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A Study on the Fire Safety Management of Public Rental Housing in Hong Kong
香港公共房屋消防安全管理制度之探討

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A Study on the Fire Safety Management of Public Rental Housing in Hong Kong

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ABSTRACT

At the end of the Pacific War, there were a large number of refugees flowing into Hong Kong from the Mainland China. Many of them lived in illegal squatter areas. In 1953, a big fire occurred in Shek Kip Mei squatter area which rendered these people homeless. The disastrous fire embarked upon the long term public housing development in Hong Kong. Today, the Hong Kong Housing Authority (HKHA) which was established pursuant to the Housing Ordinance is charged with the responsibility to develop and implement a public housing programme in meeting the housing needs of people who cannot afford private rental housing.

It is always a big challenge for the HKHA to manage and maintain a large portfolio of residential properties which were built across several decades under different architectural standards and topology. In particular, to ensure that the building stocks are maintained in a safe and habitable state remains fundamental importance.

It is understandable that buildings constructed many years ago are unlikely to fully comply with current fire safety code. While endeavors on alteration and improvement works on fire safety provisions are always taken by HKHA, there may still be technical constraints on the scope of works to be undertaken. It is a general acceptance that good fire safety management (FSM) plays a key role in elevating the fire safety level of a building.

In this research project, attempts will be made to study how organized and structured FSM will contribute to fire safety of existing HKHA buildings. A literature review will first be conducted on various fire risk assessment techniques. The local fire safety legislations and hence major deviations of the existing building stocks from the current fire safety codes; as well as the FSM practices in HKHA will also be reviewed. Although there is no mandatory requirement on FSM, the FSM practice within the HKHA is found to be structured and organized.

The ignition frequencies of the housing stocks are further analysed empirically based on the available records of the fire incidents. There is no observed overall significant variation in the number of fires per block for each Block Group within the 5 years from 2006 to 2010; despite those older blocks may not be designed as per the current fire codes in comparison with those newer design blocks.

Furthermore, Fault Tree Analysis (FTA) technique will be used to study the effect of FSM on the reduction in fire risk level on a conceptual basis. Although the probabilities of basic events are not exactly known, it is possible to have an analysis

on a comparative basis. Through a questionnaire approach to the professionals in the building industries (comprising Building Services Engineers, Building Surveyors and Estate Managers); the various probabilities are estimated to evaluate the risk level reduction as a result of structured FSM. The results reveal that the improvement in risk level is quite substantial.

Finally, the thesis will discuss on the development and implementation issues for a FSM system in the setting of HKHA. While the FSM system in the organization is structured and organized, it is not a formal and systemic one. A formal system similar to that of occupational health and safety is therefore proposed. In addition, a Fire Safety Management Index scheme is also put forward to encourage the property owners and managers to commit on FSM as an interim measure even though formal legislation is not in place. The scheme will provide a means of recognition on the achievement of a high standard of building management regarding fire safety; which certainly adds values to the property.

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List of Publications

During the period of candidature and research process, the following papers have been submitted to the International Journal on Engineering Performance-Based Fire Codes for publication:

Yeung, C.H., (2007a), "Fire safety management of public rental housing in Hong Kong", International Journal on Engineering Performance-Based Fire Codes, Vol. 9, No. 4, pp. 163-176.

Yeung, C.H., (2007b), "Review of fire safety legislation in Hong Kong", International Journal on Engineering Performance-Based Fire Codes, Vol. 9, No. 4, pp. 177-182.

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CHAPTER 1 Introduction

1.1 Brief History of Hong Kong

Hong Kong is a coastal island located in the southern part of mainland China. Early in the 19th Century, Hong Kong was just a small fish village. Following the outbreak of the First Opium War, it was ceded to the British Administration under the Treaty of Nanking in 1842. Further on in 1860, the Kowloon Peninsula and the Stonecutter's Island were also ceded to the British as a result of China's defeat in the Second Opium War under the Convention of Peking. Later on in 1898, Britain obtained a 99 years lease (i.e. until 1997) of Lantau Island and the adjacent northern lands which is commonly referred to as the New Territories. As the lease was close to its expiry, the British and the Chinese governments had conducted several discussions on the sovereignty of Hong Kong. In year 1984, the two countries signed the "Sino-British Joint Declaration" and eventually Hong Kong was reunited to the People's Republic of China in 1997. Thereafter Hong Kong became the Hong Kong Special Administrative Region of Mainland China. During the past decades, Hong Kong has turned from a manufacturing based economy into a leading financial hub in the Asia Pacific Region with the Hong Kong Stock Exchange ranked the sixth largest in the world.

1.2 Development of Public Rental Housing (PRH) in Hong Kong

At the end of the Pacific War, there were a large number of refugees flowing into Hong Kong from the Mainland China. Many of them lived in illegal squatter areas. In 1953, a big fire occurred in Shek Kip Mei squatter area which rendered these people homeless. The government therefore established the then Resettlement

Department to construct resettlement blocks to house these victims and this disastrous fire embarked upon the long term public housing development in Hong Kong (Fung, 1996). At the same time, the former Hong Kong Housing Authority was also set up as a voluntary organisation to provide low cost rental housing to those lower income classes. In 1973, the new statutory body Hong Kong Housing Authority (HKHA) was established pursuant to the Housing Ordinance (Laws of Hong Kong, 2008d). The current HKHA is charged with the responsibility to develop and implement a public housing programme in meeting the housing needs of people who cannot afford private rental housing.

The established missions of the HKHA are threefold namely:

- To provide affordable quality housing, management, maintenance and other housing related services to meet the needs of local citizens
- To ensure cost-effective and rational use of public resources in service delivery and allocation of housing assistance in an open and equitable manner
- To encourage a competent, dedicated and performance-oriented team

This is also illustrated as shown in Figure 1.1

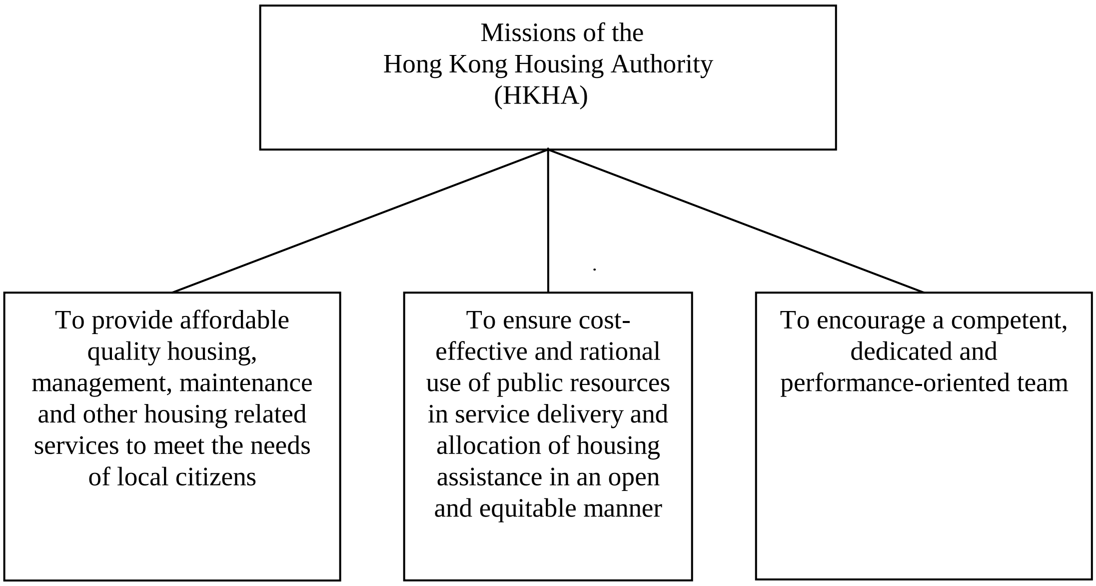

Figure 1.1 Missions of the HKHA

According to statistics at year end of 2010, about 30% of the local population is living in public rental housing (PRH) flats. The housing stock for estates where all blocks are wholly let to tenants is totaled at 158 estates or 1,113 blocks (HKHA, 2010). There are also additional rental blocks which are located within “Tenant Purchase Scheme Estate” (TPS), “Home Ownership Scheme Court” (HOS), “Buy or Rent Court” (BRO) and “Interim Housing” (IH) which comprise a mixed mode of tenancy and ownership. The huge workforce from such “root grass” class has been contributing to the economic development in Hong Kong; and the provision of affordable accommodation to the low income group helps to maintain social stability. To ensure a safe, healthy and enjoyable living environment for those citizens, proper management and maintenance of the PRH stocks is of paramount importance.

1.3 Overview of fire safety performance in Hong Kong

Under the Fire Services Ordinance, the Fire Services Department (FSD) is held responsible for extinguishing the fires and advising on fire protection measures (Laws of Hong Kong, 2005b). After putting out the fires, the FSD will also compile and publish the fire call statistics on their website every year. The fire information provided by the FSD includes:

- Classification of fires (by occupancy)
- Classification of fires by causes
- Occupancy where major fire occurred (No. 3 alarm[1] and above)
- Injuries and fatalities

In general, Hong Kong has a good fire safety record in terms of low life loss figure within the international setting. Tsui and Luo (2005) have compared the fire death tolls amongst the major countries in the world from 1997 to 1999 based on the statistical data from the Geneva Association[2]; as well as the information gathered from the Hong Kong Census and Statistics Department (HKCSD).

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[1] The FSD has classified fire alarm into 5 levels. The number 1 alarm is for fires reported without too much information available. Number 2 alarm is for fires for special hazard occupancies such as hotel, hospital and oil refinery etc. Number 3 alarm and above is for fires which are beyond the resource capability of the fire service personnel initially dispatched; which are hence considered as major fires.

[2] The Geneva Association was established in 1973 in Geneva of Switzerland and is a non-profit making think tank for strategically important insurance and risk management issues. The World Fire Statistics Centre is affiliated under the Geneva Association and collects statistics on national fire costs and death figures from some 20 leading countries and reports annually to a United Nations Committee. The Centre’s main objective is to persuade governments to adopt various strategies to reduce the cost of fire incidents.

By using a similar approach, the current fire death toll of Hong Kong is also estimated in Table 1.1 from 2006 to 2008. Firstly, the number of fire deaths for the 3 consecutive years are taken from the FSD web page (FSD, 2012) and the corresponding populations in the period are further extracted from the population tables of Hong Kong Census and Statistics Department (CSD, 2012). The number of deaths per 100,000 persons are hence calculated and averaged over the 3 years; whereas the death tolls for other countries are taken from the Geneva Association Information Newsletter (Geneva Association, 2011). The death tolls from 1997 to 1999 and 2006 to 2008 are compared as shown in Table 1.2.

Overall speaking, it is noted that Hong Kong performed pretty well in this aspect against other developed countries as it consistently ranked second to Singapore but better than UK and USA.

Table 1.1 Estimation of fire death figures in Hong Kong in 2006-2008

Year	**2006**	**2007**	**2008**
No. of fire death (civilians and fire fighters)	14	17	10
Population in Hong Kong	6,904,300	6,938,400	6,963,900
Fire deaths per 100,000 persons	0.2028	0.2450	0.1436
Average fire death per 100,000 persons in Hong Kong in 2006-2008	**0.20**		

Table 1.2 Comparison of fire death figures amongst major countries in 1997-1999 and 2006-2008

	1997-1999 (Tsui and Luo, 2005)	**2006-2008 (Geneva Association, 2011)**
Country	Fire death per 100,000 persons	Fire death per 100,000 persons
Singapore	0.18	0.11
Hong Kong	**0.39**	**0.20** (from Table 1.1)
Australia	0.69	0.48
UK	1.18	0.80
Canada	1.38	1.15 (only for 2000-2002)
USA	1.56	1.21
Japan	1.69	1.62

Despite the good performance in fire safety, several tragic fires did occur in the past history of Hong Kong which had taken tens of lives. A notable example is the Garley Building Fire (Hong Kong Standard, 1996). On 20 November 1996, a fire broke out in the then Garley Building located in Jordan district. Before the fire occurred, there was welding works being undertaken for the lift renovation project. The lift landing doors were removed and enclosed by wooden hoardings. The building was not equipped with sprinkler system and some tenants in the lower floors were not responsive to the alarm raised by the smoke detectors for taking it as false alarm. The fire developed rapidly in the open lift shaft and eventually killed 39 people and injured 81 people. Due to the large number of fatalities, the incident had also attracted the attention of the media worldwide.

Another recent example is the Cornwall Court fire happened on 10 August 2008. Cornwall Court is a composite building almost 49 years old and located in Mong Kok district. The fire started early in the morning inside a nightclub at mezzanine floor. The smoke generated soon spread throughout the building and killed four people including two firemen.

These two tragic incidents manifested that there are management and maintenance deficiencies in managing those old existing buildings. It is frequently criticised that should there be good management of the buildings, the incidents would not have occurred.

1.3.1 Number of Fire Calls in Hong Kong

The number of fire calls in Hong Kong is generally declining throughout the years. Very often, the frequency of fire occurrence is described as the ignition frequency per year. Amongst the different occupancy type, residential buildings continue to have the highest number of fire call, followed by commercial occupancy. However, when the ignition frequency is expressed as the number of fire call per year per m^2 floor area, Leung (2009) has found that commercial occupancy ranks first and followed by residential occupancy from year 2002 to 2007; likely due to the large numbers of residential blocks.

Lin (2005) has performed similar analysis for the fire occurrences from 1985 to 2001 in Taiwan and observed that industrial occupancy has the highest figure of annual fire ignition rate per floor area, then followed by residential occupancy.

In order to have an appreciation on the fire frequencies in Hong Kong, the fire statistics from year 2000 to year 2010 is extracted as shown in Table 1.3 and Figure 1.2 (FSD, 2012). While the number of fire calls is declining, residential buildings still stand at the top of the list amongst other occupancies. It is therefore imperative to pay attention to residential building fires.

