occurrence of accident for entry into the PCSES system.

With the consent of the Development Bureau, a total of 421 sets of accident cases related to E&M works for the period between 2001 and 2015 were provided by the Electrical and Mechanical Services Department (EMSD) and the Architectural Services Department (ArchSD) of the Hong Kong Government. It was decided to exclude the accident data before 2001, since the injury report form had been revised significantly in 2001. Based on the injury report form, an EXCEL file with 18 variables describing the characteristics of accident has been developed for data input.

3.4 Descriptive Statistics

There were 170 (40.4%) E&M works related accident cases collected from the Electrical and Mechanical Services Department (EMSD), and 251 (59.6%) from the Architectural Services Department (ArchSD) of the Hong Kong Government. As most of the construction works are physically demanding and performed under outdoor environment, the construction industry is very much male-dominated (Agapiou, 2002). It is not surprising that a vast majority of the injured workers were male and only 3 (0.7%) injured workers were female. Over 97% of injured workers were non-imported labourer while only 1.4% of them were imported labourer. With the “Construction Workers Registration Ordinance” effect from December 2005, all workers carry out construction works on construction sites must be registered under the Construction Workers Registration Authority (Construction Workers Registration Authority, 2015). Workers of E&M installations need to be registered as “Registered Skilled Worker” for their own trades. Referring to Figure 5, workers aged 34 or below accounted for 44.5% of the E&M work related accidents collected in this study

whereas registered E&M workers aged 34 or below only accounted for 15.44% of the registered E&M workers in Hong Kong as on 30 September 2015. It indicated that young E&M workers were more prone to accidents due to inexperience. The findings are in line with Chi *et al.* (2005), Salminen (2004) that young workers had a higher non-fatal injury rate than older workers. The research of Choudhry and Fang (2008) further pointed out that the most effective safety training for new construction workers is learned by doing or by gaining experience. New workers become more aware of construction safety when they accumulate more working experiences.

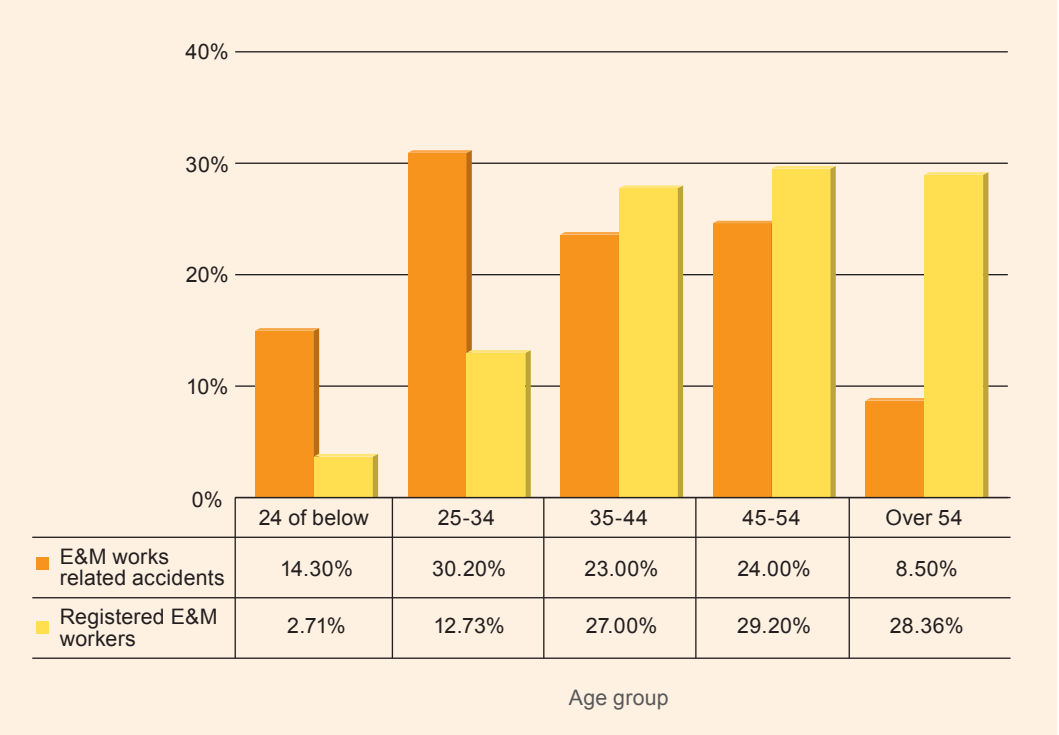

Figure 5 Age distribution of registered E&M workers
(as at 30 September 2015) and E&M accident data analysed by age
(Sources: Construction Workers Registration Authority, 2015)

