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Research paper

Fire Hazard Assessment During Construction of A Mixed-Use Development Project In Kuala Lumpur

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Abstract

Construction by nature is inherently dangerous, with a high degree of hazard and risk. Serious fire has occurred in building under construction, which will not delay their completion dates and loss of life, but also result in serious monetary losses. The objectives of this paper are to investigate the causes of fire hazard during the construction phase; assess the risk level arising from the fire hazard during the construction phase; and tpropose safety control measures of fire hazard during the construction phase. Primary data is obtained from the respondents of a mixed use development project in Kuala Lumpur via questionnaire surveys. The data is analysed via Statistical Package for the Social Science (SPSS) and Hazard Identification, Risk Assessment and Risk Control (HIRARC). The findings show that the most important causes of fire hazard of a mixed-use development project are related to workers site activities. Meanwhile, HIRARC identifies that fire hazard from hot works and use electrical tools are the most important risks. Lastly, safety control measures were proposed to control the identified fire hazard by improving the operating procedure of hot works and use of electrical tools as well as implementing good housekeeping practices and inspection at the workplace.

Keywords: *Construction site; fire hazard; fire safety; mixed-use development project; risk assessment matrix*

1. Introduction

The construction project fire frequently occurs in recent years, some of which have greater impact, namely on August 14, 2007, the Shanghai World Financial Center Fire accident; on July 27, 2008, Jinan Olympic Sports Center Gymnasium fire accident; on February 9, 2009, CCTV North Side Building fire accident; as well as on November 15, 2010, 728 Jiaozhou Road, Jingan District, Shanghai, a 28-story floor facade wall construction of high-rise residential fire accidents, which brought about huge casualties and property losses [1]. This is happened due to insufficient safety control measures done during construction periods. The sufficient and effectiveness of safety control measure are depending on the fire hazard assessment through their risk level at construction site.

Fire occurs in buildings under construction will not only delay the completion dates and loss of life, but also result in monetary losses as the structure may need to be partly and wholly demolished and rebuilt. Once a severe fire incident occurs in a building structure, catastrophic structural damage can occur. In the event that the structural integrity of the building structure is compromised, threats to life safety can dramatically increase. Furthermore, structural properties of both steel and concrete are observed to undergo severe degradations when exposed to elevated temperatures, with respect to structural properties observed under ambient conditions [2]. Thus, it is important to identify activities leading to fire hazard at construction site, particularly during the construction phase.

In Malaysia, more often than not, fire outbreaks occur as result of human factors, such as carelessness, negligence or simply a lack of fire safety awareness [3]. Therefore, all the construction activities during the construction phase that can cause to fire hazard must be identified and controlled especially related to the human factors. It can be controlled via proper recommendations of safety control measures at construction site.

Thus, this paper aims to appraise the fire hazard assessment during construction phase of building construction via case study of a mixed-use development project in Kuala Lumpur. The findings will help in controlling the fire hazard during the construction phase, especially involving the mixed-use development project. To achieve the aim of this paper, the following objectives are identified: a) to investigate the causes of fire hazard during the construction phase; b) to assess the risk level arising from the fire hazard during the construction phase; and c) to propose safety control measures of fire hazard during the construction phase.

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2. Literature Review

2.1. Fire Hazard in Construction Site

Fire is a process involving rapid oxidation at elevated temperatures accompanied by the evolution of heated gaseous products of combustion, and the emission of visible and invisible radiation [4].

Construction sites tend to have a potential abundance of all three components of the fire triangle as shown in Figure 1. Typical sources of heat on construction sites include soldering or blazing of pipes, grinding, welding, smoking, lead work, temporary heaters, combustion engines, temporary electrical supplies, lights, etc. Typical sources of combustible material include gas bottles, waste, diesel, petrol, fuel-driven plant, etc [5]. Oxygen is ever present but is also enhanced through oxidising agents and oxygen bottles.



Figure 1: Triangle of fire

2.2. Causes of Fire Hazard

A lot of literature discussing the impact and causes of fire in the residential and commercial buildings are reviewed by this paper together with general construction sites fire issues that can be surveyed through questionnaire in the construction site.