Table 1.3 Fire Statistics in Hong Kong

OCCUPANCY	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Public area	528	619	518	490	497	413	347	338	467	425	518
Squatter areas	95	72	98	151	100	47	87	96	109	123	89
Vehicle	515	467	480	458	480	414	438	378	340	293	285
Housing estates	1586	1496	1399	1392	1618	1526	1667	1613	1589	1341	1347
Factory buildings	165	149	146	135	160	149	157	116	124	122	62
Institutional buildings	112	175	137	120	163	191	181	195	202	190	250
Non-domestic buildings	587	581	476	440	452	472	435	443	434	464	371
Domestic buildings	2935	2827	2760	2674	2241	1827	1744	1621	1601	1588	1562
Electric-others	165	85	72	88	85	94	79	90	92	81	50
Vegetation	1469	1947	1499	1678	2115	1664	1232	1230	1501	1294	819
Unwanted alarm	29607	29631	27548	24448	21744	25766	21846	20717	24007	25405	30710
False alarm	4612	4307	4131	3801	3425	3492	3302	3119	3296	2922	3108
Temporary housing area	3	0	0	0	0	0	0	0	0	0	0
Vessel	26	30	23	27	27	37	34	22	17	24	15
Others	2384	2178	1917	1872	1985	1649	1719	1660	1734	1499	1418
Total Fire Call	**44789**	**44564**	**41204**	**37774**	**35092**	**37741**	**33268**	**31638**	**35513**	**35771**	**40604**

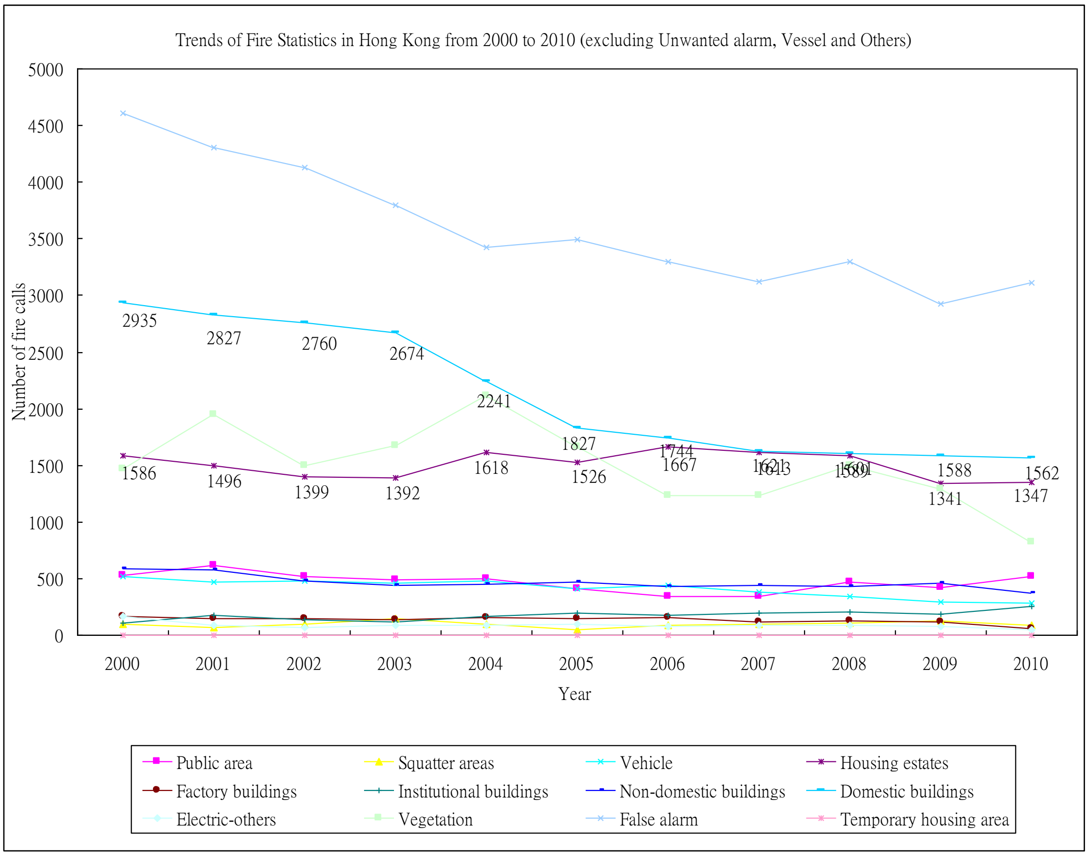


Figure 1.2 Trends of Fire Statistics in Hong Kong from 2000 to 2010 (excluding Unwanted alarm, Vessel and Others)

The number of fire calls for "Public Rental Housing (PRH)", other "Domestic Buildings" and the "Total Fire Calls" are further shown in Figure 1.3 for comparison. It appears from the histogram that the number of fire calls in PRH is quite stable throughout the 11 years; which is generally in the region of 1,500 cases each year albeit the increase in the number of housing stock. On the other hand, the number of fire calls in private domestic buildings is generally declining, probably due to better awareness of citizens on fire precautions and a gradual rise in living standards.

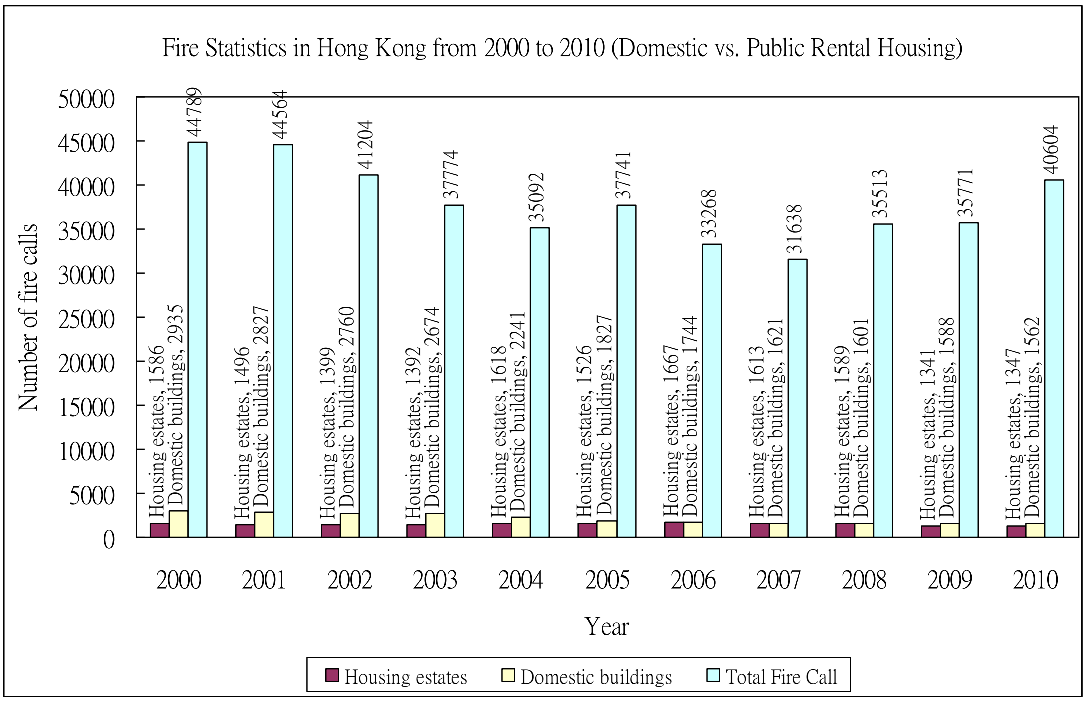


Figure 1.3 Fire Statistics in Hong Kong from 2000 to 2010 (Domestic vs. Public Rental Housing)

1.3.2 Classification of Fires by Causes

The FSD also provides the information on classification of fires by causes. The information from 2000 to 2011 is shown in Table 1.4 and Figure 1.4 respectively. It is generally observed that the causes throughout the 11 years are about the same. There is a dropping trend on the fires caused by false alarm, careless handling or disposal of cigarette ends, and food stuff (stove overcooking). It is also prominent that the most frequent cause of fires, i.e., “careless disposal of cigarette ends, matches and candles” dropped drastically from 2005. It is likely that it is the positive side effect of the enactment of the Smoking (Public Health) (Amendment) Bill 2005, where the vast majority of indoor areas of the workplace and public places are banned from smoking. The Bill was introduced into the Legislative Council on 11 May 2005 and passed into law on 19 October 2006.

Table 1.4 Classification of fire calls by causes from 2000 to 2010

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Sparks from welding & oxygen acetylene cutting	106	112	84	86	85	70	75	92	82	55	55
Children playing with matches	95	113	74	81	96	103	132	120	117	66	51
Over-heating of engines, motor & machinery	252	210	211	205	197	122	126	124	92	84	93
Careless disposal of joss sticks, joss paper & candles etc.	284	398	399	281	301	351	330	285	220	259	183
Food stuff (stove overcooking)	2675	2668	2689	2563	2497	2113	2187	1941	1863	1738	1794
Careless handling or disposal of cigarette ends, matches and candles etc.	3726	3749	2976	3160	3467	2246	1889	2002	2326	2010	1560
General electric fault	1182	1112	1007	863	898	888	759	780	795	763	807
Miscellaneous	877	849	895	983	1087	1599	1605	1438	1494	1435	1313
Unknown	212	255	191	222	801	352	340	377	411	355	312
False alarm	4612	4307	4131	3801	3425	3492	3302	3119	3296	2922	3108
Deliberate act* / Undetermined* / Suspicious circumstances#	1084	1097	958	1022	444	580	641	623	796	674	616
Unwanted alarm	29607	29631	27548	24448	21744	25766	21846	20717	24007	25405	30710
Control burning	77	63	41	59	50	57	36	20	14	5	2
Total	**44789**	**44564**	**41204**	**37774**	**35092**	**37739**	**33268**	**31638**	**35513**	**35771**	**40604**

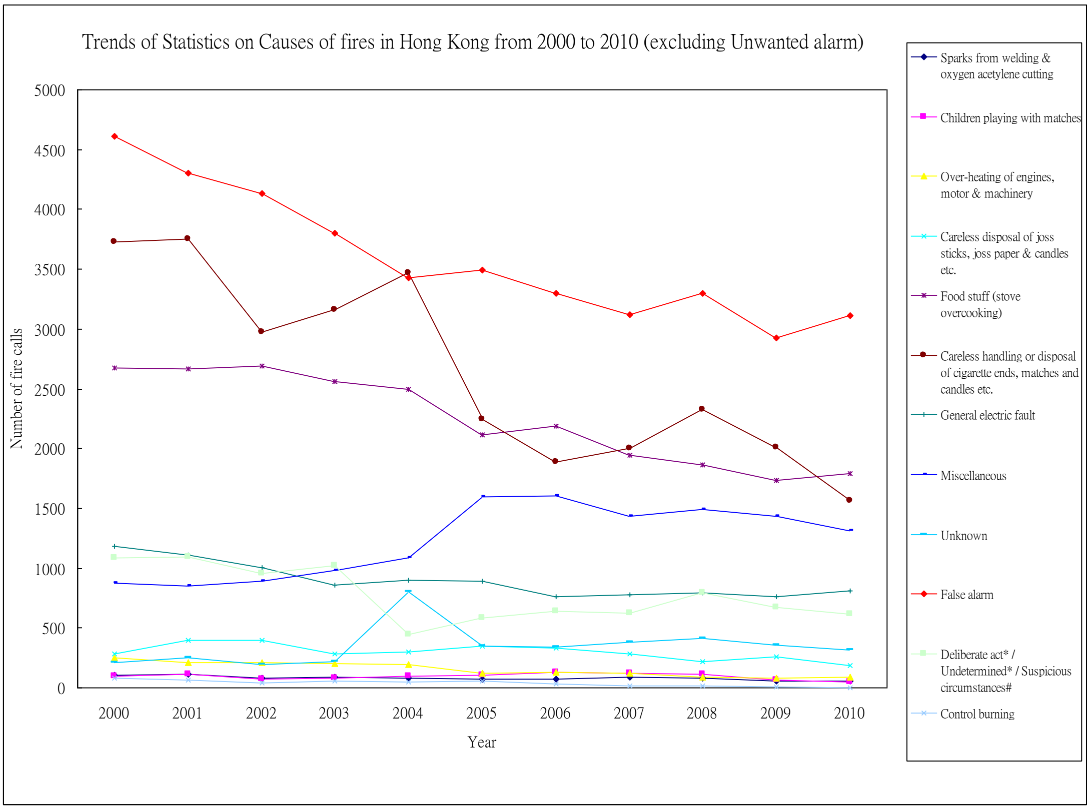


Figure 1.4 Trends of Statistics on Causes of fires in Hong Kong from 2000 to 2010 (excluding Unwanted alarm)

If we look at the causes of fires in year 2010 depicted by Figure 1.5 and discarding the five non-technical causes (namely unwanted alarm (75.63%), false alarm (7.65%), miscellaneous (3.23%), deliberate act/undetermined (1.52%), and unknown (0.77%)), the major causes become:

- Food stuff (stove overcooking) (4.42%)
- Careless handling or disposal of cigarette ends, matches and candles (3.84%)
- General electrical fault (1.99%)
- Careless disposal of joss sticks, joss paper and candles etc. (0.45%)
- Over-heating of engines, motor and machinery (0.23%)

- Sparks from welding and oxygen acetylene cutting (0.14%)
- Children playing with matches (0.13%)
- Control burning (0.005%)

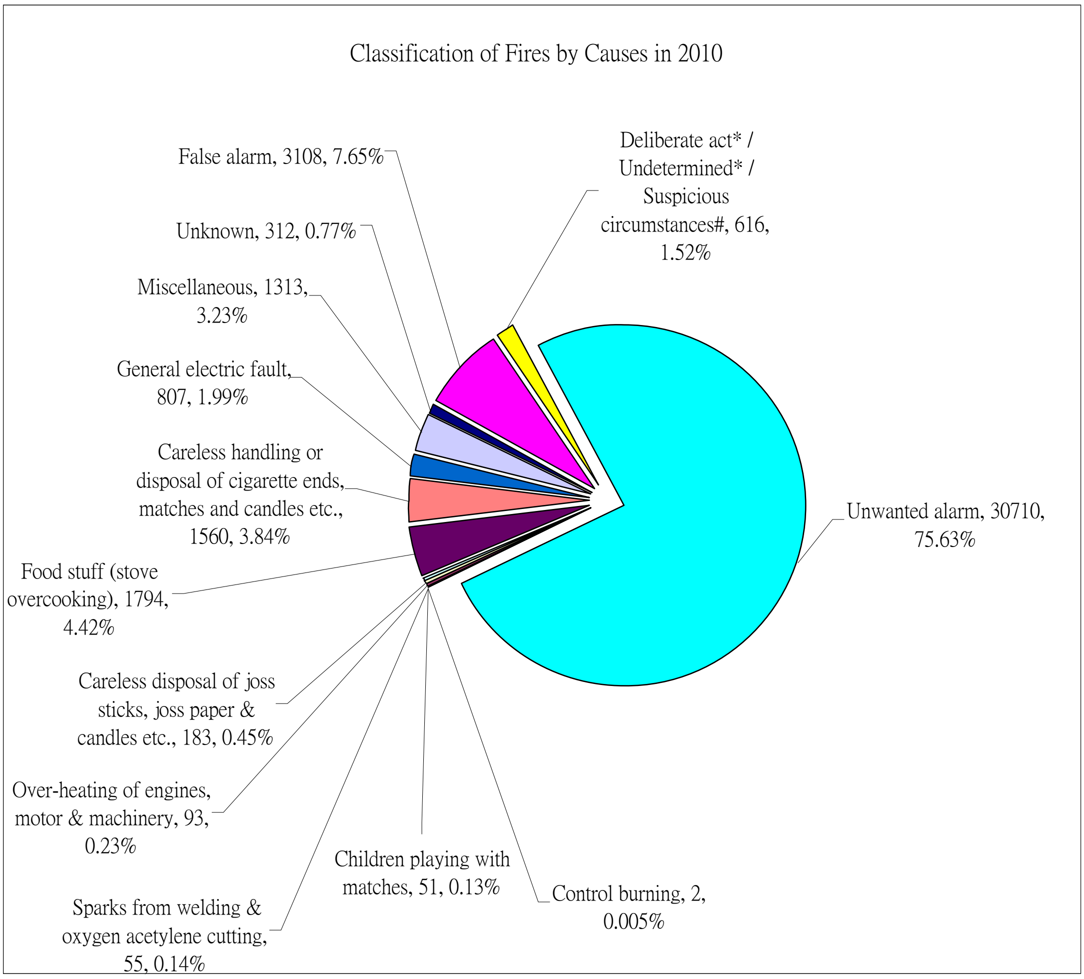


Figure 1.5 Classifications of Fires by Causes in 2010

It should be noted that the detail causes in respect of individual classes of occupancies have not been provided by FSD; and the causes would be taken as typical of buildings in Hong Kong. Accordingly, efforts on fire prevention should be concentrated on the first three causes.

It is also interesting to note that false alarms still account to 7.65% of the total fire calls. This should be seriously looked into because repeated false alarms within a building will decrease the awareness of the occupants to initiate an evacuation during genuine fires; while draining fire services resources at the same time for attendance of false incidents.

1.4 Background of the research

HKHA is the landlord of some 1,113 rental building blocks with some “older buildings” aged at 45 years. The “older buildings” constructed many years ago may not fully comply with present prescriptive fire safety code requirements. Yet there is no compromise on the life safety objective in view of the huge number of residents involved. While endeavors on alteration and improvement works on fire safety provisions are always taken by HKHA, there may still be technical constraints such as locating suitable accommodation space for installing standby generators, space constraint on constructing smoke lobby etc. Moreover, the nuisance caused to the tenants during the extensive period of alteration works may sometimes be politically unpalatable.

As revealed by the fire statistics, the overall number of fire calls throughout the 11 years from 2000 to 2010 for PRH is generally quite stable. It is a general acceptance that good fire safety management (FSM) plays a key role in elevating the fire safety level of a building. It is contemplated that the fire safety performance of those “older buildings” managed by HKHA may not be inferior to that of the newly constructed ones as well as those private buildings because of good management and established procedures. In this research project, attempts will be made to evaluate the fire safety level of those “old” PRH buildings and study how organized FSM will contribute in elevating the fire safety level of these buildings. Finally, a formal and structured FSM system will be proposed in the setting of HKHA.