3.5 Cluster Analysis

Cluster analysis was conducted on the variables of E&M works related accidents to identify groups with different pattern of accidents. To assess complex relations between E&M accidents and accident outcome, seven key variables were selected for analysis (indicated in Table 4). Previous literature indicated that types of works, type of accident and workers' length of experience were crucial features of construction accidents (Siu *et al.* 2003, Choudhry and Fang, 2008, Camino López *et al.* 2008 and Rozenfeld *et al.* 2010). Thus, these variables were chosen for analysis. Moreover, variables related to the accident outcome such as body part injured, injury nature, severity of injury and period of incapacity were also selected to form the cluster model. The 421 E&M accident cases were formed into three clusters (Figure 6).

Cluster 1 (Workers with more than 15 years of working experience undertaking electrical wiring installation)

Cluster 1 included 115 accident cases. This cluster consists of workers with more than 15 years of working experience in construction and involved in electrical wiring installation. A vast majority of accidents in this cluster were caused by fall of person from height and resulted in upper limb fractures. Due to the higher severity of accident, the injured workers needed hospitalization for more than 24 hours and suffered over 100 days of incapacity for work. These accidents mainly involve falls from ladders or working platforms. Serious accidents may happen when the worker falls due to sudden collapse of ladder or working platforms or lose his balance while conducting installation works. Numerous studies supported that fall of person from height caused a greater number of severe and even fatal accidents in the construction sector (Hinze and Gambatese, 2003; Camino López *et al.,* 2008 and Wong *et al.,* 2016). Hence, the long period of incapacity of workers incurred extra financial costs, including loss due to absence from work of the injured workers, inefficiency after resuming work of the injured workers, medical expenses, fines and legal expenses and loss due to damaged material or finished work, etc. (Tang *et al.,* 1997 and Tang *et al.,* 2004).

Cluster 2 (Workers with up to 5 years of working experience undertaking electrical wiring installation)

Cluster 2 included 156 accident cases, which represent 37% of the reported E&M accidents. Workers with less working experience (i.e. 0-5 years) undertaking electrical wiring installation work are classified in cluster 2. Slip, trip or fall on same level was the most common accident type in this cluster. Most of the victims were suffered from contusion, sprain or twist of lower limbs. The injured workers suffered less severe injury with no hospitalization or with hospitalization for less than 24 hours and not more than 20 days of incapacity for work. The findings are in line with the research of Lipscomb *et al.* (2006) that individuals performing electrical wiring works suffered slip/trip injury at a significant higher rate than other types of work. Major slip/trip injuries were related to soft tissue injuries such as sprains, strains or contusions and more commonly led to injuries of lower extremity

(Courtney *et al.* 2002 and Lipscomb *et al.,* 2006). Slips and trips are regarded as one of the most significant type of construction accidents (Kemmlert and Lundholm, 2001; Layne and Pollack, 2004 and Lipscomb *et al.,* 2006). Lipscomb *et al.* (2006) found that environmental factors, such as slippery or uneven working surfaces, weather and lighting, were the most frequent and common contributor to slip/ trip injuries. Besides, poor housekeeping and human factor (i.e. lapse of attention, carelessness or rush to finish work, etc.) also contribute to these accidents (Chang, 2001; Lipscomb *et al.,* 2006).