[6] identified the major causes of fire at workplace by illegal smoking, improper storage, fire protection facilities not installed, poor consciousness among personnel fire safety, electrical fault, hot work activities and lack of awareness. This is supported by [7] who identified staff negligence, factors of fire equipment and facilities, electrical wiring short circuit and, flammable and combustible materials are the causes of fire hazard. Other causes of fire hazard stated by [7] are careless during construction, improper operation, staff's unsafe behaviour and, poor and unqualified skills among staff for in preventing fire.

Another study, which concentrates on fire and related incidents in Dubai, United Arab Emirates, showed that the three factors causing fire were negligence of workers, lack of health and safety awareness, and poor education and skilled workers [8]. The cause of fire as stated by [8] are the fire hazards which the minimisation of them would automatically reduce the fire accidents from occuring. These lists of causes of fire hazard are summarised further as shown in Table 1.

Table 1: Causes of fire

No.	Causes of Fire
1.	Lack of fire safety campaign and awareness
2.	Fire-fighting equipment and facilities malfunctions
3.	Unsafe behaviour
4.	Staff/workers negligence
5.	Poor hot work activities
6.	Poor electrical equipment and wiring
7.	Careless construction
8.	Ignites the flammables and combustible materials
9.	Poor and unqualified skills in the fire event
10.	Improper work operation

2.3. Safety Control Measures for Fire Hazard

For a successful fire hazard control at construction site, all parties, such as contractors and developers, are encouraged to adopt and implement specific fire safety procedures and approaches to reduce the potential risk and impact of fire [2]. In other words, a specific of fire safety plan should be developed before commencement of construction activities and must be implemented before the entire construction activities are on-going. This is why this paper is materialised in achieving the aim of fire safety control measures proposal.

[1] identified and proposed that the workers shall have a proper fire safety education and training system; flammable and inflammable, and explosive dangerous goods management system; fire, electricity, gas management system; fire safety inspection system; emergency plan drill system; and fire performance of insulation materials as the control measures in the prevention of fire hazard. This is supported by [7] that every organisation must strengthen their daily management of the key parts; strengthen fire safety management of key personnel and carry out fire safety publicity and education training; strengthen the daily management of fire safety and clean fire hazard, and also carry out regular inspection and maintenance of firefighting equipment and facilities, for the control measures of fire hazard. Mostly, both studies by [1] and [7] are related to the administration control as their preventive measures of fire hazard.

On the other hand, [6], who concentrates on fire risk and disaster reducing factors at warehouse, stated that temperature and humidity control; moderate pressure of materials packing and sufficient space; and control of fire sources and integrated fire safety facilities as a safety control measures for fire hazard at the workplace.

While a study by [9], which concentrates on the fire safety ranking system for high-rise non-residential building, stressed that maintenance plan for proper keeping of fire safety system; staff training plan encompassing training schemes for staff; fire prevention plan such as checking the heat-generating appliances; maintenance, including repairing damages of passive systems such as escape routes and fire doors of the buildings; maintenance of active systems such as detectors, sprinklers, extinguishers, fire hydrants, and hose-reels; information and plans on layout, escape routes, and information signs for occupants; and good housekeeping in the buildings, such as proper disposal of rubbish are important as a safety control measures for fire hazard at the workplace.

The safety control measures for the fire hazard discussed are captured in Table 2 by depicting all the lists of causes of fire from the various sources.

Table 2: List of safety control measures for fire hazard

No.	Safety Control Measures of Fire Hazard
1.	Inspection and maintenance of fire-fighting equipment and facilities
2.	Routine safety inspection
3.	Insulation construction materials
4.	Good housekeeping practices
5.	Proper Emergency Response Plan (ERP)
6.	Appropriate training
7.	Adequate information and signages of fire event
8.	Proper storage of hazardous materials
9.	Sufficient fire safety equipment and facilities

3. Methods

3.1. Data Collection and Analysis

Five essential stages are involved in undertaking this paper, which include literature review, development of questionnaire, questionnaire survey, data analysis and interpretation, proposal of control

measures and conclusion. A comprehensive literature review on activities leading to safety and fire hazard during construction phase of general construction projects, causes of fire hazard and risk assessment methods, and also their control measures are undertaken from various sources via proceedings, construction industry journals, industry guidelines as well as safety and health requirements for the construction site.