1.5 Aims and objectives

The fire safety level of a building can be assessed through fire risk assessment techniques. At present, there is little information available on quantifying the contribution of good FSM in reducing the fire risk of buildings. In this research, it is aimed to assess and compare the fire safety level of those existing PRH buildings with and without a structured FSM system in place. In order to achieve the aim, the following objectives will be entailed:

(a) To have a literature review on the current fire risk assessment techniques.

(b) To have a review on the fire safety legislation in Hong Kong and identify the deviations from the current prescriptive fire codes of those “old” PRH buildings.

(c) To review on the FSM practices of HKHA.

(d) To analyse the fire ignition frequencies of the existing housing stocks based on the available fire records.

(e) To adopt the fault tree analysis (FTA) technique to evaluate the fire risk of an example PRH building.

(f) To adopt the same technique to evaluate and compare the fire risk level of the example building under enhanced and organized FSM on a conceptual basis.

(g) To develop a formal and systemic FSM system in the setting of HKHA.

(h) To report on the findings and recommendations.

1.6 Research methodology

As the starting point of fire safety management, fire risk assessment to facilities and buildings is usually taken as the indispensable and foremost process. Therefore the current fire risk assessment methods available to the practitioners will firstly be reviewed. Such common methods include the Qualitative, Semi-quantitative, and Quantitative approach. In order to gauge the contribution of FSM as a fire safety strategy, it is considered that the Quantitative method is a suitable one. It is followed by a review of the current fire safety legislations and the departmental manuals to identify the deviations from current fire codes of the “old” HKHA buildings; and the core FSM practices within the organization. The existing fire incident records will also be retrieved to analyse the ignition frequencies of different building design types. The application of FTA as a risk analysis technique will be reviewed and the industry software “Fault Tree+” will be utilized to evaluate the quantitative contribution of the FSM in reducing the fire risk on a conceptual basis. Since there is in lack of any reliable data for various basic events, questionnaires are sent out to industry experts to estimate the probabilities of these events for the sake of comparative study of FTA. Thereafter, management principles and safety management concepts are reviewed with reference to a systemic FSM system. Hence, a formal FSM system will be proposed and developed within the organizational setting of the HKHA. Finally, the conclusions and recommendations on further research will be discussed. The research methodology is outlined in Figure 1.6.

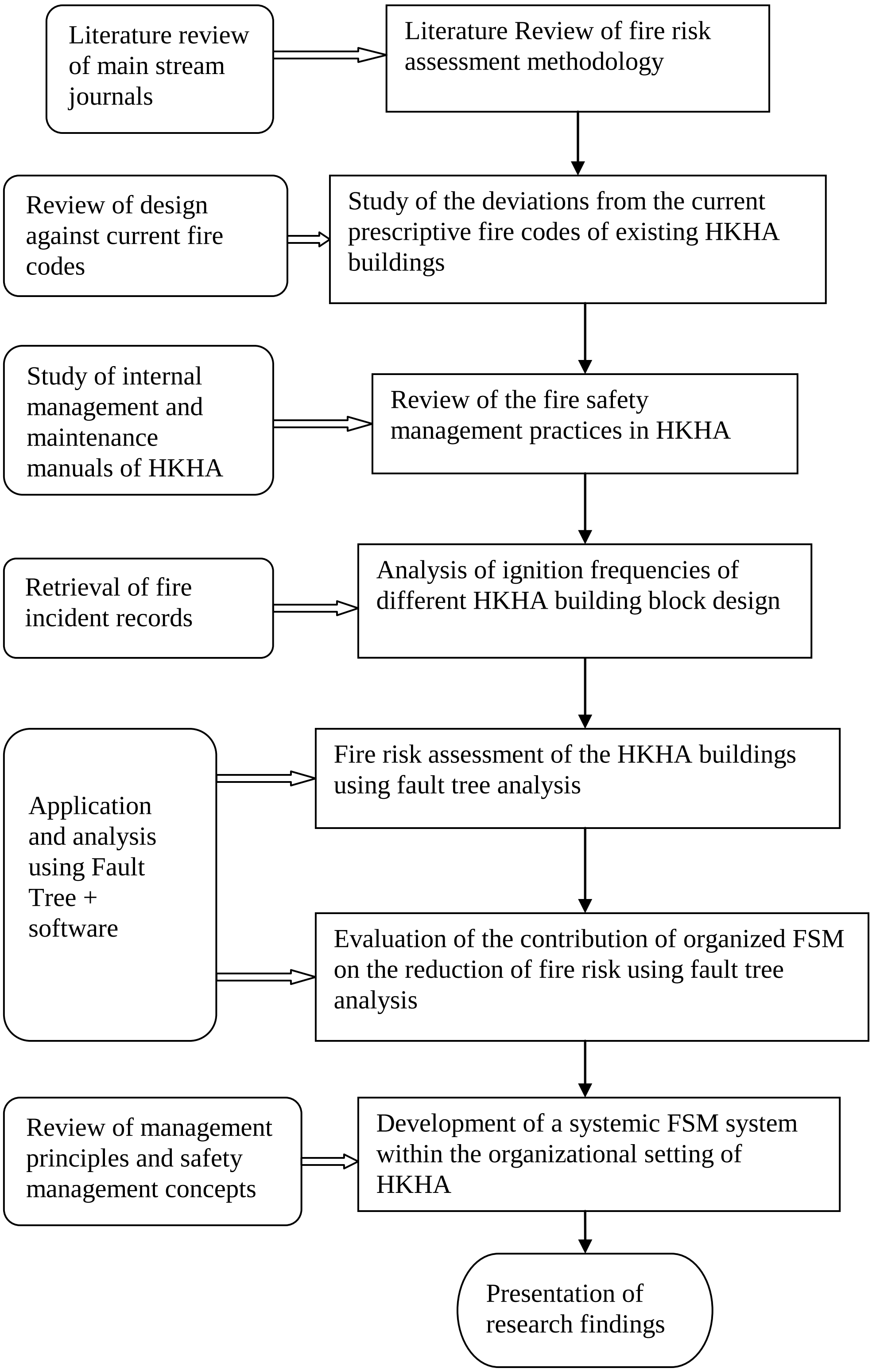


Figure 1.6 Research Methodologies

1.7 Contribution

HKHA owns and manages some 1,113 rental buildings which provide affordable accommodation to those low income groups. To provide a safe and comfortable accommodation for them is critical to maintain social stability. Some “old” buildings constructed many years ago may not fully comply with current prescriptive fire codes. Some people living in these buildings may be apprehensive about fire safety and there are political cry for various enhancement works from time to time. Amongst various improvement measures that can be considered to upgrade the fire safety level, enhanced FSM would be one of the alternatives. The optimum choice can be developed through a risk based approach (Hui, 2006; Belsham, 2009). FTA technique can be applied to assess the improvement in fire risk level of these buildings with organized FSM in place. The research attempts to evaluate the quantitative effect of structured FSM on a conceptual basis so that its role can be clearly established.

Once the quantitative effect of FSM is recognized, the extent of modification works to those “old” buildings can be narrowed while retaining an acceptable risk level. Although the research is focused on PRH, the approach can be applied to other types of buildings where a choice of structured FSM is installed to mitigate the fire risk level; which the execution of extensive improvement works is prohibitive either on cost or technical constraints.

While it is reckoned that structured FSM is an effective tool in elevating the fire safety level of existing buildings, it is found that conventional fire safety engineering research only concentrates on the technical aspects of building design such as fire and smoke dynamics, fire-resisting structures, occupant evacuation routes, and fire fighting systems. Very little research has been done on fire safety management and the development and implementation issues are not clearly understood. This research attempts to bridge this gap by studying the FSM system in the case of HKHA. By applying safety management concepts, it is possible to develop a formal systemic FSM system in the setting of HKHA.

Since FSM is not yet a mandatory requirement under the local fire safety ordinances, a Fire Safety Management Index (FSMI) is further proposed as an interim measure to boost the fire safety culture and commitment of the property management companies towards FSM within their managed portfolios and the general public at large.

1.8 Organisation of the thesis

This research thesis is organised into 8 Chapters. Chapter 1 gives an introduction to the development of PRH as well as the current fire statistics regarding fire safety performance in Hong Kong. Since HKHA owns 1,113 PRH blocks with some buildings constructed many year ago, the importance of maintaining a fire safe habitat for the tenants is emphasized. Although the “older” buildings may not fully comply with the current fire codes; they may still be reasonably fire safe because of organized management. This forms the background of the research, which attempts to discuss and quantify the contribution of organized FSM as one of the strategies of building fire safety. The objectives and the proposed research methodology are further outlined. Despite the fact that FSM has been revisited in the literature, its quantitative effect is seldom studied and reported. Moreover, there is very little current research on the application of safety management principles to FSM. It is expected that this thesis will throw light on the issue and contribute to a wider research on the same in future.

Chapter 2 provides the literature review about the fire risk assessment methodologies currently available to the industry practitioners. Firstly, the concept of risk, and the principles of establishing risk tolerance such as comparison against some acceptance criteria are reviewed. The methodologies range from Qualitative, Semi-quantitative and Quantitative approaches are reviewed and their application and choices discussed. The Quantitative approach is by far the most tedious one because of the difficulties in getting the quantitative data. The typical methods of estimating the fire risk through historical data, mathematical models, and engineering judgements are presented. Since the research attempts to quantify the contribution of organized FSM, the Quantitative approach will be adopted to the scene of those existing building stocks of the HKHA.

Chapter 3 will provide a review of the fire safety legislation in Hong Kong from the perspectives of passive fire protection, active fire protection and fire safety management. While there is little legislative control on FSM, its importance is increasingly revisited in the literatures. The Chapter goes on to outline the history of PRH development programme in Hong Kong since 1954 in the wake of the devastating fire in Shek Kip Mei squatter area. Since then, different types of PRH were constructed with varying topographies. It is understandable that those buildings constructed decades ago may not fully comply with present day fire codes; which are constantly evolving. The Chapter will therefore scrutinise on the deviations from the current prescriptive fire codes of existing HKHA buildings. The improvement works undertaken by HKHA throughout the years will also be described.

Chapter 4 will recapitulate the Fire Safety Concept Tree (FSCT) from the National Fire Protection Association (NFPA, 2007). This is actually the cornerstone of any fire safety design. Under the umbrella of the FSCT, the role of FSM is discussed. The FSM requirements from the literatures will be reviewed. The Chapter focuses on the review of the fire safety management practices of HKHA through studying the procedures manuals and documentations on the management and maintenance of HKHA's property portfolios. As the HKHA is a public and quasi-government body, the FSM is structured and organized within the organization. It has been investing heavily on fire safety education, and there is very close liaison with the FSD. Nevertheless, it is in lack of a formal FSM system, which is crucial to the success of managing fire safety.

In Chapter 5, the existing fire incident records of PRH will be analysed to identify the frequency of occurrence of fires inside flats from the year 2006 to 2010. The frequency of occurrence is generally very low and the yearly and diurnal variations of the fire events are also discussed. The ignition frequencies of the various building Block Groups throughout the five years will be analysed and further compared against the number of the building stocks. It is found that the ignition frequency per block does not vary significantly irrespective of the block design.

In Chapter 6, the principles and techniques of Fault Tree Analysis (FTA) will be introduced. The procedures for constructing the fault tree will be outlined and the causes of the top event "A flat on fire" will be discussed. A questionnaire approach is adopted to collect the views from various construction professionals regarding the causes, the probabilities of the basic events, and the likely contribution of FSM in reducing the chances and consequences of fires. An analysis on the returned questionnaires will be presented. Thereafter, the analytical tool "Fault Tree+" software will be adopted to conduct analysis on the risk level of PRH buildings and the quantitative effect of FSM on a conceptual basis. Such demonstration would give us an insight on the contribution of organized FSM on the reduction of fire risk in buildings.

In Chapter 7, fundamental management principles and safety management concepts are reviewed; and the development and implementation issues of a FSM system in the setting of HKHA will be studied. Although the FSM procedures in the HKHA are well organised, there is no FSM system which is formally documented and committed by the top management such as the Director of Housing. It is proposed that a formal scheme similar to other safety management system be instituted with the view of continual improvements. Moreover, a Fire Safety Management Index is also proposed as an interim measure to encourage the property management companies on committing FSM.

Finally in Chapter 8, it will give the conclusion of the research, and recommendation for further research. The limitations on the research findings will also be discussed.

CHAPTER 2 Literature Review

2.1 Fire Safety Management and Fire Risk Assessment

The occurrence of accidental fire is a random process and there are a lot of uncertainties leading to such events. Ramachandran (1999) pointed out that "The objective of fire safety/risk management is therefore to reduce risk to life and property to very low levels acceptable to a property owner and society at large." He further elaborated that management of fire safety involves three tasks: risk evaluation, risk reduction and risk transfer.

Risk evaluation involves the identification of various risk factors such as the presence of combustibles and the estimation on the frequency of fire starting characteristic to particular premises or compartments. Risk reduction concerns with the development and implementation of extra measures to bring down the risk level to an acceptable norm. Finally, risk transfer deals with shifting of part of the fire loss to an insurance company by procuring a suitable fire insurance cover.

Fire risk assessment forms the first and integral process in fire safety management. In the following paragraphs, a detail review on fire risk assessment methods will therefore be discussed.

2.2 Definition of risk

Risk can mean different things to different people. In our daily lives, we have to expose to a varying degree of danger, hazard, and hence risk; and lay people generally use the three words interchangeably. For instance, we may have the chance of being stuck by a reckless driver while crossing the street, and we may have the chance to lose money in betting games. It is not easy to have a single unified definition for risk as risk can involve numerous disciplines which do have the interest on the subject. The meaning of risk depends very much on the perception of risk to an individual and how the risk will affect his/her interest such as personal well being or financial impact.

Due to the ubiquity of risk in our daily lives, more and more research has been done on understanding the nature of risk. The meaning of "risk" has been defined by the Oxford Dictionary as "hazard, chance of bad consequences, loss etc., or exposure to mischance". Risk is often seen as the likelihood that an individual will experience the effect of danger (Short, 1984). The International Organisation for Standardisation defines risk as the effect of uncertainty on objectives where an effect is a deviation from the expected and objectives can have different aspects such as financial, health, safety, and environmental goals (BSI, 2009).

Meacham (2004b) has categorized risks from 4 perspectives namely, engineering, social, psychological and political. Within these boundaries, Meacham (2004b) has given one definition to risk as "the possibility of an unwanted outcome in an uncertain situation, where the possibility of the unwanted outcome is a function of three factors: loss or harm to something that is valued (consequence), the event or hazard that may occasion the loss or harm (scenario), and judgement about the likelihood that the loss or harm will occur (probability)". As far as the fire engineering community is concerned, the unwanted outcome is damage to property or injury/loss of human life; the event is a fire incident; and the possibility of the event is the chance or frequency that the fire would occur.

The British Standards Institution (2001) defines fire risk as the “product of probability of occurrence of a fire to be expected in a given technical operation or state in a defined time, and consequence or extent of damage to be expected on the occurrence of a fire”.

Furthermore, the Society of Fire Protection Engineers (SFPE, 2005, 2007) defines “fire risk” as the potential for realization of unwanted, adverse consequences, where fire is the hazard that may induce the loss or harm to human life, health, property, business continuity, heritage, the environment, or some combination of these.

All these definitions are generally originating from the classic engineering definition of risk, where the probabilities and the consequences of the unwanted events are to be addressed in dealing with risk issues.

2.3 Risk perception

Risk perception is the subjective judgement that people make about the characteristics and severity of a risk. The term “subjective” inherently implies that the feel of risk is purely personal and principally based on an individual’s own experience and not founded on reliable data sets and thus tends to be intuitive. Research interests on risk perception emerged in the 1960s largely on the launching of nuclear energy as a clean fuel, which attracted public opposition on account of safety and disposal of radiological wastes. The public perception on risk is a growing important topic to the government because it has a direct bearing on policy making and development both on technological and social-political issues.

Throughout the past decades, a large volume of research work has been conducted on risk perception and there are two main schools of thoughts around to explain the perception of risk namely: Psychometric Paradigm and Cultural Theory.