Cluster 3 (Workers with up to 5 years of working experience in air-conditioning work)

Cluster 3 included 150 E&M accident cases with workers who were involved in air-conditioning installation works with 0-5 years of working experience. The workers' injuries were caused by multi-types of accidents such as exposure to fire, stepping on object and crushing, etc. and laceration or cut on upper limbs. The victims of this cluster mostly did not require hospitalization or hospitalization for less than 24 hours and incapacity for less than 20 days. This cluster revealed that air-conditioning works were the second risky E&M works. Most of the accidents occurred in Air Handling Unit (AHU) room or A/C plant room for carrying out installation or maintenance of the A/C system. A combination of project complexity, poor working conditions and hazardous nature of work is leading to variety types of accident. This cluster group included multi-types of accidents such as exposure to fire, hand tool accident, stepping on object and crushing, etc. These accident types are easily overlooked but the research findings show that multi-types of accidents contribute a significant number of accident cases.

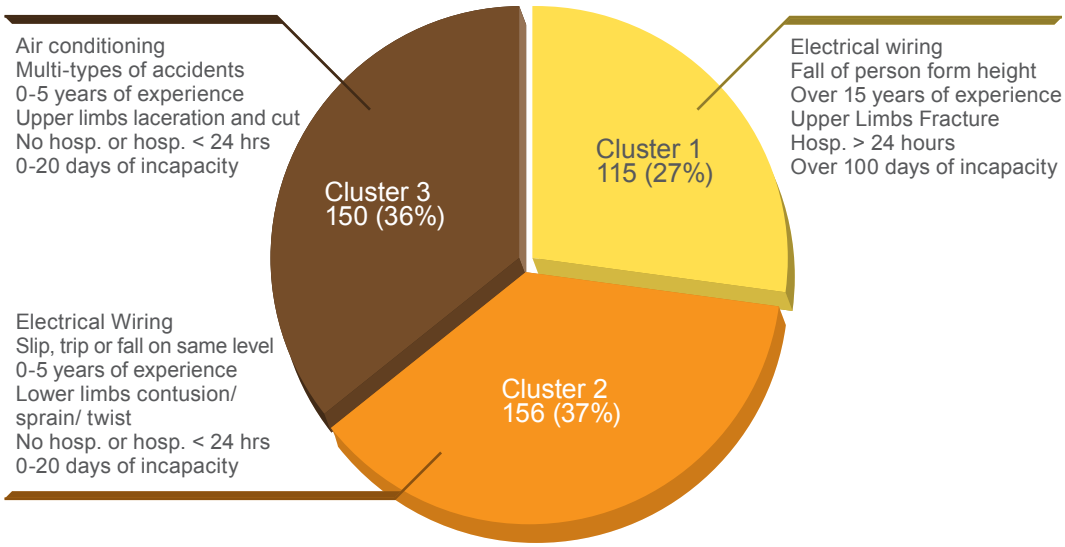

Figure 6 Cluster sizes of the three clusters of E&M accident cases.

The cluster analysis results of the 421 E&M works related accidents and their distribution in each cluster are summarized in Table 6. In terms of E&M trade, electrician accounted for the greatest number of accident cases. The current findings indicated that electrical wiring and air-conditioning installation works were the top two hazardous trades of E&M works, accounted for about 41% and 31% of all E&M accident cases respectively. E&M installation works results in various types of accidents. “Slip, trip or fall on same level” (n = 98) and “fall of person from height” (n = 87) were the most common types of E&M accident. Both accident types demonstrated a high frequency of upper and lower limbs injuries. Other types of accident (n = 99) which encompasses a range of miscellaneous accident types such as exposure to fire/ burning, dust/ foreign particle in eye, stepping on object, and crushing, etc. The patterns of injury nature and accident types varied substantially. For instance (Table 3), fracture was a major type of injury nature associated with fall of person from height. Contusion, sprain or twist were the main injury due to slip, trip or fall on same level. Fall of person from height resulted in a higher number of fracture injuries indicating that falls from an elevation could generate more severe injuries and longer period of incapacity.

Table 3 Frequency distribution of injury nature and severity with respect to the major types of accident.