The obtained data is compiled for the next stage of questionnaire development. Data collection and sampling from targeted respondents are conducted further through questionnaire survey. The survey is conducted to gather data from the mixed-use development project site personnel in Kuala Lumpur, whom consists of management staff, site supervisory and general workers. This questionnaire is measured based on a Likert's scale of five ordinal measures from one to five according to the level of agreement. After that, the data generated from the questionnaire survey is analysed using frequency analysis. The measurement tools in the survey provide quantitative indication of qualitative judgments. The rating scale used for the questionnaire is; 1 = Strongly Disagree, 2 = Disagree, 3 = Uncertain, 4 = Agree, and 5 = Strongly Agree.

The data generated from the questionnaire survey is analysed using average index of frequency analysis. The measurement tools in the survey provide quantitative indication of qualitative judgments. The average index formula is given as:

$$\text{Average Index} = \frac{\sum(\mu * n)}{N} \quad \text{..... (1)}$$

Where, μ is the weightage given to each factor by the respondents, n is the frequency of the respondents, and N is the total number of respondents.

3.2. Hazard Identification, Risk Assessment and Risk Control (HIRARC)

Risk assessment matrix of Hazard Identification, Risk Assessment and Risk Control (HIRARC) model has been used in the fire hazard assessment in this paper, which may be inherent to the system which is determined as a serious threat for selected activities in the mixed-use development project in Kuala Lumpur. The process of HIRARC is shown in Figure 2.



Figure 2: Flowchart of Hazard Identification, Risk Assessment and Risk Control (HIRARC) process

In this paper, the classified work activities were covering specific activities that lead to fire hazard during construction of mixed-use development project, namely use of gas/oxy-fuel welding, use of electric arc welding, cutting using oxy-acetylene gases, installation of power supply (electrical distribution board, sockets and electrical cables) and use of electrical tools.

The fire hazard identification is referred to the identifying of undesired work activities leading to fire hazard and their occurrence mechanism. Techniques used to conduct hazard identification in this paper are work place inspection reports, record of hazardous substances, site risk register based on the potential accident factors and, previous accident and incident investigations reports from internal and external parties. Table 3 shows the specific fire hazard in mixed-use development project in Kuala Lumpur.

Table 3: List of fire hazards during construction phase of mixed-use development project

No.	Fire Hazard
1.	Faulty electrical outlets and old
2.	Electrical cable bunching/ pinching
3.	Outdated electrical appliances
4.	Electrical heater components too close to combustible surfaces
5.	Fire sparks contact to flammable materials or combustible surfaces/ objects
6.	Faults in appliance cords, receptacles and switches
7.	Faulty lamps and light fixtures
8.	Underrated electrical cable
9.	Leak of acetylene gas
10.	Misuse of extension cords

Risk assessment consists of a series of processes related to risk analyses, assessment of the degree of risk, judgment on whether the risk is acceptable or unacceptable, and creating and assessing risk control options to accomplish this objective.

Thus, after the fire hazards are identified, the probability of occurrence and degree of harm is determined, the risk is estimated, and risk control options are evaluated based on the results. Risk measures the likelihood and severity of the accident/event sequences in order to gauge the magnitude and to prioritise the identified hazards as shown in Table 4. In this paper, the likelihood assessments in the construction site of mixed-use development project were valued based on site personnel experiences.

Table 4: Likelihood values in hazard identification

Likelihood (L)	Example	Rating
Most likely	The most likely result of the hazard/event being realised	5
Possible	Has a good chance of occurring and is not unusual	4
Conceivable	Might be occur at sometime in future	3
Remote	Has not been known to occur after many years	2
Inconceivable	Is practically impossible and has never occurred	1

While the severity can be divided into five categories. Severity are based upon an increasing level of severity to an individual's health, the environment, or to property. Table 5 indicates values of severity.