Psychometric Paradigm - in psychology, cognitive heuristics are simple rules of thumb to process information and make decision. Such psychological approach becomes the foundation of the psychometric model which emphasizes the roles of affect, emotion and stigma in shaping risk perception. Possibly, the earliest research on psychometric paradigm was executed by Tversky and Kahneman (1974) who had performed gambling experiments to see how people would estimate subjective probabilities. They found that people used the following heuristics to evaluate probability and risk:

- Availability heuristic: events that easily come to the mind or imagined are judged to have a higher probability.
- Anchoring heuristic: people often start with some pieces of known information and make adjustments to estimate the unknown risk.
- Representativeness heuristic: it is usually employed when people are asked to estimate the probability when an event belongs to a similar class or process.

Heuristics are more or less shortcuts to help people to process information and are therefore subject to biases at times. Nevertheless, the psychometric model is generally the most popular and accepted theory than others because it is relatively simple and it has provided a scientific basis as a decision making model.

Cultural Theory - the cultural theory is based on the work of Douglas and Wildavsky (1982) who view risk from the anthropology and sociology perspectives. The theory spells out that there are 4 types of social structures and people would choose to be concerned with different types of hazards.

- Egalitarians: they will concern with technology and environment
- Individuals: they will concern with wars and other threats to the markets
- Hierarchists: they will concern with law and order
- Fatalists: they will concern with none of the above

Within each social group, there are social constraints and solidarity which limit individual negotiation and outlook on risk; which in turn means that there is less personal choice. It is for this reason that the Cultural Theory is not widely pursued by researchers.

With regard to demand for risk mitigation, Sjöberg, L., (2000) found that it is related most strongly to the seriousness of the consequence of a hazard, not on how risky of an activity; whereas perceived risk is mostly related to the probability of an accident.

2.4 Risk tolerance

In order to tackle a risk issue, it is imperative to establish an acceptable risk criterion. In terms of fire safety problem, the likely criterion will be on the extent of property loss, injury or fatality. It is perfectly alright to quantify property loss by dollar value. However, people may be reluctant to define human loss in dollar terms because it may inevitably lead people to relate human life to his earning capability. In doing so, the less-privileged group would become valued less and this would lead to unnecessary embarrassment and argument. Neither would it be comfortable for a fire officer to put down the death toll as the acceptance criterion on a performance-based code.

The tolerability of risk is also influenced by how the risk is expressed and assessed (Meacham, 2004b). As an example, the annual number of fires occurred in the entire building stock would be very different from the annual number of fires occurred in various types of occupancies. Individual would be misled to tolerate on the risk figures if such are not clearly communicated to them.

In addition, the risk tolerance of individual depends largely on their perceptions of risk. Covello and Merkhofer (1993) have pointed out the following factors which affect the perception of risk:

- Familiarity - unfamiliar risks tend to be weighted more heavily than familiar risks.
- Understanding - poorly understood risks tend to be weighted more heavily than well-understood risks.

- Scientific uncertainty - risks with high scientific uncertainty tend to be weighted more heavily than risks with low scientific uncertainty.
- Controllability - risks perceived as not under personal control tend to be weighted more heavily than risks perceived to be under personal control.
- Voluntary nature - risks perceived as being imposed involuntarily tend to be weighted more heavily than risks perceived as voluntarily assumed.
- Sympathetic nature of exposed population - risks perceived as falling on particularly vulnerable and sympathetic populations tend to be weighted more heavily than risks perceived as falling on other populations.
- Dread - risks perceived as involving a particular painful or horrible form of harm tend to be weighted more heavily.

While it is very repugnant to specify the absolute fire risk level, Wilson (1984) has relayed the data from the Royal Commission on Environmental Pollution of UK which devised a list of risks and argued that a probability of $1x10^{-6}$ death for an individual per year is usually acceptable. Probably the British Standards Institution is the only institution to suggest 10^{-5} death per year at home, or 10^{-6} death per year elsewhere as a reference order for individual risk acceptance criteria (BSI, 2003b). The figures are derived from the current fire losses in the UK and on the premises that the public broadly tolerates the average risk of death from fires provided that the number of death in any one incident is small. For multiple fatality fires, societal risk of 10^{-8} death per occupant per year with 10 or more fatalities, and 10^{-9} for 100 or more fatalities are further suggested in the document. However, it should be born in mind that the authority having jurisdiction is unlikely to accept the absolute criteria unless the result of the analysis demonstrates that the potential death figure is significantly lower.

2.4.1 De Minimis risk and As Low As Reasonably Practicable (ALARP)

While it would be a dilemma to establish a hard line for acceptable risk, it is recognized that there is a certain threshold level of risk which may be tolerated in reality. This is the concept of *de minimis* risk (from the Latin "the law does not concern itself with trifles"), which means the risks below which need not be concerned.

Above the *de minimis* threshold, there is an approach to accommodate risk within a region of "As Low As Reasonably Practicable" (ALARP) within the risk range (e.g., BSI, 2010). As shown in the "carrot" diagram Figure 2.1, the ALARP region is some where lying between the two extremities of risk level. At the upper limit, it represents the risk beyond that it will not be accepted. On the other hand, the lower limit represents the risk below that it is broadly tolerable. Within the ALARP region, the upper end of the risk level would be tolerated if risk reduction is impracticable or if its cost is grossly disproportionate to the improvement gained; and the lower end of the risk level is tolerable if the cost of reduction exceeds the improvement gained. From the pragmatic and commercial point of views, the risk should always be brought towards the lower part of the ALARP region based upon cost benefit analysis.

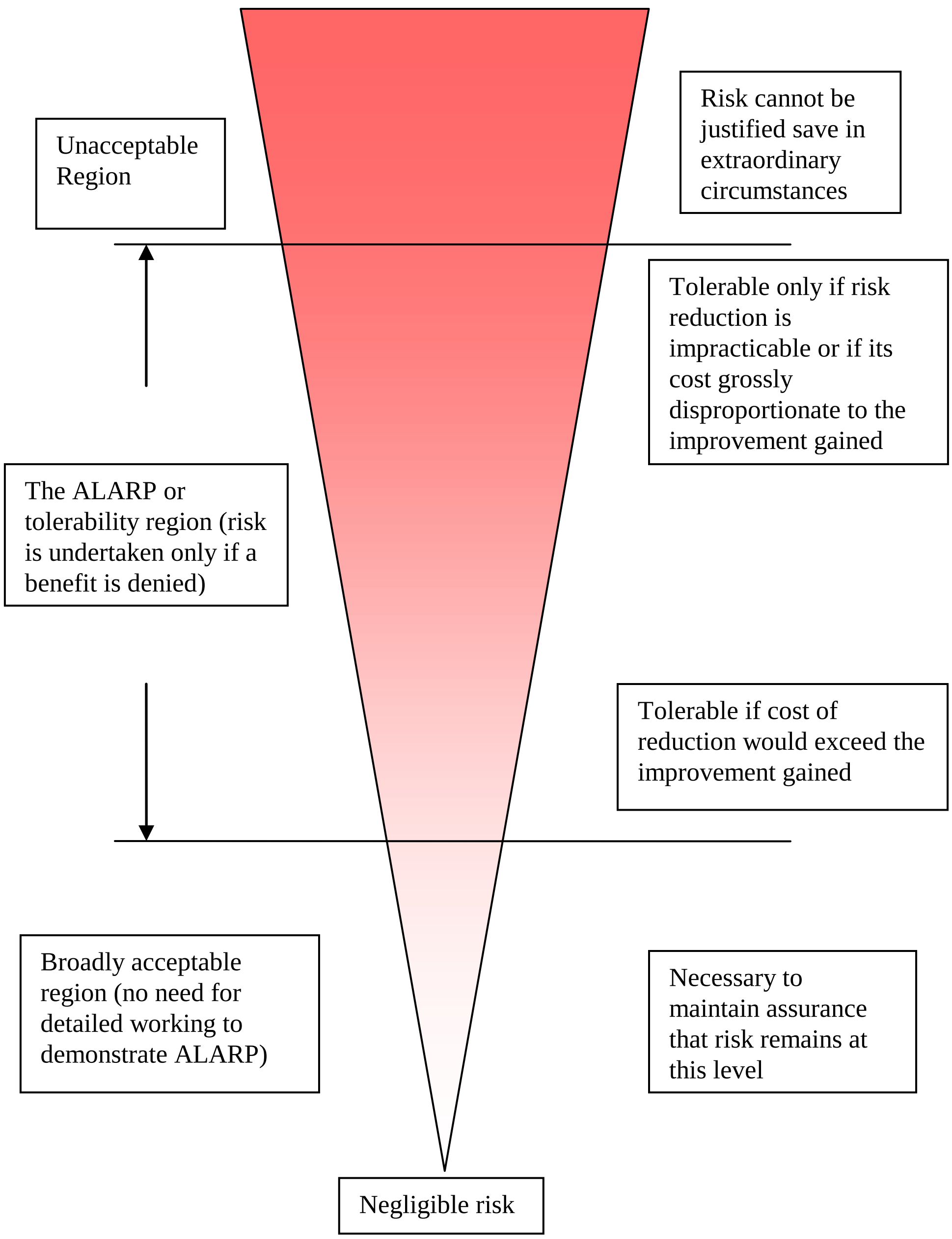


Figure 2.1 The ALARP concept (BSI, 2010)

2.4.2 Comparative approach to risk tolerance

Sometimes, it may not be easy to define the risk acceptance level quantitatively or in an expressly manner. A comparative approach could be adopted which would utilize some accepted risks in the past or for similar buildings which bear similar nature to the current hazard under consideration (e.g. Hadjisophocleous and Fu, 2004). For instance, the risk level in the prescriptive fire code can be used as the baseline against which an alternative design is developed on a performance basis (e.g., Zhao, 2000).

2.5 Individual Risk vs. Societal Risk

Before proceeding with any risk analysis, it is necessary to understand the distinct difference between Individual Risk and Societal Risk. Individual Risk is defined as the fire risk limited to consequence experienced by an individual and based on the individual's pattern of life. It is independent of the number of persons affected and can be expressed as the probability per year for an individual of being subjected to a fire.

The Societal Risk is defined as the fire risk combining consequences experienced by every affected person and group (ISO, 2005). This is concerned with multiple fatalities of the community and the risk is viewed from the society's perspective. Very often, the societal risk is described by the exceedance curve of the probability (i.e., the cumulative frequency or probability) of the event and the consequence of that event in terms of the number of fatalities. The curve is commonly known as the FN curve (i.e. frequency number curve).

In Hong Kong, a Risk Guideline has been suggested by the Planning Department (Planning Department, 2008) for the construction of Potentially Hazardous Installation (PHI), which is an installation storing hazardous material in quantities greater than a specified threshold quantity. A typical example is a liquefied petroleum gas compound serving a housing estate. The guideline requires that the maximum level of off-site individual risk associated with a PHI should not exceed 1 in 100,000 per year, i.e., 1×10^{-5} death per year.

The acceptability of societal risk is judged against the frequency and number of deaths of potential incidents at the PHI. In order to avoid major disasters resulting in more than 1,000 deaths, there is a vertical cut-off line at the 1,000 fatality level extending down to a frequency of 1 in a billion years. An intermediate region is also incorporated in the guideline in which the acceptability of societal risk should be reduced to a level which is "as low as reasonably practicable". It seeks to ensure that all practicable and cost-effective measures which can reduce risks will be considered.

While the guideline is not intended for fire safety of buildings, it can give a feel on the risk level that can be tolerated by the local community. The risk tolerance figures can be compared with those referenced in the literature. Wolski et al. (2000) has prepared a summary of the mean accepted risk level for various risk factors compiled by previous research workers. The assumed risk to life from fire in an office building can be described as: uncontrollable, catastrophic, immediate, man-made, voluntary and old (i.e. common) and the acceptable level is 1×10^{-6} death per year. This is broadly of the same order of magnitude of 1.5×10^{-6} death per year as recommended by the British Standards Institution (BSI, 2003b).

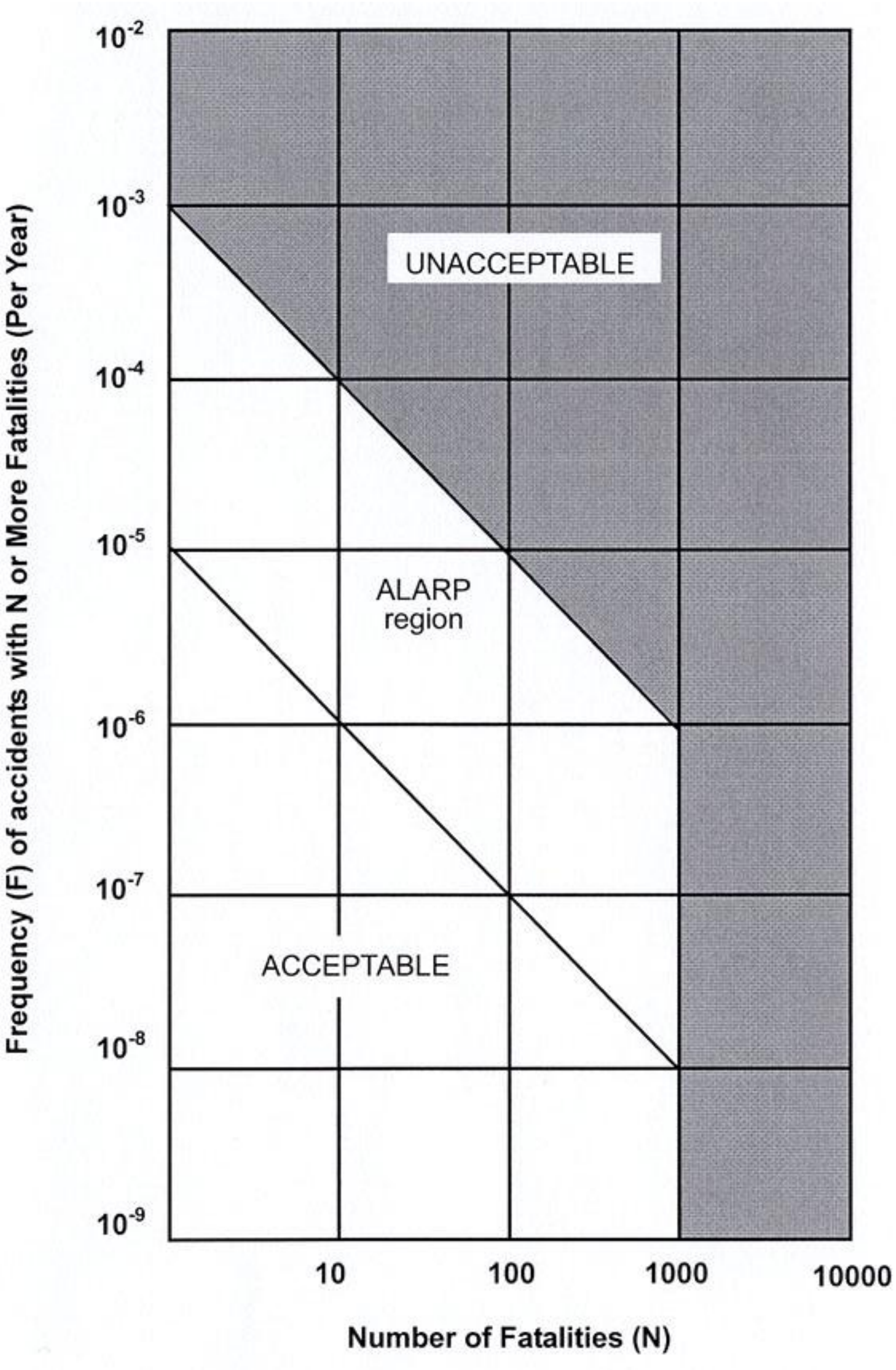


Figure 2.2 Risk Guideline for PHI extracted from Hong Kong Planning and Standards Guide (Planning Department, 2008)

2.6 Fire risk assessment methodology

Fire risk management is one of the elements of containing risk for a building or facility of an organization. In line with other risk management practice, the process includes risk assessment, risk treatment, risk acceptance and risk communication. The process can be described by the flow chart in Figure 2.3 (ISO, 2005).