	Slip, trip or fall on same level	Fall of person from height
Major nature of injury		
Laceration and cut	14	5
Fracture	26	**53**
Contusion/ Sprain/ Twist	**43**	23
Severity of injury		
No hospitalization or hosp. < 24 hrs	**72**	30
Hosp. > 24 hours	25	**56**

Over 73% (n= 308) of the E&M work related accidents occurred in RMAA works which far outweighed that of new construction works. It may be explained by the fact that the working condition of new construction works is comparatively better than RMAA works. The construction processes of new works are relatively well-planned whereas those of RMAA works are rather unforeseeable (Hon and Chan, 2013). RMAA works last for a shorter period with less safety resources and safety supervision (e.g. employment of safety officers or supervisors). The number of E&M accidents occurred in summer (i.e. from June to August) (n = 134) was significantly higher than other seasons, especially in autumn and winter, accounting for about 31% of the 421 accident cases. The high temperature and humidity environment with low wind speed is insufferable and unfavorable to safety and health of construction workers (Yi and Chan, 2014). It is believed that prolonged work in a hot environment may result in fatigue, heat-related illness and a higher chance of injury (Wong *et al.,* 2014; Rowlinson and Jia, 2015). It seems that hot and humid weather in summer is a key contributing factor for E&M works related accidents. Over 36% E&M accidents occurred in the beginning of weekdays (i.e. Monday and Tuesday) while relatively less accidents happened in the end of weekdays and weekends. This result was consistent with the findings of Camino López *et al.* (2008) that construction accidents on Monday were more frequent than on other days within a week.

The results also indicated that the majority of injured workers had less than 5 years of working experience in construction (n = 136, 32.3%), and work at that construction site with not more than 3 months (n = 220, 52.3%). Among these 220 accident cases, over half of them (n = 128) involved workers engaged in that construction for not more than one month. As construction is always risky due to its complexity and continuously changing working environment as well as the associated hazardous characteristics of E&M works, new workers who are less familiar with the site and working environment are more prone to accidents.

Other factors for E&M accidents were also evaluated. Improper procedures and poor housekeeping were the top two unsafe conditions whereas lapse of attention was the key unsafe action among the E&M accident cases. Carelessness or not concentrate were the most significant personal factor of accidents. According to Zhou *et al.* (2013), major types of improper construction procedures refer to failure to operate in accordance with safety specifications and construction guidelines. For example, the electrical workers fail to de-energize or lock out electrical circuit for electrical wiring works. Ignorance of safety procedures and proper construction processes may substantially increase the probability of E&M accidents. Besides, Bentley (2009) and Lipscomb *et al.* (2006) advocated that housekeeping or orderliness highly influence workers' exposure to slip, trip or fall hazards. E&M works undertaken on slippery or uneven floor may cause slip, trip or fall accidents when workers are not fully concentrated on their works.

Table 4 Summary of variables and their distribution in each cluster

Variable	Category	Cluster 1 (n=115)	Cluster 2 (n=156)	Cluster 3 (n=150)	Total (N=421)
Age	24 or below	19	24	17	60
	25-34	26	46	55	127
	35-44	33	38	26	97
	45-54	27	38	36	101
	Over 54	10	10	16	36
Day of week	In the beginning of weekdays	32	64	56	152
	In the middle of weekdays	38	44	38	120
	In the end of weekdays	18	25	28	71
	Weekends	27	23	28	78
Season	Spring	34	42	40	116
	Summer	30	49	55	134
	Autumn	27	28	30	85
	Winter	24	37	25	86
Type of accident*	Injured whilst lifting or carrying	4	26	23	53
	Slip, trip or fall on same level	21	50	27	98
	Fall of person from height	65	21	1	87
	Contact with electricity	0	0	9	9
	Struck by moving/ falling object	8	18	11	37
	Striking against object	2	11	25	38
	Others (e.g. exposure to fire, stepping on object etc.)	15	30	54	99
Trade of E&M works*	Air-conditioning	24	43	65	132
	Electrical wiring	73	65	33	171
	Lift and escalator	0	16	30	46
	Fire services	11	19	9	39
	Plumbing and drainage	7	13	13	33
Type of works	New construction works	36	45	32	113
	RMAA works	79	111	118	308
Length of experience* (no. of years)	0-5	32	65	49	146
	6-10	27	39	34	100
	11-15	7	16	19	42
	Over 15	40	25	32	97
	Unknown	9	11	16	36
No. of month at this site	0-3	72	82	66	220
	4-6	16	25	21	62
	7-9	8	15	17	40
	10-12	7	9	8	24
	Over 12	8	11	17	36
	Unknown	4	14	21	39