Table 5: Indicated severity in hazard identification

Severity (S)	Example	Rating
Catastrophic	Numerous fatalities, irrecoverable property damage and productivity	5
Fatal	Approximately one single fatality major property damage if hazard is realised	4
Serious	Non-fatal injury, permanent disability	3
Minor	Disabling but not permanent injury	2
Negligible	Minor abrasions, bruises, cuts, first aid type injury	1

After that, qualitative data is converted to quantitative data and the rates are given to fire hazards based on the risk matrix. One of the most common risk assessment tools to evaluate risk is risk matrix ranking which includes consequence, likelihood and severity axis, thus the combination of these parameters gives an estimate of risk ranking (level) as shown in Figure 3. Risk is calculated as Risk = Likelihood X Severity.

Likelihood (L)	Severity (S) 1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

High Medium Low

Figure 3: Risk matrix to identify the risk value

Severity or extent of the injury or ill health were to occur can be rated in the following ways: 5 (severe) = may cause death and /or severe irreversible disability, and/ or permanent ill health, 4 (major) = severe injury or illness, 3 (moderate) = usually reversible; injury or illness resulting in days off work, 2 (minor) = first aid medical treatment and 1 (insignificant) = no treatment required. The likelihood, or the chance of each of the situations or events actually occurring, can be rated in the following ways: 5 (almost certain) = will probably occur immediately or within a short period of time, 4 (likely) = will probably occur in time, 3 (possible) = might occur in time, 2 (unlikely) = could happen but only rarely 1 (rare) = has the potential to occur, but probably never will.

The analysed data is then interpreted and the result is used in the initial proposal of the safety control measure for fire hazards in the mixed-use development project in Kuala Lumpur.

4. Results

This section is concerned the results that can contribute to the construction organisation of mixed-use development project in Kuala Lumpur. The method used in this paper has great potential as a periodic monitoring device for identifying and assessing any change in fire hazard and can be effectively used to point out the organisation's strengths and weaknesses. The results of this paper are discussed in the following subsections.

4.1. Causes of Fire Hazard during Construction Phase

Overall result of data analysis showed that the respondents strongly agreed that all is the causes of fire hazard during the construction phase of mixed-use development project in Kuala Lumpur. Table 6 indicates that the most important causes of fire hazard in the mixed-use development project in Kuala Lumpur are 'unsafe behaviour', 'poor hot work activities' and 'careless construction' with the rating scale 4. These causes are related to each other. When the construction activities are under careless construction practices without proper method or standard operating procedure, this automatically encourages the unsafe behaviour among workers at the construction site. Poor hot work activities are also apparently related to the these careless construction practices, where all parties in the construction site should have proper planning and procedures for the hot work activities.

Table 6: Most important causes of fire hazard in mixed-use development project in Kuala Lumpur

Item No.	Causes of Fire Hazard	Average Index	Category of Rating Scale
1	Unsafe behaviour	4.16	4
2	Poor hot work activities	3.86	4
3	Careless construction	3.59	4

4.2. Risk Level Arising From Fire Hazard during Construction Phase

Via risk assessment that is undertaken using the risk matrix ranking, it is found that the most critical fire hazard arising from construction activity of mixed-use development project as shown in Table 7 is fire sparks contact to flammable materials or combustible surfaces/objects during hot work activity. The risk ranking for this fire hazard is under high risk category that needs an urgency action to minimise the risk. Other critical fire hazards are leak of acetylene gas and, fault in appliance cords, receptacles and switches based on the rankings given by the respondents. The results translated that the poor hot work activities, such as welding works and cutting using oxy-acetylene gases, are the major contribution to fire hazard in the mixed-use development project in Kuala Lumpur, and followed by use of electrical tools work activities.