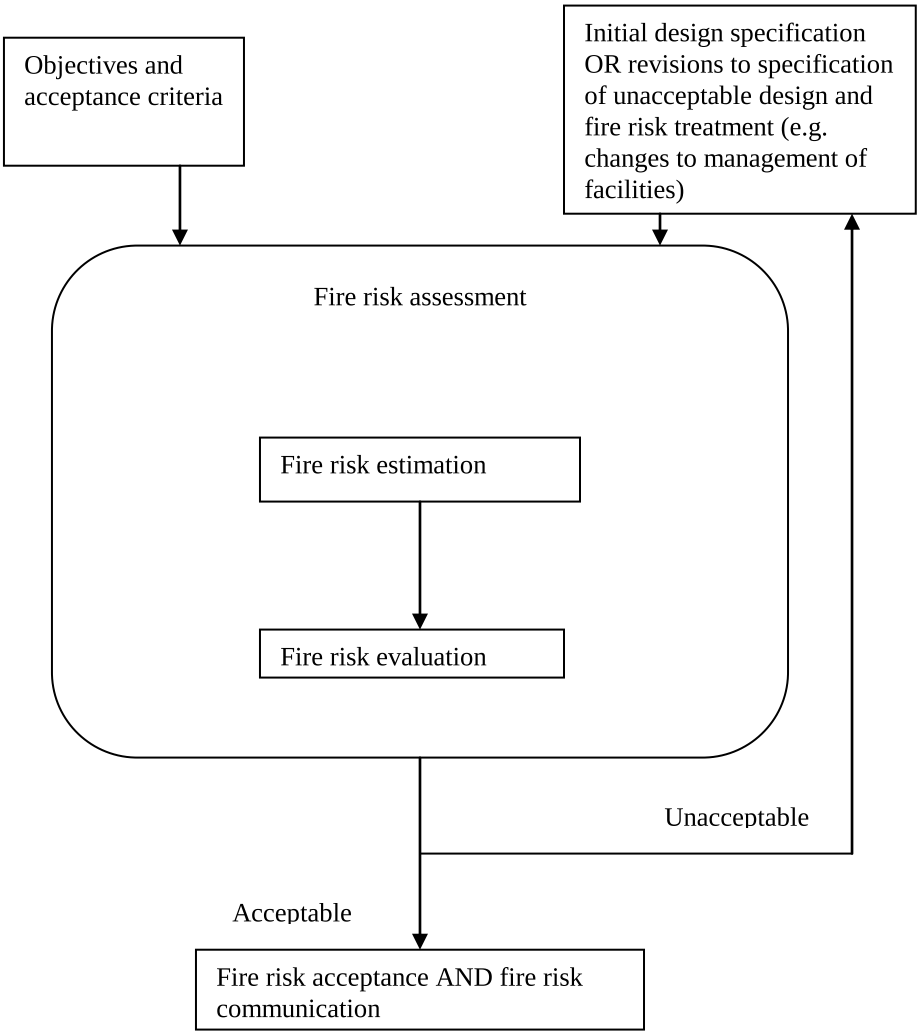


Figure 2.3 Fire risk management flow chart (ISO, 2005)

On its own, fire risk assessment can be defined as the "well-defined procedure for estimation of the fire risk associated with a building design, other design, or other subject of study, and for evaluation of the estimated fire risk in terms of a well defined criterion of acceptable risk (ISO, 2005). As denoted in the flow chart, the fire risk assessment procedure is pivotal to the entire fire risk management system. While there may be a variety of fire risk assessment methodologies, Frantzich (1998) suggested that in the chemical industry, risk analysis can be grouped into 3 levels namely Qualitative, Semi-quantitative, and Quantitative. This classification is also adopted by the SFPE in the recent publication "SFPE Engineering Guide to Application of Risk Assessment in Fire Protection Design" (SFPE, 2005).

2.6.1 Qualitative fire risk assessment

The qualitative approach is by far a quite simple approach which is based upon experiential judgement on the analysis of risk and the determination of an acceptable level of risk. It may take the approach of narratives or checklists which primarily focus on the hazard identification without emphasis on the probabilities or consequences of the events. The assessor can use a checklist to identify the presence of various fire hazards such as storage of excess amount of flammable substance but the relative importance of each hazard is not addressed. For example, Hassanain and Hafeez (2005) proposed a check list of 66 items for fire risk assessment survey of restaurants. The survey items are grouped under five main divisions including causes of fire, fire detection system, fire suppression system, evacuation systems, and management and maintenance measures. However, the assessor could only identify the presence of those items and give a recommendation as per accepted safety practice but the checklist fails to aid as a risk-informed decision tool. Probably the major advantage is that it can be used by a trained person and detailed and cumbersome assessment which requires the help of experienced experts is not entailed.

An enhanced qualitative approach could be developed by incorporating a fire risk matrix. In Figure 2.4, the matrix is drawn with consequence on one axis and the likelihood of the hazard occurring on the other axis. The matrix may be even set up with weighting factors to the consequences, or may be symmetrical, depending on the application and complexity of the facility. Inside each cell, the risk level may generally be classified as Low, Moderate, or High corresponding to the probability and the consequence ratings by reference to the past fire incidents or institutional corporate risk strategy. The levels of risk may be linked to decision rules such as management attention or the time scale within which crisis response is initiated. For instance, the fire risk of the district substation of an electricity supply undertaking would be ranked as High because the company cannot afford to have district wide power outage to its customers which obviously will attract extensive media coverage. Some people would consider the process as a first step of risk assessment such that detail quantitative study would be conducted to those hazards which are found to be of “High” risk. Sometimes, it may also be deemed as a semi-quantitative method if numerical grading be awarded to the risk parameters.

		Consequence Rating			
		Negligible	Marginal	Critical	Catastrophic
Probability Rating	Frequent	*Moderate*	High	High	High
	Probable	*Moderate*	*Moderate*	High	High
	Occasional	Low	*Moderate*	*Moderate*	High
	Remote	Low	Low	*Moderate*	High
	Improbable	Low	Low	Low	*Moderate*
	Risk Level				

Figure 2.4 Fire risk matrix (adapted from NFPA (2003) pp. 3-162)

Some typical examples of the probability levels and the consequence categories are also suggested by NFPA (2003) and reproduced in Table 2.1 and 2.2 respectively.

Table 2.1 Probability (p) Levels, adapted from NFPA (2003) pp. 3-162

Frequent	Likely to occur frequently or experienced ($p > 0.1$)
Probable	Will occur several times in system life ($p > 0.001$)
Occasional	Unlikely to occur in a given system operation ($p > 10^{-6}$)
Remote	So improbable that it can be assumed this hazard will not be experienced ($p < 10^{-6}$)
Improbable	Probability of occurrence cannot be distinguished from zero ($p \sim 0.0$)

Table 2.2 Consequence Categories, adapted from NFPA (2003) pp. 3-162

Negligible	The impact of loss is so minor that it has no discernible effect on the facility or its operations.
Marginal	The loss has a noticeable impact on the facility. The facility may have to suspend some operations briefly. Some monetary investments may be necessary to restore to full operations. May cause minor personal injury.
Critical	The loss will cause personal injury or substantial economic damage. Loss could not be disastrous, but the facility would have to suspend at least part of its operations.
Catastrophic	The loss produces death or multiple death or injuries, or the impacts on operations are disastrous, resulting in long-term or permanent closing. The facility ceases to operate immediately after the fire occurred.

Most of the current practices relating to fire safety are based upon a qualitative assessment of risk and the formulation of measures necessary to mitigate them. In order for an assessor to assess the risk qualitatively, the categorization suggested by the Fire Precautions (Workplace) Regulations 1997 UK can be used for this purpose as shown in Table 2.3.

Table 2.3 Qualitative Risk Categorization

Qualitative Risk Categorization	
Low	Areas where there is minimal risk to persons' lives, where the risk of fire occurrence is low, or the potential for fire, heat and smoke spreading is negligible and people would have plenty of time to react to an alert of life.
Normal	Areas where an outbreak of fire is likely to remain confined or spread slowly with an effective fire warning allowing people to escape to a place of safety.
High	Areas where the available time needed to evacuate the area is reduced by the speed of development of a fire, e.g. highly flammable or explosive materials stored or used in bulk quantities; also where the reaction time to the fire alarm is slower because of the type of persons present or the activity in the workplace, e.g. where elders, physically impaired persons staying or people sleeping in the premises etc.

The above categorization is a simple technique and is subjective in some cases. Proper formal training should be provided to the assessor to avoid ambiguity during the assessment. The major shortcoming of such approach is that the reality of complex fire problems may be ignored, and the evaluation could only give indication on the degree of risk in the broad sense.

2.6.2 Semi-quantitative fire risk assessment

Semi-quantitative fire risk assessment method usually takes the form of point system, numerical grading or risk ranking system in prioritizing the risk level of different buildings. While the assessment is not undertaken in a very extensive manner, the approach will give an assessment on the various contributing risk factors and the calculation results will give a more robust comparison on the relative level of risk than qualitative assessment.

Since such assessment is applied mainly on the relative or comparative risk of buildings, it can be used even where there is no statistical fire data on the occupancy. In addition, the introduction of explicit safety factors is not necessary as uncertainties in the base design and alternative design will balance out during the course of analysis.

The semi-quantitative fire risk assessment methods are relatively simple to use. Four typical assessment techniques are further outlined below.

2.6.2.1 The Point Scheme

Marchant (1982) had proposed a point scheme to assist administrators in allocating resources to maintain an acceptable level of risk for patient wards within hospitals. The scheme requires the identification of fire safety components and the assignment of percentage contribution values such that the gross percentage of all identified components can be aggregated. Using this scheme, a maximum score of 100% is possible which means perfect fire safety. It is then possible to set level of fire safety which must be attained with reference to acceptable norm or statutory requirements. Alternatively, the improvement works among hospitals can be prioritised based on their respective points scored.

2.6.2.2 The Gretener Method

The Gretener Method was developed in the 1960s in Switzerland primarily for the insurance industry as a risk ranking system (Watts, 1995). In the system, there are 5 risk factors to be considered as shown in the following equation:

$$R=(PxA)/(NxSxF) \tag{2.1}$$

where R is the overall Risk,

P is the potential hazard,

A is the activation or ignition hazard,

N is the normal protection measures,

S is the special protection measures,

F is the fire resistance of the structure.

In essence, the risk level is calculated based on the 2 contributing risk factors in the nominator and the 3 positive factors in reducing the risk in the denominator. The higher the value of R, the higher will be the overall risk level. Where the risk level for a building is calculated to be less than or equal to 1.3, it is considered as acceptable.

2.6.2.3 The Fire Safety Evaluation Method (FSES) or Fire Risk Index Method

In USA, the “Life Safety Code” (NFPA, 2009) is the authoritative code for fire safety design of buildings. In order to evaluate an alternative design which would achieve an equivalent level of fire safety, the National Institute of Standards and Technology (NIST) developed the FSES (NFPA, 1998) in the 1970s which is a multi-attribute evaluation method to determine the relative safety levels among design options. Originally, the FSES was developed for health care facilities. In its present form, the system further includes other occupancies including correctional facilities, board and care homes, and business occupancies as well.

The system is developed on the assumption that a relatively small number of factors account for most of the fire protection problem. Under the FSES, there are a number of fire safety parameters which are accorded with different points depending on their positive or negative effects to fire safety. The parameters for each of the 4 occupancy types are extracted and shown in Table 2.4. The resulting score of a design option is obtained by summing up the respective points of those parameters. The manipulation is quite easy to arrive at the risk ranking of the design. An alternative design can be considered “safer” if the total score is higher than that of a base design.

Table 2.4 Fire Safety Evaluation System for different occupancies (NFPA, 1998)

Occupancy Type	**Safety Parameters**
Health Care Facilities	1. Construction
	2. Interior Finish (Corridors and Exits)
	3. Interior Finish (Rooms)
	4. Corridor Partitions/Walls
	5. Doors to Corridor
	6. Zone Dimensions
	7. Vertical Openings
	8. Hazardous Areas
	9. Smoke Control
	10. Emergency Movement Routes
	11. Manual Fire Alarm
	12. Smoke Detection and Alarm
	13. Automatic Sprinklers
Detention and Correctional Facilities	1. Construction
	2. Hazardous Areas
	3. Fire Alarm
	4. Smoke Detection
	5. Automatic Sprinklers
	6. Interior Finish (Corridor and Egress)
	7. Interior Finish (Other Areas)
	8. Cell/Sleeping Room Enclosure
	9. Separation of Residential Housing Areas from Other Areas
	10. Exit System
	11. Exit Access
	12. Vertical Openings
	13. Smoke Control
Board and Care Occupancies-Apartment Building	1. Construction
	2. Hazardous Areas
	3. Manual Fire Alarm
	4. Smoke Detection and Alarm
	5. Automatic Sprinklers
	6. Separation of Board and Care Home Unit and its Exit Route from Other Spaces
	7. Exit System
	8. Exit Access
	9. Interior Finish
	10. Vertical Openings
	11. Smoke Control
Business Occupancies	1. Construction
	2. Segregation of Hazards
	3. Vertical Openings
	4. Sprinklers
	5. Fire Alarm
	6. Smoke Detection
	7. Interior Finish (Exit Routes and Rooms/Suites)
	8. Smoke Control
	9. Exit Access
	10. Exit System
	11. Corridor/Room Separation (Compartmentation)
	12. Occupant Emergency Programme

Another variation or enhancement of the FSES can be found in the risk indexing for historic buildings (Watts, 2001). This approach is still a multi-attribute evaluation method which recognizes that there are varying levels of weighting factors for each fire risk factors. The evaluation scheme can be represented by the following equation:

$$E(x_1,\ldots x_i,\ldots,x_n)=\Sigma w_i R_i(x_i) \tag{2.2}$$

where $E(x_1,\ldots x_i,\ldots,x_n)$ is the evaluating function for the set of parameters x_1 to x_n ,
w_i is the respective weighting factors,
$R_i(x_i)$ is the normalizing functions of the attributes' grades.

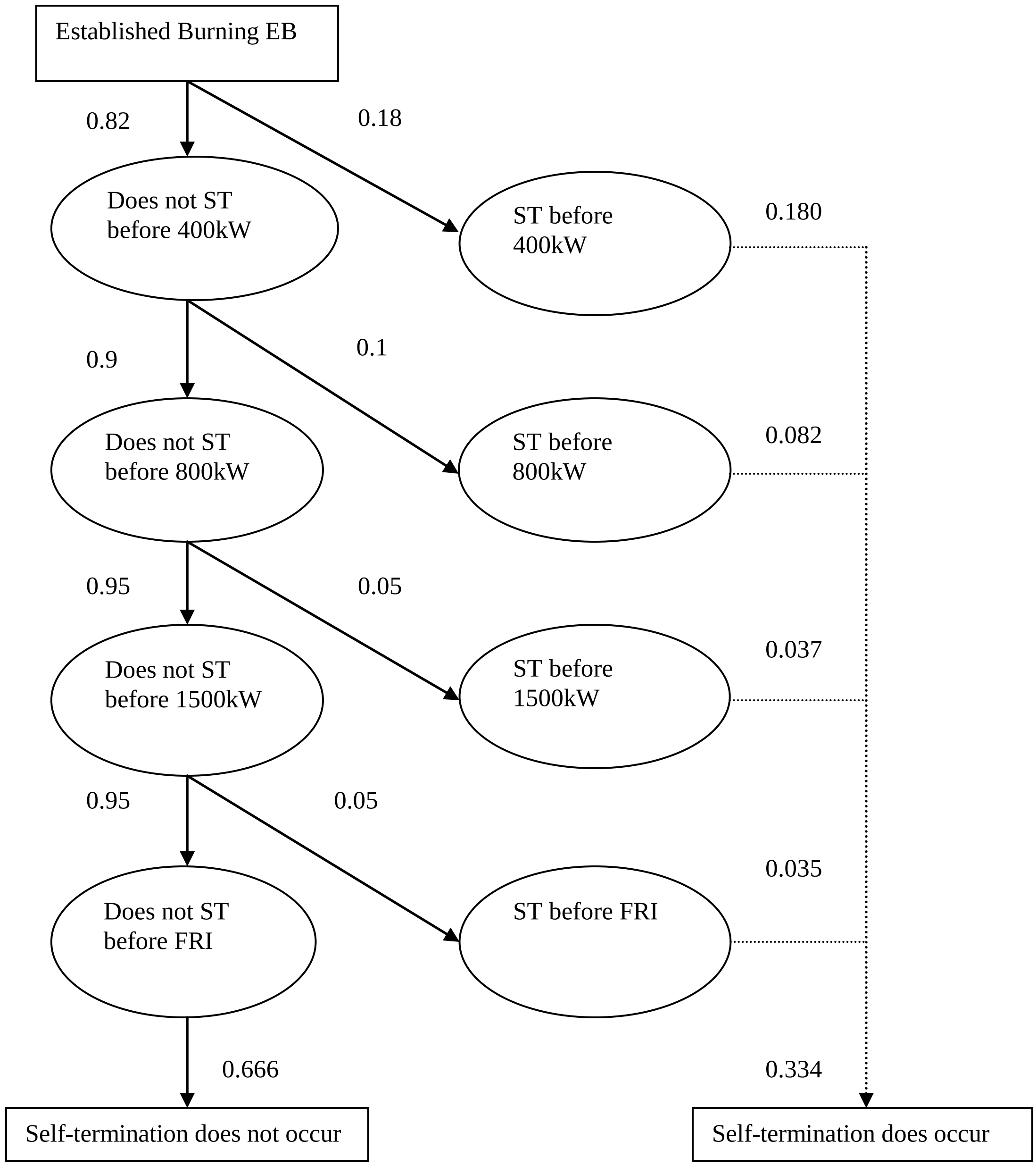
The parameters can be chosen through examination or reference to other risk indexing methodologies or other prescriptive codes. On the other hand, the weighting factors can be developed through an expert panel utilizing established decision making techniques such as Delphi technique (Harmathy, 1982, 1986). More advanced decision making technique such as Analytical Hierarchy Process (AHP) can also be adopted in ascertaining the weighting factors (Meacham, 2004a).