Table 4 Summary of variables and their distribution in each cluster

Variable	Category	Cluster 1 (n=115)	Cluster 2 (n=156)	Cluster 3 (n=150)	Total (N=421)
Body part injured*	Head	16	48	5	69
	Neck & Trunk	16	47	0	60
	Upper limbs	45	5	140	190
	Lower limbs	41	56	5	102
Injury nature*	Laceration and cut	15	20	64	99
	Crushing	3	4	7	14
	Fracture	73	12	27	112
	Contusion/ Sprain/ Twist	15	96	27	138
	Electric shock	0	0	9	9
	Others (e.g. multiple injuries, burn, abrasion, freezing etc.)	9	24	16	49
Severity of injury*	No hospitalization or hosp.<24 hrs	16	128	127	271
	Hosp. > 24 hours	99	20	21	140
	Fatal	0	4	0	4
	Pending confirmation	0	4	2	6
Period of Incapacity* (no. of days)	0-20	34	121	112	267
	21-40	18	15	16	49
	41-60	3	6	3	12
	61-80	4	4	1	9
	81-100	3	1	2	6
	Over 100	53	9	16	78
Agent involved	Portable power or hand tools	5	10	20	35
	Material being handled or stored	13	28	29	70
	Ladder or working at height	55	25	4	84
	Floor, ground, stairs or any working surface	13	54	42	109
	Electricity supply, wiring apparatus or equipment	3	3	13	19
	Others (e.g. gas, pipe, machinery, scaffolding etc.)	26	36	42	104

Table 4 Summary of variables and their distribution in each cluster

Variable	Category	Cluster 1 (n=115)	Cluster 2 (n=156)	Cluster 3 (n=150)	Total (N=421)
Unsafe action	Use unsafe equipment/use equipment unsafely	6	10	13	29
	Adopting unsafe position or posture	22	30	20	72
	Failure to use personal protective equipment	10	22	26	58
	Use unsuitable access	11	10	8	29
	Lapse of attention	40	52	50	142
	Others (e.g. operating with authority, failure to secure objects etc.)	26	32	33	91
Unsafe condition	Improper procedure	40	45	39	124
	Poor housekeeping	31	60	25	116
	Inadequate working space / platform	7	11	13	31
	Inadequate tool and protective equipment	12	11	23	46
	Others	25	29	50	104
Personal factor	Incorrect attitude / motive	12	15	19	46
	Lack of knowledge or skill	11	10	9	30
	Fatigue / exhaustion	3	2	5	10
	Carelessness / not Concentrate	78	98	90	266
	Others (e.g. physical defects, unsafe act and another person etc.)	11	31	27	69

*Key variables used in the cluster analysis

4 RECOMMENDATIONS

In order to improve the safety performance of E&M works, some implementation strategies are suggested as follows.

4.1 Support from Developers and Main Contractors

The participants of interviews and focus group meetings strongly suggested that the support from developers and main contractors would be effectively enhance the safety performance of E&M works. Support from the Clients and the main contractors to drive the safety culture and safety attitudes of workers that can fundamentally improve the safety of E&M works.

Corporate culture, allocation of safety resources and support of top management have significant impact on project safety. The safety culture of a company will effectively enhance the safety awareness of workers. It is recommended to arrange safety campaign regularly by main contractors to encourage safety awareness of their subcontractors. The reward criteria may base on safety performance of the subcontractors (i.e. proper use of ladder and good housekeeping, etc.), coupons for safety equipment will be awarded to well-performed subcontractors. It is important to educate frontline workers on construction safety. This requires the support and promotion of a company's top management. Besides, developers' initiatives to invest in safety design for repair and maintenance and to formulate a reasonable working schedule are vital to reduce safety risk of E&M works.

4.2 Design for Safety

Consideration of incorporating safety buildings facilities for building maintenance at the design stage will substantially reduce the risk of accidents during building maintenance. It is necessary to consider the maintenance procedures and provide sufficient safe access and working area for repair and maintenance works at the design stage. As architects may not fully understand the actual situation of building maintenance, early involvement of E&M subcontractors at the design stage would be important to facilitate a plan for building maintenance. The opinions from frontline workers and sub-contractors would be highly valuable to help incorporating necessary safety facilities (e.g. size of working platform, number and location of anchor bolts). Incorporation of safety design and safety facilities need full support from developers and design teams.