Table 7: Most important risks of fire hazards in the mixed-use development project in Kuala Lumpur

Item No.	Fire Hazard	Risk Values	Risk Ranking
1	Fire sparks contact to flammable materials or combustible surfaces/objects	16	High
2	Leak of acetylene gas	12	Medium
3	Faults in appliance cords, receptacles and switches	12	Medium

4.3. Proposal of Safety Control Measures of Fire Hazard during Construction Phase

Overall result from the data analysis of safety control measures of fire hazard in the mixed-use development project in Kuala Lumpur showed that the respondents are uncertain and agreed for all the proposed safety control measures. Table 8 indicated that the least important safety control measures of fire hazard in the mixed-use development project in Kuala Lumpur are 'proper storage of hazardous materials', 'good housekeeping practices' and 'sufficient fire safety equipment and facilities' with the rating scales 3 and 2 of average index. These apparently need more commitment and intention from the construction industry players involved in the mixed-use development project in Kuala Lumpur. Therefore, these least important fire hazard safety control measures have been the focus of this paper as the proposal of the fire safety improvement in tackling and reducing the total number of fire hazards in the mixed-use development project in Kuala Lumpur.

Table 3: Least important safety control measures of fire hazard in mixed-use development project in kuala lumpur

Item No.	Safety Control Measures	Average Index	Category of Rating Scale
1	Proper storage of hazardous materials	2.44	2
2	Good housekeeping practices	2.47	2
3	Sufficient fire safety equipment and facilities	2.67	3

5. Discussion and Recommendations

The finding from this paper provides a number of managerial measures to the mixed-use development project in Kuala Lumpur. For the organisation to achieve zero lost time incident during construction phase, several aspects of the process should be stressed from the management level to the site supervisory level. The recommendation from result is to propose safety control measures of fire hazard that could be adopted in the current safety management system of mixed-use development project and implemented them as daily practices to control the fire risks.

There are recommendations from result which are discussed in this paper, namely proper storage of hazardous materials, good

housekeeping practices, sufficient fire safety equipments and facilities, and proper standard operating procedures for hot work and use of electrical tools activities. These safety control measures are proposed to reduce the identified fire hazards from specified fire hazards, hot works and use of electrical tools activities.

In the proper storage of hazardous materials of safety control measures, the listed common hazardous materials that are always used in construction site including mixed-use development project are flammable liquids which are diesel, petrol and thinner, compressed gas which is acetylene and other hazardous materials. These hazardous materials should not be stored together. Containers of flammable liquids, gas cylinders and other hazardous materials should preferably be stored in open compounds, which are securely fenced, shaded from the sun and remote from pits, drains and low lying areas. Meanwhile, any electrical fittings, namely lights and switches, within these stores of hazardous materials should be suitable for an environment, where a flammable or explosive atmosphere may be present and be selected and installed by competent persons. The heat from electrical fitting should also be considered and protected from directly contact to the hazardous materials.

Meanwhile, good housekeeping of safety control measures of fire hazard is essential on all construction sites as waste material, including all non-essential combustible wrappings and packagings, if allowed to accumulate, provides an excellent designated area with fire-extinguisher equipments. Therefore, the combustible wastes should be minimised and all combustible wastes, packing materials, woods, shavings and oily rags must be regularly removed from the building and disposed off at the approved landfill area.

Besides that, rubbish chutes that are used should be constructed outside the building and be off fire resisting construction. Combustible materials should not be allowed to accumulate in or near the chute. The rubbish chute also needs regular maintenance to ensure its functionality is under good performance. In addition, all collected waste materials awaiting disposal off must be kept in an area at least 10 meters away from the structure upon which work is being undertaken, temporary accommodation, smoking shelters, stores and equipment. This is to ensure one of the main elements of fire factors os eliminated, and automatically fire is extinguished if it happened. Separate metal bins, with close-fitting metal lids, must be provided for flammable materials, for example oily rags. Additionally, any type of rubbishes must not be burned on site.