In a local example, Lo (1999) also suggested a system of fire risk ranking with the fire safety attributes developed by extracting the prescriptive requirements of relevant fire codes. Fuzzy set principles are adopted in compiling the questionnaires during the opinion elicitation process. The relative weighting factors are developed by professional judgement on linguistic scores before being converted to numerical values. The risk ranking framework can be used to aid judgement on the priority of fire safety improvement works accorded to existing buildings.

2.6.2.4 Building Fire Safety Engineering Method (BFSEM)

Most of the "Building Fire Safety Engineering Method" (BFSEM) was developed at the Worcester Polytechnic Institute in the USA led by Professor R.W. Fitzgerald (Wade and Whiting, 1997). It is a kind of semi-quantitative fire risk assessment method using a probabilistic risk assessment approach but without consideration on the consequence. The model is developed to evaluate fire safety from the onset of established burning (EB) such as a flaming fire from a basket waste paper. Quantitatively, EB can be defined as a fire having a flame size of 20kW, i.e. about a flame height of 250 mm. It is difficult to predict the behaviour of fires below 20kW because a lot of factors will affect the initial combustion characteristics (Fitzgerald, 2004, pp. 21). Intuitively, EB will continue so long as sufficient fuel is present and there is adequate ventilation.

The fire risk analysis is usually conducted by means of continuous value network (CVN) and single value network (SVN) diagrams exemplified by Figure 2.5 and 2.6 respectively. In the CVN diagram, the development of the fire from EB to various stages of heat release rate is shown as a chain of outcomes. In turn, each stage of fire development can be described by a SVN diagram to show the snap shoot of incidents leading to that particular stage of heat release rate such as the SVN diagram under automatic sprinkler suppression mode in Figure 2.6.



Legend:

EB: Established burning

ST: Self-termination

FRI: Full Room Involvement, i.e. flashover has occurred

Figure 2.5 Continuous Value Network Diagram of Established Burning (adapted from Wade and Whiting, 1997)

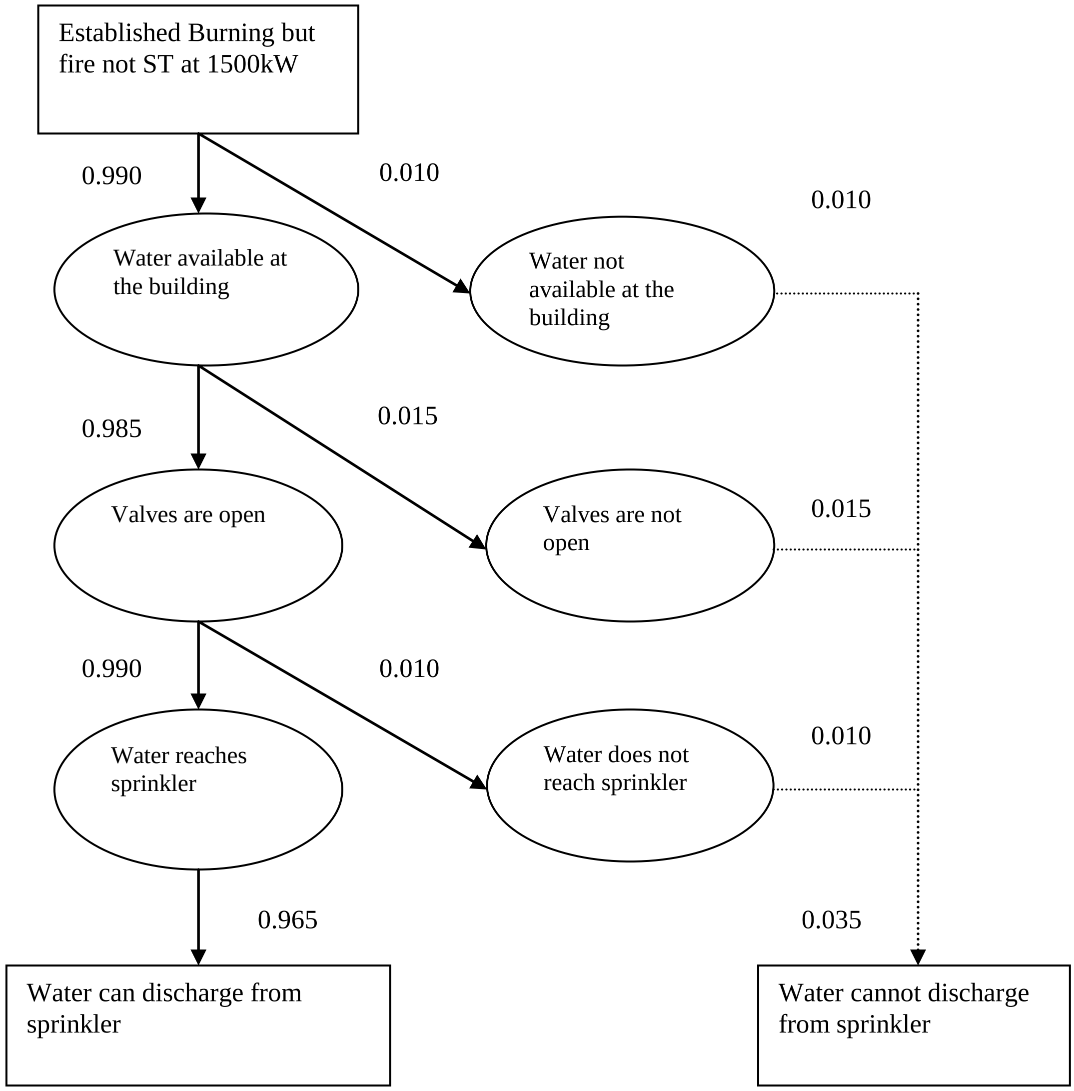


Figure 2.6 Single Value Network Diagram of Automatic Suppression by Sprinkler (adapted from Wade and Whiting, 1997)

The BFSEM model will consider the probability of fire self-terminating (I), automatic suppression (A) and manual suppression by the fire services (M). The subjective probabilities are to be estimated and entered by the analyst in the SVN diagrams of I, A and M to indicate the probability of self-terminating when the fire grows to different sizes under different snap shoots. The probabilities of these 3 elements are then combined to form the probability of confining the fire to defined areas (L) such as the room of fire origin under various fire sizes using another SVN. Finally, a CVN is constructed to show the probabilities of confining the fire under various stages of fire sizes. These probability values against increasing fire sizes can be drawn as an L curve for better visualization. The risk assessment is carried out by comparison among the L curves of the alternative design options.

The model can be further enhanced to provide analysis on life safety by incorporating a smoke curve Sm (Fitzgerald, 2004, pp. 329). The Sm curve describes the fire safety performance in maintaining tenability such as visibility or concentration of toxic species of a target space which is a space of concern for life safety. To construct the Sm curve, we need to consider whether enough smoke reaches the boundary of the target space and whether enough smoke has penetrated and accumulated inside the target space to render it untenable under a progressing time step as per Figure 2.7.

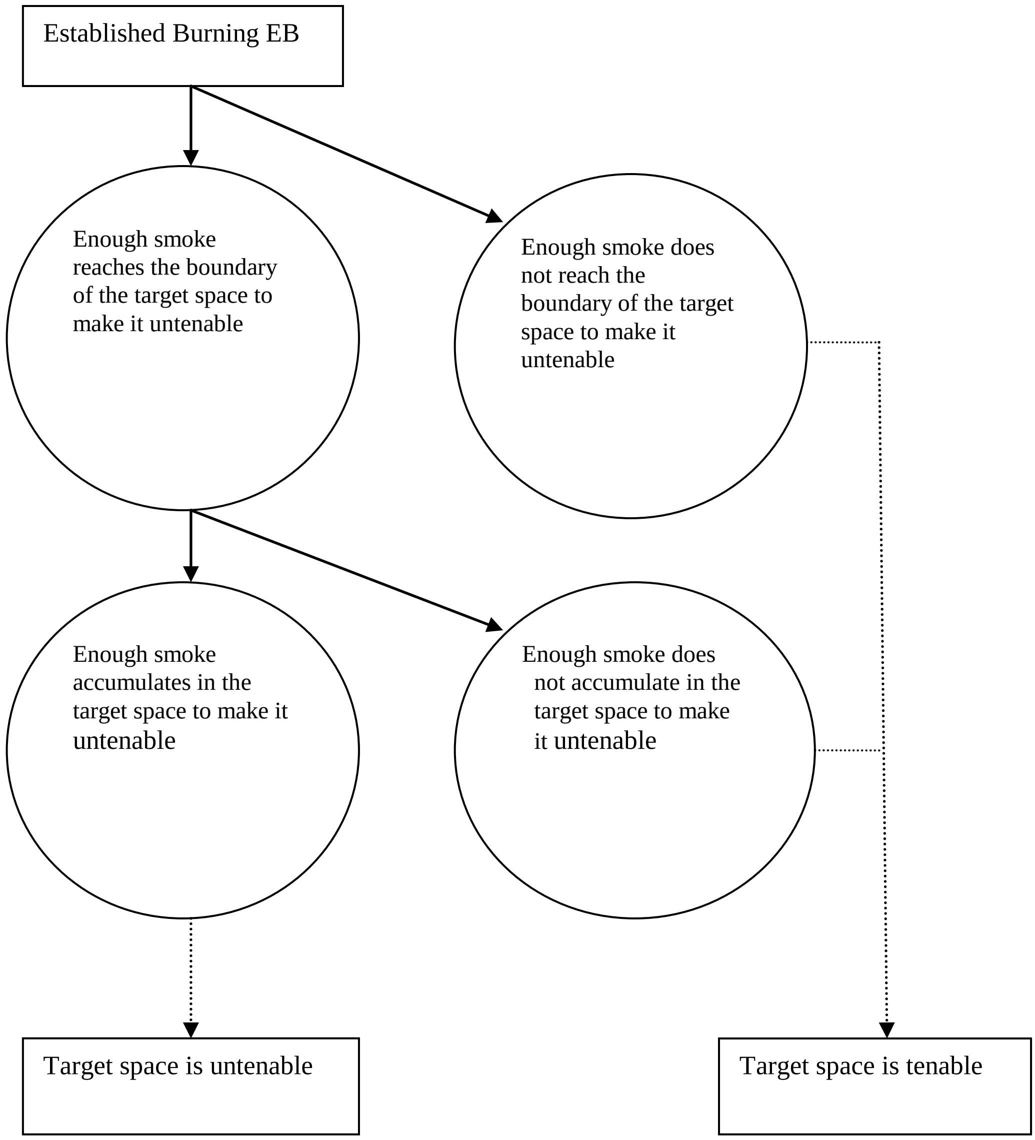


Figure 2.7 Single Value Network Diagram of Smoke Analysis (adapted from Fitzgerald, 2004)

For each of the time step chosen, the fraction of the smoke generated that reaches the target space boundary and further accumulates in the target space will be evaluated by deterministic methods. The analyst will need to exercise his judgements on assigning the subjective probabilities that the target space will remain tenable at each time step. The success probabilities in maintaining the target space tenable can be plotted on a time scale to form the Sm curve.

Although the BFSEM provides a systematic approach in assessing fire safety performance, it relies heavily on the users who are required to have in-depth knowledge on fire safety engineering and fire dynamics for exercising engineering judgement on the subjective probabilities. The method will become quite tedious for complex buildings and computer programme is necessary to carry out the analysis.

2.6.3 Quantitative fire risk assessment (QRA)

Quantitative risk assessment method; which is also described as Probabilistic Risk Assessment (BSI, 2003b); is by far the most extensive and labour intensive methods which utilize the probabilistic approach to estimate the risk based on the following formula:

$$\text{Risk} = \Sigma(P_i \times C_i) \qquad (2.3)$$

where Σ represents the summation of all probable fire scenarios,

P_i is the probability of occurrence of a fire scenario,

C_i is the consequence of that fire scenario.

Originally, QRA was developed for risk assessment in the chemical industry. Though not too popular, the principle can be equally applied for building fire safety engineering. The risk calculation formula is in essence a weighting of the consequence of a hazard by its frequency of occurrence. A hazard with a high frequency of occurrence and low consequence will bear a similar risk level to a hazard with low frequency of occurrence but high consequence. This is a way to normalize different hazards so that they can be compared on a common ground. QRA provides very detail information of the risk nature and is very useful to aid decisions. Moreover, such approach tackles the analysis of all scenarios in a holistic manner.

Frantzich (1998) further introduced an extended QRA concept to take care of the uncertainties of the scenarios. The probability and the consequence of each scenario are treated as a distribution function. The estimation of the risks are repeated for the standard QRA for a large number of times with the probability and consequence variables taken randomly according to Monte Carlo sampling technique. The extended QRA can be presented in a way to express the degree of certainty of an average risk profile by specifying the confidence intervals.

2.6.4 Estimation of fire risk

In any fire risk estimation process, the two parameters probability and consequence must be known for each hazard in order to calculate the fire risk. There are three common methods to evaluate the probability and consequence of an event, namely, past fire statistics, mathematical model, and engineering judgement.

- Past statistics - Past fire records and statistics provide a good reference point for the probability of fire occurrence in different occupancies as well as the severity of the consequence. This is actually a form of "frequentist" approach to probability estimation. Nevertheless, it requires that a detail fire statistical record be available such that the data can be used for risk calculation. Unlike USA where there is a computerized National Fire Incident Reporting System (NFIRS), the immediate data available from the local FSD are only the count of number of fires and casualties, and the classification of fire causes by types and occupancy. No details on fire damage or rooms of fire origin are available. Probably, further refinement by FSD on the reporting system after putting out a fire is necessary, in order that more fire statistical data can be generated for future application of the QRA.

- Mathematical models - Very often, the fire data for a specific type of occupancy may not be readily available. Moreover, the reliability and failure rate of plant and equipment may be out of record. In this case, the event tree and fault tree may be constructed to model the event and hence to develop the required probabilities. Since the calculation of the probabilities of the top event depends on the conditional probabilities of events down the fault tree, the probability value of the top event may still depend on the reliability of other secondary data under such circumstances.

  On the other hand, there are deterministic computer models (SFPE, 2008) already developed to estimate the consequence of fire development, smoke movement, structural response and evacuation times. They can also predict the time to untenability.

  The major advantage of using model is that it provides an estimate based on a rationalised method. Any change in the design can be re-assessed logically and systematically by fresh input to the model again for tracking the effect of change.

- Engineering judgement - Engineering judgement is defined as the process exercised by a professional who is qualified by way of education, experience and recognized skills to complement, supplement, accept or reject elements of a quantitative analysis (BSI, 1999; Australia Building Code Board, 2005). In the case of fire risk assessment, the qualified fire safety engineer or building services engineer has a key role to play in presenting the data and hence the analysis of the results based on his professional expertise in the application of the risk assessment technique. Typically he should have the sense on the likely range or order of magnitude of the variables and outcomes, and the probable chances of occurrence of the events, the severities and the potential consequences. The judgement is primarily built upon the professional experience and exposure of the engineer.