The interviewees expressed that there is a room for promoting Construction Design Management (CDM) in the Hong Kong construction industry. The CDM process aims to improve the health and safety of construction projects by taking a structured approach on how health and safety of construction and subsequent operations are designed and managed. Currently, it is only published as a guidance note by the Development Bureau. It is recommended to implement CDM mandatorily in both public and private sector projects. Publication of guidance or Code of Practice (CoP) related to safety of building maintenance would be effective to draw attention of developers to maintenance safety and consider the incorporation of safety access and related facilities.

The participants of focus group meetings and interviews strongly suggest that developers should propose maintenance plans to the Buildings Department, which needs to be approved by the Labour Department. (i.e. upload to the Electric Platform for the Sales of First-hand Residential Properties).

Design for Maintenance Activities for Air-Conditioning Works

Most of the maintenance activities for air-conditioning need to be carried out at height outside the external wall of a building. Air-conditioning specialists are relatively more concern about safety design for repair and maintenance works. Some safe design for air-conditioning maintenance works are listed below and illustrated in Figure 7-9.

(a) Consideration of incorporating facilities such as anchor bolts and working platforms and providing sufficient safe access and space for building maintenance at the design stage may substantially reduce the risk of accidents during building maintenance. The installation of anchor bolts can be used to prevent workers falling from height.

(b) Due to limited working space for air-conditioning works, it is desirable that workers can repair the air-conditioning compressors directly through an internal access opening.

(c) A service platform or maintenance corridor can be designed and constructed for centralizing the installation of plumbing and drainage and air-conditioning compressors. It facilitates a safe and direct access for maintenance workers through an internal opening door.

Figure 7 Maintenance corridor design
(Source: Provided by interviewee)

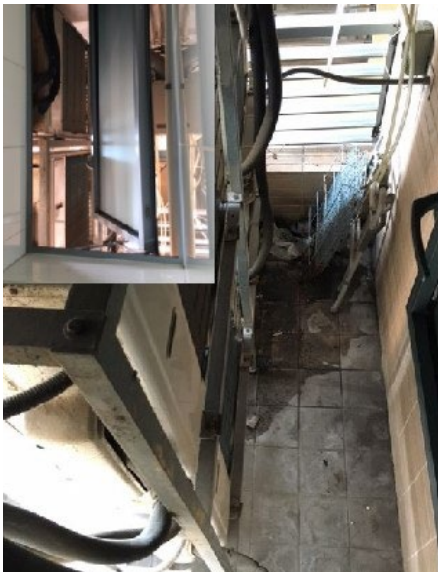

Figure 8 Working platform with an internal access opening

Figure 9 Anchorage point installed in a residential building (Source: Yam *et al.,* 2007)

Design for Maintenance Activities for Lift Works

Some safety design for lift maintenance works are summarized as follows:

(a) Lift pits vary in depth depending on the speed of the lift car. High speed lifts may have lift pits up to 4m deep. It is desirable that workers can access to the lift pit directly through an entrance at the basement level.

(b) It is common to use cat ladders to access the lift machine rooms. It would be dangerous for workers to climb up a cat ladder with heavy tools, equipment or materials. To enhance the safety of workers, it is suggested to install permanent inclined ladders with railing, instead of cat ladders.

(c) It is suggested to make reference to the design of the Housing Authority to install fall protection anchor points at the lift lobby (i.e. near lift door). The anchor point for fall arrest device can be used to prevent accidents related to fall of person from height.

(d) A switch lock on the Operation Switch should be installed to ensure that the operation of the lift-under-repair is under the sole control by the lift workers and prevent any unauthorized control of the lift car.

(e) Suitable guard-rails and toe-boards should be provided at all four edges on top of a lift car. The guard-rails should be designed to render safe and easy access and egress of workers.