The next proposed safety control measure is sufficient fire safety equipment and facilities should be provided in construction site. There should be an adequate provision of appropriate portable fire extinguishers, approved and certificated by an independent, third-party certification body, in accordance with the requirements. At the same time, site personnel must be sufficiently instructed and trained to be able to use the portable fire-fighting equipment provided on site. Besides that, where structures are being constructed predominantly of combustible materials, additional portable fire extinguisher must be provided. This also applied when the number of hot work activities increased at construction site and additional portable fire extinguishers are must. Site personnel who are directly involve with the hot work activities shall plan their activity through looking on overall fire safety aspects.

In addition, all the fire extinguishers must be located in conspicuous positions near exits on each floor in the building. In the open area, they should be suitably protected from the environment and prominently signed pictogram of fire extinguishers. Periodic inspection and maintenance are also important for fire extinguisher, and appointed person in construction site shall ensure these are performed well.

Based on the safety requirements, all portable fire extinguisher equipment must be serviced annually by a qualified person in accordance with requirement and the maintenance service date recorded, including marking on the appliances. The appointed person in construction site must ensure the marking on the appliances of fire extinguisher equipment always there by weekly inspections. As work progress in construction site, the adequacy of portable fire extinguisher equipment must be reviewed. Thus, proper planning during early stage of building construction must be done to ensure sufficient number of fire extinguisher equipment in the building until it is completed.

On the other hand, emergency route access in the building and emergency assembly point should be boldly identified and designated. The identified and designated of emergency route access and assembly point shall also be informed to all site personnels. At same time, proper signage must be displayed and no materials obstructed the identified and designated of emergency access route and assembly point.

In tackling and minimising the listed of highest risk ranking of fire hazard in mixed-use development project, the operating procedures of hot works and use electrical tools should be developed and approved by the top management before its implementation at construction site. Operating procedures must include the step-by-step instructions to help site personnels and workers to carry out routine operations of hot works and use electrical tools.

In addition, where hot works cannot be avoided, the guidance set out in internal operating procedure should be followed. Hot works should only be undertaken by suitably trained staff at a dedicated area away from the main area of construction work or storage of materials. A ‘permit-to-work’ system also should be adopted to ensure all site personnels, whom involved, are aware on the safety aspects before work started and to ensure the site is safe before it is left out.

Meanwhile, electrical supply installations, both temporary and permanent, must be installed in accordance with safety requirements. All electrical installations must be undertaken by a competent electrician. A competent electrician should inspect all installations, especially those of a temporary nature, regularly and test them at intervals not greater than every three months and following all alterations. The results of tests and inspections should be recorded. Electrical cabling and tools should be protected against damage from construction site activities in the vicinity. It must also be in good condition before used. Portable electrical equipment used on site shall carry durable labels that are subject to periodic inspection and testing. Where portable or temporary lights are required, these should be located well away from combustible materials. Where possible, main switches, other than those controlling security and automatic fire detection system, should be turned off when work ceases and all equipment must be unplugged when not in use.

Additionally, based on these findings, it appears that site safety implementation and compliance must be improved in terms of site inspection and monitoring. According to [10], the periodic site inspections conducted by the person in-charge are vital in the fire prevention and control from ground sources of fire. The said fire inspection report should be written and received by project management, which means that an inspection must be highlighted to the management for their attention and further action in fire hazard controls.

6. Conclusion

In overall, all the paper objectives are successfully achieved. This paper finds that the adoption of the average index instrument is proved appropriate in measuring the causes and control measures of fire hazard during the construction phase and the risk assessment matrix for the assessment of fire risk level. Importance of fire hazard causes for construction of the mixed-use development project in Kuala Lumpur is also pointed out. The causes of fire hazard identified unsafe behaviour, poor hot work activities and careless construction as the most important fire hazards. Meanwhile, fire sparks contact to flammable materials or combustible surfaces/objects is assessed as the highest rank of fire risk level. For the fire hazard control measures, proper storage of hazardous materials, good housekeeping practices and, sufficient fire safety equipment and facilities are proposed for further improvement for better safety practices within the mixed-use development project in Kuala Lumpur.

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