Nevertheless, there may be some pitfalls when utilizing engineering judgement in determining the probabilities. For instance,

- Individuals will tend to underestimate low probabilities while overestimating high probabilities. That is, very low probabilities will be estimated as zero, and very high probabilities will be estimated as one or nearly one.
- Individuals will tend to misestimate unique or high hazard events, treating them as impossible (probability zero) if they have never occurred and as

more likely than they really are if they have ever occurred, particularly if they have occurred recently.

- Individuals will tend to treat conditions that are not independent as if they were independent, which means treating conditional probabilities as if they were unconditional.
- Redundant systems may not significantly increase reliability as much as individuals assume. For instance, even where multiple sprinkler systems are installed, a deficient water supply or improper maintenance techniques may compromise operation of all systems. System reliability can be a complex function of component reliability, and individuals are not equally skilled at estimating human-error reliability and mechanical reliability.

In order to improve the credibility of the decision through engineering judgement, a panel of experts can be deployed in the elicitation process such that individual bias on the chance variables or experiential exposure could be minimised. The "Delphi Method" (Harmathy, 1982), which is a structured and formalized procedure, is frequently used to make decisions on subjects involving variables of statistical nature and hence the discipline of fire science. The Delphi procedure have three features namely anonymity, controlled feedback, and statistical group response. After several rounds of the exercises, the spread of opinions amongst individual experts can be narrowed to the extent that can be used for analytical decision.

2.6.5 Evaluation of fire risk

Once the fire risk has been calculated, the risk level is to be evaluated against some established acceptance criteria, or to be compared amongst various design options.

This is the key and concluding step of the entire fire risk assessment process and to communicate on the acceptance of the design scheme, or to modify the fire safety strategy. The revised design option will be repeated for the risk estimation process so as to ensure an acceptable level of risk is achieved.

In fire risk assessment exercise for existing facilities, the evaluation process would even give advice to the senior management or owner on the next course of action. Should the fire risk level is found to beyond tolerability, such risk can either be further reduced through the implementation of mitigation measures, or procurement of additional fire insurance cover to transfer part of the risk.

2.7 Limitation of fire risk assessment techniques

Fires in buildings are complex and dynamic in nature. Fire risk assessment is by no means an easy task. As pointed out by Brannigan et al., (1996), risk models have a number of inherent limitations:

- Predictive uncertainty increases as the system becomes more complex.
- Retrospective analysis may not be able to give us adequate information as to the range of potential disaster paths.
- Safety factors for coping with risk have limited value in an environment in which the disaster path is not well understood.

Despite the above, fire risk assessment when properly applied and documented by a qualified professional does provide a rational analysis to the fire safety problem. It would also provide a feasible solution especially on a comparative basis.

2.8 Fire safety evaluation of existing buildings

For the design of new buildings, risk assessment (typically QRA) can be used as an approach to compare several design options for equivalency, or to obtain a balanced design among the various fire safety strategies, or to aim at a cost-effective design (Cornelissen, 1996).

However, the situation is quite different for risk appraisal of existing buildings. The setting of the acceptance datum is always one of the major challenges. If the building is constructed many years ago, it is inherent that the building would not satisfy the present day prescriptive codes. It may not be reasonable to demand the owner to upgrade the existing building to the current requirement standard. There are always technical and resources constraints in carrying out alteration works. This is especially the case for large organizations managing a range of estates exemplified by the HKHA; or other large companies owning diversified rental properties. The risk ranking assessment to a portfolio of properties for prioritizing the improvement programme could be one of the alternatives. As pointed out by Stollard (1993), "additional hardware might not always be the most cost effective way of improving fire safety in a particular building, it might be far more safe and cost efficient to simply revise the management practices or re-examine the buildings utilization". It is essential that the balancing of risks and safety precautions in existing buildings be undertaken properly.

2.9 Choice of risk assessment methods

In order to conduct a fire risk assessment efficiently, it is imperative to select an assessment method within the options available. The fundamental considerations on the choice of risk assessment methods should be based on:

- The objectives of the study - The objectives of study will have a direct bearing on the choice of risk assessment method. If a prioritization process among different risks is required, it would be sufficient to conduct a qualitative assessment. Otherwise, a quantitative approach should be used.
- The need of the decision makers - If a good deal of risk details on the consequence is required for decision making, obviously the quantitative technique using event tree and fault tree analysis is the right choice.
- The type and range of risks being analysed - The qualitative approach is usually suitable for in-house fire risk assessment of corporations seeking to mitigate the risks. For fire safety design of buildings, the semi-quantitative or quantitative approach is required.
- The potential of the consequences - If a severe consequence is involved such as the fire risk study for a PHI affecting a local population, it would be normal to use extended QRA so as to ascertain the societal risk established on a FN curve.
- The degree of expertise, human and other resources required - The resources for QRA is much heavier than qualitative assessment. Sometimes, specialist consultants such as fire safety engineers are to be hired for the assessment and design process. The additional resources would need to be allowed in the budget exercise.

- The availability of information and data - Qualitative risk assessment which produce general risk profiles does not require details for the risk data. On the contrary, the availability of reliable data is always the major problem for quantitative fire risk assessment. In the absence of various information and data such as failure statistics of equipment, it would be necessary to derive the figures through fault tree analysis or searching from guide books. Other special techniques such as Delphi technique can be adopted by an expert panel to estimate the likely probability and consequence values.
- The need for regular updating and modification of the risk assessment - Fire risk for buildings are required to be re-assessed when there is any change in occupancy type or design. If a risk-based approach is adopted for the initial design, the Expected Risk to Life (ERL) should be re-verified to ensure it is code compliant before proceeding with any alteration works.
- Regulatory and contractual requirements - In UK, it is currently a mandatory requirement for the employer to conduct fire risk assessment for the workplace of the employees from an industrial safety perspective under the Fire Safety Order 2005 (Department for Communities and Local Government, 2007). If the workplace has 5 or more employees, then the risk assessment must be formally recorded for inspection by the Authority Having Jurisdiction. A qualitative fire risk assessment may suffice in this regard. However, there is no similar specific requirement in Hong Kong, albeit the general obligation for the employer to provide a safe working environment such as the maintenance of the means of escape free from

obstruction and the proper installation of exit signs (Laws of Hong Kong, 2000).

2.10 Summary

In this Chapter, the general concepts of risk and risk acceptance are reviewed and presented. While the acceptance of the risk level is not well defined, probably the ALARP concept is by far the most widely adopted principle in setting the risk tolerability as it will reflect the prevailing standard of social, economic and technological level of the affected community.

The currently available methodologies for risk assessments are then discussed. The Qualitative approach can be used as the screening technique for identifying those risks which may warrant detail investigation, whereas the Quantitative approach is the most informative one to aid making decision. The Semi-quantitative approach is probably an optimum approach as it would be less tedious but also provides a sufficient degree of information for decision making. The limitations and considerations in choosing the methodology appropriate to an individual case are also highlighted. All in all, all types of methodologies do require some sorts of assumptions which depend on the engineering judgements of the analyst. Provided that the methodology is properly applied and documented by a qualified professional, the assessment process provides a logical analysis to the fire safety problem and the comparison of various alternative options.

CHAPTER 3 Review of Deviations from the Current Prescriptive Fire Codes of Existing HKHA Buildings

3.1 Introduction

In this Chapter, a detail review will be conducted on the fire safety legislation in Hong Kong. It will be followed by a recap of the history of PRH development in Hong Kong with the design features of each block type described. It is obvious that buildings constructed many years ago may not conform to present day prescriptive fire codes. The Chapter would therefore compare the fire safety design provision of these block types against the current prescriptive code books and scrutinise the deviations.

On other occasions, there is criticism that the local government always responds to fire tragedy by merely revamping or tightening of fire safety regulation (Walters and Hastings, 1998b) without serious thought on the part of FSM. However, FSM can play its role through mitigating some of the fire risks and arrangement of supplementary measures to reduce the risk contributing factors. This is particularly important in the case of HKHA with a large portfolio of properties built across a wide range of years.

3.2 Why Legislation

Canovan (1988) had once pointed out that during medieval and early modern times; most cities in the world were devastated by fire at least once. Law was therefore developed increasingly to control the danger from fires. He further proposed that legislation on fire safety might serve a number of functions:

- Criminal liability for arson and safety standards for electrical goods and chemicals aim to minimize outbreaks of fire.
- Fire separation and distance requirements between buildings aim to prevent the spread of fires.
- Regulations on means of escape and access for fire-fighters aim to reduce the risks to persons in case of fires.
- Regulations on flammability of contents and the handling of explosives aim to keep the fire hazard under control for buildings in use.

However, one must bear in mind that legislation and enforcement cannot be extended without limits and hence compromising societal resources. Canovan (1988) stressed that education and publicity to achieve a public sense of responsibility for fire safety should be the long term goal.

3.3 The Building Fire Safety Legislation in Hong Kong

Hong Kong had once been under the British Colonial Administration for over a hundred years. The local legislation and the relevant codes are more or less modeled on the British Law.

Fire safety aspects of buildings in Hong Kong are regulated under the Buildings Ordinance (BO) (Laws of Hong Kong, 2008a) and Fire Services Ordinance (FSO) (Laws of Hong Kong, 2005b) with the Buildings Department (BD) and Fire Services Department (FSD) as the Authority Having Jurisdiction (AHJ) respectively. In principle, the Ordinances are developed to address the three key areas of the fire safety equation: passive fire protection, active fire protection, and the fire safety management aspects.

3.3.1 Legislation on passive fire protection of buildings

The BO is set up to maintain a minimum safety and health standards in the design, construction, maintenance, alteration and usage of a building. The building developer or property owner must engage an "Authorised Person" (AP) (an architect, structural engineer, or building surveyor registered with the BD) to carry out the design and supervision of the building works. At the same time, the works must be carried out by a Registered General or Specialist Contractor (RC). Furthermore, where the works entails structural content, a separate "Registered Structural Engineer" (RSE) must be employed to handle and certify the structural design, calculation and details.

Currently, there are 14 building regulations under the BO. Amongst these regulations, the Building (Planning) Regulations (Laws of Hong Kong, 2008b) specify the planning requirements for amenities and safety; which includes fire safety such as the provisions of fire escapes and access for fire fighting and rescue. On the other hand, the Building (Construction) Regulations (Laws of Hong Kong, 1997) lay down the requirements of structural design, use of material and the requirements of fire resisting construction to prevent the spread of fire and maintain structural stability.

To enable the design professionals to get an understanding on the "deem to satisfy" requirements; BD has published 3 Code books namely the "Code of Practice for the Provision of Means of Escape in Case of Fire", (Buildings Department, 1996b), "Code of Practice for Provision of Means of Access for Firefighting and Rescue Purposes", (Buildings Department, 2004), and the "Code of Practice for Fire Resisting Construction", (Buildings Department, 1996a). These Codes of Practice aim to amplify the relative Regulations.

3.3.2 Legislation on active fire protection of buildings

Under the BO, the FSD is empowered to issue the fire certificate for a building to endorse the fire services installations (FSI) as indicated in the submitted building plans. Prior to the issuance of an Occupation Permit (OP), the BD has to be satisfied that the relevant fire certificate has been endorsed by FSD to this effect. This arrangement also applies to alteration and addition works in buildings. As far as FSI is concerned, the Fire Service (Installations and Equipment) Regulations (Laws of Hong Kong, 2004c), and the Fire Service (Installation Contractors) Regulations (Laws of Hong Kong, 2008c) are directly relevant.

The Fire Service (Installations and Equipment) Regulations require that all installation, inspection and maintenance works of FSI shall only be carried out by Registered Fire Services Installation Contractors (RFSIC). It also prescribes that the owner of FSI which is installed in any premises shall keep the FSI in efficient working order at all times and to have the FSI be inspected by a RFSIC at least once in a year. To this end, a “Codes of Practice on Minimum Fire Services Installations and Equipment and Inspection, Testing and Maintenance of Installations and Equipment” (MFS) (Fire Services Department, 2005) has been published to spell out the types of fire engineering systems to be installed in a particular type of building occupancy together with the technical specification on testing and periodic maintenance requirements. Any FSI is deemed to be in efficient working order if it complies with the MFS.

Within the ambit of the Fire Service (Installation Contractors) Regulations, there are three classes of RFSIC, i.e.

- Class 1: Contractors who are fit to carry out works for fire detection systems.
- Class 2: Contractors who are fit to carry out works for installations which contain pipes and fittings to carry fire extinguishing medium. Typical examples are fire hydrants and sprinkler systems.
- Class 3: Contractors who are fit to carry out works for portable equipment such as fire extinguishers.

With the increase in complexity of building design, other sophisticated FSI including audio/visual advisory system, emergency lighting, pressurization of staircase, smoke extraction system, and ventilation/air-conditioning control system have been incorporated in the MFS since 1990. However, there is no appropriate Class of RFSIC at the moment to take up such advanced fire protection installations and FSD only promulgated Circular Letter to designate Class 2 Contractors to certify such installations. Actually it is questionable that whether the existing Classes of RFSIC possess the expertise knowledge in certifying advanced systems such as smoke management systems.

For fire safety purpose in particular, building ductwork systems are also regulated by the FSD by virtue of the Building (Ventilating Systems) Regulations (Laws of Hong Kong, 1998) which prescribes the fire dampers of the ventilating systems be certified by a Registered Ventilation Contractor annually.

3.4 Legislation on Licensing of business operation

Due to the presence of specific hazard relating to individual business characteristics, the law requires the operators of the following businesses to obtain a licence before operation:

- Restaurants/food business
- Clubs/clubhouses
- Educational establishments/schools
- Hotels/Guesthouses
- Child care centres
- Drug dependent person treatment and rehabilitation centres
- Massage establishments
- Bedspace apartments
- Residential care homes for elderly
- Karaoke establishment
- Amusement games centres
- Places of public entertainment

The miscellaneous ordinances or requirements governing the licensing process had been summarized in the literature (Tsui and Chow, 2004). Again, BD and FSD are the advisors to the respective licensing authorities on the technical aspects of the fire safety measures on passive and active fire protection. After all, the legislation aims to impart to the business operators a responsibility in providing a fire safe environment for their customers or visitors.

3.5 Legislation on handling of dangerous goods

In order to control the manufacture, storage or usage of any "dangerous goods" in a building, a Dangerous Goods Ordinance (Laws of Hong Kong, 2004a) is in force. Under the Ordinance, there is the Dangerous Goods (Application and Exemption) Regulations (Laws of Hong Kong, 2001) which categorise 11 types of dangerous goods together with their maximum exempted quantity. Other than Category 1 dangerous goods (i.e. explosives) which comes under the jurisdiction of the Commissioner of Mines, the rest 10 Categories of dangerous goods are within the ambit of such regulation. Any building owner or occupier who intends to use or store any dangerous goods in excess of the exempted quantities shall apply for a licence from the FSD.

3.6 Legislation on upgradation to aged commercial buildings

Apart from the BO and FSO which are fundamental to regulate fire safety, there are other ordinances which were enacted to improve the fire safety measures to aged commercial buildings consequent to tragic fire incidents.

In 1994, a bank fire occurred which took 13 lives (South China Morning Post, 1994). The government then convened an investigation team which recommended that those "prescribed commercial premises" (PCP) (i.e., banking, off-course betting centres, jewelry or goldsmith's business on premises that have a security area, supermarket, shopping arcade) with a high and changing population to have the fire safety measures upgraded (Hong Kong Government, 1994). This tragedy ultimately led to the enactment of the Fire Safety (Commercial Premises) Ordinance (Laws of Hong

Kong, 2004b) which came into operation in May 1997.

During the interim period, unfortunately, another tragic fire occurred inside an aged high-rise commercial building in 1996 (Hong Kong Standard, 1996) which killed 39 and injured 81 people. The fire is commonly known as "Garley Building Fire", and the large number of casualties also attracts the attention of international media. Later on, the aforesaid ordinance was further extended to cover the entire building of those "specified commercial building", which are commercial buildings constructed before 1987 when sprinkler installation was not a mandatory requirement at that time[3] (Chow, 1991). The Fire Safety (Commercial Premises) (Amendment) Ordinance was thus brought into operation in June 1998. In essence, the ordinance aims to bring the fire safety standard of those aged commercial buildings to present day standard through the retrofitting of sprinkler system and other FSI, as well as the enhancement of construction on passive fire protection.