4.3 Reasonable Project Schedule

A reasonable project schedule is important to improve safety performance of E&M works. With a tight working schedule and long working hours, workers may neglect the safety procedures and overlook the hazardous of working environments. Consideration of safety issues when developing the project schedule at the planning stage would be substantially reduced the risk of accidents during construction. The formulation of reasonable project schedule in E&M works need fully support from developers. It is recommended that through the enhancement of the current common standard forms of contract. Compulsory comments from E&M nominated subcontractors should be included as part of the essential substantiations of master programme and delay recover measure submissions from main contractors to contract supervisors. In addition, the timing of comments and decisions from contract supervisors on main contractors' extension of time claims should be well defined in contract conditions, to avoid the situation of self-accelerations and unnecessary progress compression in E&M works.

4.4 Attract New Entrants

The problem of manpower shortage in E&M industry has become more serious as the young generation is unwilling to work on construction sites. It is suggested to implement some initiatives to attract young people to join the industry. Some recommended measures include improving the image of the industry, enhance the site facilities, and increase the income and welfare of E&M workers.

4.5 Develop and Implement Safety Procedures and Risk Assessment Processes

Some interviewees expressed that it is important to conduct risk assessment by safety personnel at the tender stage. It helps to identify hazardous works such as confined working spaces, work at height and corresponding safety equipment, and to estimate the cost for safety investment (e.g. provision of working platform and scissor lift). It is also required to make a risk assessment of health and safety to employees and others who are exposed on construction sites, especially for specific hazards (e.g. work at height, hazardous substance, manual handing, and use of plant, etc.). A risk assessment may identify people who are being affected by the activity, the requirements of personal protective equipment, suggested additional risk control measures, and any applicable guidance related to the operation. Besides, good safety planning and coordination, sufficient work spaces and time, good sequence of work, and provision of fall prevention devices can effectively reduce the risk of E&M works.

4.6 Extend the Pay for Safety Scheme (PFSS) to Frontline Workers

Under the Pay for Safety Scheme (PFSS), when main contractors have complied with the stipulated safety requirements, payment will be made to the contractors. However, no incentive would be awarded to the frontline workers for carrying out those safety items. It is suggested to extend PFSS to subcontractors and to frontline workers. The main contractor may apportion part of the payment received from the client under the PFSS to their E&M trade subcontractors. For instance, the main contractors would pay or award their subcontractors for fulfilment of stipulated safety requirements. The subcontractors may award their workers (e.g. cash or coupons) based on their safety performance for motivation. It is suggested by the interviewees that the government should actively promote construction safety through implementation of incentives scheme.

4.7 Application of New Technologies

Push-fit Pipes

Push-fit pipes are a new technology in pipe design. The use of push-fit pipes may facilitate a safer working process of plumbing works. The push-fit pipes can be jointed and fixed without welding process. It can reduce accidents related to cut by hand tool or burn when welding.

Building Information Modeling (BIM)

Building Information Modeling (BIM) can be applied for hazard identification and correction at both planning and construction stages. It is an advanced method for creating a virtual representation. With the 3D visualization, construction project teams can know exactly the operation procedures and safety hazards for frontline site management to set up corresponding preventive measures for workers. It would be valuable to establish a systematic database of 3D simulated method statement for E&M installation works. Some supporting documents such as safety precautions, standard working procedures and stipulated training certificate for E&M workers may also illustrate in each 3D simulated method statement.

With the publication and implementation of BIM Standards from the CIC in September 2015, more BIM applications in construction lifecycle are viable. 3D simulations can be used on top briefing or training notes to demonstrate the working procedures and safety plan directly to the workers. It is suggested to explore the feasibility of using Cloud-based BIM platform for workers. The workers can download the BIM video directly via their mobile phone application. BIM creates virtual model which can be applied for coordination with different E&M trades. It would be useful for detecting and reporting of clashes and design conflicts and space analysis for large equipment (e.g. generator for electrical works), with reference to the construction sequence.

Guided Suspended Working Platform (Guided-SWP)

Conventionally, lift installation works requires scaffolding in the lift shaft. It is suggested to use the guided suspended working platform instead of bamboo scaffolding inside a lift shaft to provide a comfortable and safe work environment for lift installation workers. By using Guided-SWP, lift installation workers can move along the lift shaft to install the lift equipment such as guide rails, and landing door operators, etc. in a safer and more efficient manner. It can also reduce the risk of lift shaft works.

Use of Rechargeable and Wireless Hand Held Tools

The current trend of the construction industry is to use wireless hand held tools such as electrical drill, saw, cutting machine and handy task lights which is battery operated and rechargeable to replace traditional tools. The advantages of using wireless hand tools include (1) prevent accidents related to contact with electricity or electric discharge, and (2) prevent trip over electrical wire.

4.8 Enhance Training and Supervision to High Risk Group

It would be most effective to formulate targeted safety measures for those high risk groups. It is recommended that workers who are new comers to a construction site should receive more training and be mentored by more experienced E&M specialists. Suitable training should be provided to workers before they start working, and before being assigned to a job which requires new skill and after any deficiency is detected (Ling *et al.* 2009). Lee (1991) promoted the introduction of safety orientation programmes for new workers to strengthen their safety awareness. With adequate safety training, the competent safety person would be responsible to identify safety hazards, check safety equipment, and remind the corresponding workers constantly. The safety personnel should closely supervise the workers involved in high-risk activities such as electrical wiring works and work at height etc., to ensure proper use of personal protective equipment and to correct any unsafe action and condition.

4.9 Safety Measures for Electrical Works

Electrical hazards are significant issues that threaten the safety of E&M workers. Special attention should be given to works involved electricity. The use of “Lock out tag out device” is recommended for electrical works. It is an effective safety procedure which is used in the construction industry to ensure that no hazardous power sources will be turned on accidentally when the E&M work is carried out. Generally, the key for the lock out device would be kept by the person in charge for the electrical works. "Permit-to-Work" system should be conducted by Registered Electrical Worker (REW) and the Safety Officer (required in ArchSD’s projects) to assess and ensure that the risk at work is to be properly controlled. The permit-to-work system should include (1) risk assessment of the task; (2) identify the hazards; (3) define safety precautions; (4) implement the system; and (5) monitor the system. For preventing electrocution accidents in ArchSD’s projects, it is a contractual requirement that all portable electric tools, site lighting and other electrical devices should be operated at 110 volts obtained by use of a step-down transformer.

4.10 Safety Measures for Working at Height

A vast majority of accidents are caused by fall of person from height and results in severe injuries. It is suggested that safety measures should be implemented to prevent recurrence of fall accidents. E&M works often involve the use of ladders. Ladders were found to be the most common agent involved in fall accidents. Workers were injured with ladders being used to perform installation tasks or gain access to areas in most accident cases. Ladder is designed only for temporary use or provides access to different elevations. Workers should be prevented to perform prolonged tasks on ladders (Bentley *et al.,* 2006). It also indicated that "better control" and "enhance monitoring" of using ladders are the key measures to ensure the safe use of ladder, thus, minimize fall accidents from ladders. Safety checking system for equipment (i.e. ladders, hand tools, and safety harness, etc.) should be established to ensure all the equipment were in safe working order. Safe means of support such as platform ladders and working platforms should be provided for access or work at height to reduce accidents related to work at height. It is encouraged to use platform ladders instead of "A" ladder for E&M works. It provides a more stable platform with railing for workers and reduces accidents related to work at height. When the task involves electrical works, fiberglass ladders would be used. It is recommended to enhance promotion of platform ladders within the construction industry. As the resources of small and medium enterprises (SMEs) are inadequate, it is valuable to explore the feasibility to provide financial support for SMEs to purchase platform ladders.

4.11 The Way Forward

The research findings indicate that the root causes of E&M accidents in new construction works and on RMAA works are distinct. With an increasing, government required, volume of E&M related RMAA works in Hong Kong in recent years, it is likely that the number of E&M accidents in the RMAA sector will also increase. As the extension of this project, the research team has submitted a research proposal entitled "Electrical and Mechanical Safety in Repair, Maintenance, Alteration and Addition (RMAA) Works" to the Research Grant Council (RGC) 2016/2017. The proposed research project has been successfully approved and commenced from January 2017. The focus of this project is to reveal the causes of accidents on E&M works and provide recommendations to improve the safety and health of E&M practitioners on RMAA works, particularly for those two accident types (i.e. fall of person from height and electrocution). It is expected that the research will bring tremendous value in better safeguarding E&M workers' health and safety.

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2018

CIC Research Report No. CICRS_014