3.7 Legislation on upgradation of old composite and domestic buildings

In 1998, two serious fires occurred in two composite buildings which consist of mixed mode occupancy of commercial and domestic use. This has triggered public concern on the fire safety aspect of this type of buildings. Following that, the FSD and BD had inspected similar buildings territory-wide and found that the fire safety conditions of most of them were unsatisfactory (Security Bureau, 1998). In view of

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[3] For buildings with building plans first submitted for approval between 1973 and 1987, the provision of a sprinkler system was a mandatory requirement for all commercial buildings and the commercial portions of composite buildings exceeding 30 metres in height or more than 10 storeys. From March 1987 onwards, it became a mandatory requirement for all commercial buildings with floor area exceeding 230 square metres to be installed with sprinklers.

the relatively high fire hazard of the commercial portions of these buildings, the Fire Safety (Buildings) Ordinance was enacted in 2002 to require the owners and occupiers of pre 1987 composite buildings and pre 1987 domestic buildings to upgrade the FSI and building construction to present day standard. Due to operational considerations, the Ordinance is eventually implemented in July 2007 (Laws of Hong Kong, 2007c).

According to the two authorities, it is planned to inspect all the target composite buildings within the first 9 years, and to inspect the target domestic buildings in the ensuing 1 year. In other words, the enforcement action would hopefully be completed within 10 years (Buildings Department, 2009).

3.8 Legislation on fire safety management

The main objective of fire safety management is to ensure that in case of fire, all the safety measures provided will be available and occupants will be able to use them; and they can be guided to escape to a place of safety (Malhotra, 1987).

The Building Management Ordinance (BMO) (Laws of Hong Kong, 2007a) enforced by the Home Affairs Department (HAD), facilitates the incorporation of owners of flats in a building in providing management. HAD can further impose mandatory management of buildings that are not managed or poorly managed. A Code of Practice on Building Management and Maintenance (BMM) (Home Affairs Department, 2000) has been published under Regulation 44(1) of the BMO to lay down the details of the management and safety for the communal areas of a building. Fire safety forms part of the elements within the Code. In general, it requires the owner or property manager to properly maintain both the passive and active fire protection measures and not to block the escape route. If the owner fails to comply with the fire safety aspects, FSD can issue a “Fire Hazard Abatement Notices, Direction, or Orders” to the owner or even to institute prosecution.

Although the BMO provides for governance on building management with respect to fire safety, the role of the property manager is not well-defined. Walters and Hastings (1998a) had once stated that “if the government is serious about improving fire safety in buildings in Hong Kong, they should address the role and responsibility of the property managers in the fire legislation”. Recently, the government has issued a consultative document on the “Regulation of the Property Management Industry” (HAD, 2011) regarding the establishment of a licensing scheme for the property management companies (PMC). The document generally concludes that the PMC should be licensed on a single tier basis, whereas the professional property management practitioners are licensed either on a single or two tier bases. An independent statutory body funded by levy on property transactions will also be set up for dealing with the regulatory affairs upon enactment of the legislations. Regrettably, the proposed licensing scheme only focuses on the quality performance issues of the PMC and the relevant practitioners without details on how fire safety aspects as a key element of property management can be further enhanced.

In the scene of Hong Kong where clusters of high-rise buildings are built, the importance of fire safety management is increasingly revisited (Chow, 2001). In fact, a recent study by Tsui and Chow (2004) further recommended that the property management company should appoint a suitably qualified fire protection manager to take account of the total fire safety issues such as preparation and implementation of a structured fire safety management plan, as well as the coordination with the fire safety management personnel of tenants and occupiers.

In Singapore, it has already introduced the Fire Safety Manager scheme which aims to assist the building owner in ensuring building fire safety at all times. This scheme applies to any commercial and industrial building with gross floor area exceeding 5,000m^2 or an occupant load of more than 1,000 persons, and high risk premises such as hospitals or buildings with activities involving hazardous substances (Boo, 2009). Under the scheme, the building owner is required to appoint a certified Fire Safety Manager in managing fire safety. The fire safety performance in Singapore in terms of death per 100,000 persons persistently ranks first as noted in Chapter 1. The appointment of a qualified Fire Safety Manager can be considered as one of the contributing factors.

3.9 Paradigm shift from Prescriptive Code to Performance-based Fire Codes

The present arrangement of fire safety legislations is primarily prescriptive in nature. Both the BO and FSO give clear guidance on how a building is to be designed and constructed with specific requirements on passive and active fire protection details as amplified in the Code books. The design professionals must follow the Codes strictly in order to get the approvals from the AHJ. While those traditional buildings are designed in accordance with the Prescriptive Code (PC) with success, the unprecedented change brought about by the innovative design and technological advancement has created the impetus for fostering the Performance-based Fire Codes (PBFC). By the term performance-based, we aim at a building performance which satisfies the fire safety goals, in contrast to the prescriptive approach which simply describes an acceptable solution.

Another key driver for switching to PBFC stems from the social-economic development. In 1997, the Organisation for Economic Co-operation and Development[4] (OECD) produced a Report on Regulatory Reform on the need for a change in government attitudes towards regulation (OECD, 1997). The report covers many areas of regulation where performance-based regulations have taken over prescriptive regulations. It is envisaged that PBFC allows for greater economic development with the market, rather than the government, determining the most efficient way to meet standards.

To meet the changing need for the fire safety design of sophisticated structures (e.g. Lam, 1995) and to tie in with the advanced countries in advocating the Performance-based design (e.g.; Hadjisophocleous, Benichou and Tamim, 1998; Buchanan, 1999), the BD had released a Practice Note (PNAP) in 1998 (Buildings Department, 1998) to allow the AP to adopt the Performance-based approach. By virtue of the PNAP, AP may have an option in their building design where a particular aspect of the

[4] The Organisation for European Economic Cooperation (OEEC) was established in 1947 to run the US-financed Marshall Plan for reconstruction of a continent ravaged by war. By making individual governments recognise the interdependence of their economies, it paved the way for a new era of cooperation that was to change the face of Europe. Encouraged by its success and the prospect of carrying its work forward on a global stage, Canada and the US joined OEEC members in signing the new OECD Convention on 14 December 1960. The Organisation for Economic Co-operation and Development (OECD) was officially born on 30 September 1961, when the Convention entered into force. Other countries joined in, starting with Japan in 1964. Today, 34 OECD member countries worldwide regularly turn to one another to identify problems, discuss and analyse them, and promote policies to solve them. The mission of the OECD is to promote policies that will improve the economic and social well-being of people around the world.

existing Codes, say the means of escape, cannot be fulfilled. The Performance-based design is generally viewed as an alternative rather than a waiver of the PC, whereby the designer is required to demonstrate its equivalence to the PC. The designer must submit his Performance-based proposal for vetting by the Fire Safety Committee under the Chairmanship of an Assistant Director of the BD. While the PNAP provides a preliminary framework for implementing the PBFC, there is no mention on the post-occupancy evaluation on total fire safety, or how the fire safety management scheme is monitored.

3.10 Development of PRH in Hong Kong

3.10.1 Resettlement Estates (1954) and Government Low Cost Housing (1961)

At the end of the Pacific War, Hong Kong was confronted with a large influx of refugees from Mainland China and many of them lived in illegal squatter areas. In 1953, a devastating fire occurred in Shek Kip Mei squatter area which rendered 50,000 people homeless. The Resettlement Department was immediately set up in the next year to deal with the clearance of the squatters and the resettlement of the victims and this had marked the history of public housing development in Hong Kong (Yeung and Wong, 2003). The then Public Works Department (PWD) was responsible for the design and construction of the H-shaped six or seven storeys Mark type resettlement blocks.

Later on in 1961, the PWD started to build Government Low Cost Housing to house the low income families on the waiting list of PRH. These blocks were managed by the former Hong Kong Housing Authority which was established in 1954. Despite these efforts, a lot of people were still living in poor squatters.

3.10.2 Ten Years Housing Programme (1973)

In order to have a more systematic approach in tackling the housing issue, the then newly appointed Governor Sir Murray MacLehose announced the launch of the Ten Years Housing Programme cum establishment of a new HKHA in 1972. The HKHA is charged with the responsibilities of policy formulation, while the Housing Department is the executive arm to implement the various programmes.

The Programme was devised to provide PRH with reasonable living standard to those in need and it was expected that the squatter problem could be cleared. However, during the programme period, there was a continual influx of illegal immigrants from Mainland China creating additional demand for housing and thus the programme target could not be met. Therefore in 1982, the government announced that the Ten Years Housing Programme would be extended for another five more years to 1987. After all, the programme had a major achievement in decentralizing the population from the urban districts to various satellite towns in the New Territories.

3.10.3 Home Ownership Scheme (1976)

As a result of the bourgeoning economy in the 1970s and the growing aspirations for home ownership, the government launched the Home Ownership Scheme aiming at:

- Encouraging the better-off sitting tenants to purchase their own accommodations and to release their flats to those in need.

- Providing an opportunity for the lower income groups to purchase their own home while they are unable to afford in the private property market.

All along, this scheme is very successful and well received as the sale of flats are usually over-subscribed. Since these sold flats are totally under private ownership, the responsibilities of management and maintenance are under the sole arrangement of the flats owners and their management agents similar to that of private properties.

3.10.4 Long Term Housing Strategy (1987)

Following the implementation of the housing programme from 1954 to 1985, the government conducted a thorough review in 1987 and introduced the Long Term Housing Strategy accordingly. In essence, it is a policy statement reaffirming the government's determination to build affordable housing for all households up to 2001 (Hong Kong Special Administrative Region Government, 2002). The government envisaged that the redevelopment for all non-self-contained PRH will be cleared and more sitting tenants would be offered the assistance to purchase their own flats.

All in all, the development of PRH in Hong Kong is a successful story throughout the past decades and should be proud of by local citizens. The success is also recognized worldwide.

3.11 Types of PRH

The types of PRH that are constructed have constantly improving both in design and provision. It can generally be mapped to the development of the housing policy and the rise in living standard as a result of the take-off of the local economy. The building configuration has been transformed from basic accommodation to totally standalone flats that are comparable to that of private properties. The characteristics of various building types (e.g., HKIE, 1999) are described below.

3.11.1 Mark I and Mark II

During the 1950s, the main objective of the housing programme is to build basic accommodations for those fire victims and refugees. The construction works need to be speedy and only basic provisions would be acceptable. To this end, the Mark type blocks were constructed which are characterized by an H-shape with a central corridor access of 6 to 7 storeys. There is an external corridor access around each storey and only public toilets and bathrooms are provided. Cooking is carried out at the corridor beside the flat entrance.

3.11.2 Slab Blocks

Land supply is always scarce in Hong Kong. In the 1960s, it was realized that a “high-rise approach” was necessary to house a large amount of people effectively. This marked an era which high-rise PRH blocks with lift access to every three alternative floors were built. Slab Blocks with central corridor access to each flats located at both sides are typical examples. The living conditions are significantly improved as balcony, toilets and cooking facilities are provided inside each flat.

3.11.3 Twin Tower

Being constructed in the 1970s, the twin tower blocks take the form of two square-shaped towers which are linked together by a lift bobby. Starting from this era of

PRH development, lift service is provided to each floor. The central core of each tower forms a light yard for the corridor. In addition, toilets and cooking facilities are provided inside each flat.

3.11.4 1-H, 2-H, and 3-H Blocks

As the name implies, these types of blocks take the shape of an “H”, with either 1, 2 or 3 blocks being linked together. There is a lift lobby for each “H” wing, and a corridor access to the flats. Toilets and cooking facilities are generally the same as those of Slab Blocks and Twin Towers.

3.11.5 Trident Blocks

During the 1980s, the HKHA began to build blocks with multi-rooms concept similar to the private residential units. Permanently divided kitchens, toilets are provided inside each flat. The Trident blocks are constructed with 3 typical wings merging to a central lift lobby which becomes a symmetrical “Y” shape. Natural daylight and ventilation can reach each room inside the flats. These Trident blocks are largely built in those new town development sites.

3.11.6 Linear

The Linear Blocks were built in the 1980s as an enhanced design to those “H” blocks. These blocks are mainly built in the Kowloon peninsula. Again a multi-room design concept is adopted with permanent toilets and kitchens.

3.11.7 Harmony Series

In order to tie in with the rising living standard, the Harmony series were launched in 1990s. The concept of modular design of 1-bedroom, 2-bedroom, 3-bedroom and 1-person flat is introduced to offer a mix of different flat sizes and the opportunity of reducing the construction cost. The provision is actually very close to that of private properties as fixed bedrooms are provided in addition to kitchens and bathrooms. Emergency generators are also provided to meet the new fire safety requirements for high-rise buildings.

3.11.8 Concord Series

Originally, the Concord series are designed and built as Home Ownership Scheme flats which are intended for sale purpose. The Concord series ride on the modular concept of the Harmony series. The interior provision is further upgraded with mirror cabinet and kitchen cabinet in the toilet and kitchen respectively. Some of these blocks are being changed as rental flats as a result of the moratorium in sale of HOS flats in 2001 in view of the economic climate.

3.11.9 Non-standard Design

In recent years, the HKHA moves towards a non-standard design approach so as to optimize the use of a local site's unique topography, access, area and constraints to meet specific needs. Such design would allow more efficient use of land which is scarce in Hong Kong. In addition, micro-climate study is also carried out during feasibility stage for better planning of natural ventilation and daylight. The recently completed Shatin Pass Estate is a good example of such design which is built on a sloping area.

Amongst the types of buildings constructed by the HKHA, one of the common design features is that the corridor ends are ventilated to the open air. In the design of H Block and Linear Blocks, the corridors are also ventilated to the open air along the entire wings as the flats are located only in single side of the corridors. This design feature is good in terms of fire safety as smoke dispersion is very effective in case of fires.

3.12 Deviations of the PRH from the current fire safety codes

Since the PRH estates are constructed across several decades, it is inevitable that those older buildings may not fully comply with the present day fire safety requirements. The fire safety design features of the “old” PRH buildings are generally compared with the current edition of the three fire code books from the Buildings Department (1996a, 1996b, 2004), as well as the code book from Fire Services Department (2005). The deviations from these code books are enlisted in Tables 3.1 to 3.4.

Table 3.1 Deviations from the “Code of Practice for the Provision of Means of Escape in Case of Fire”, (Buildings Department, 1996b)

Item	Clause referred	Clause requirements	**Deviation**
1	13.5 (b)	A protected lobby should be provided to each staircase unless the staircase is at least having 50% of its perimeter is open from the balustrade to the underside of the staircase above.	Protected lobby is only provided to the staircases of Harmony, Concord series and beyond.
2	14.3 (b)	For flats where the direction of travel from the exit door to the staircase is in one direction only, the sum of the direct distance and travel distance should not exceed 18m.	The sum of the direct distance and travel distance for dead-end flats in H, Single I and Harmony blocks exceeds 18m.
3	14.3 (c)	The distance along the centre line of the exit route between two staircases should not exceed 48m.	The distance along the corridor between two staircases in Slab, Twin Tower, and Harmony blocks exceeds 48m.

Table 3.2 Deviations from the “Code of Practice for Fire Resisting Construction”, (Buildings Department, 1996a)

Item	Clause referred	Clause requirements	**Deviations**
1	9.3	The door giving access from the flats to the internal corridor should have a Fire Resisting Period (FRP) of not less than 1/2 hour.	The main door of each flat does not have the requisite FRP except Harmony, Concord series and beyond.
2	9.3	Fixed light having an FRP of not less than 1/2 hour may be installed in the separating wall between the flat and internal corridor at a height of not less than 1.8m.	The louvre windows of flats open to the corridor is 1.54m above finished floor level and do not have the requisite FRP in Slab, Twin Towers, H and Linear blocks.
3	11.3 (b)	Fire resisting door to be provided to the staircase enclosure giving access to the staircase.	No fire-resisting door is provided to the staircases of Slab, Twin Towers and Linear blocks.
4	11.7	The external opening of the staircase shall have a separation of 6m from other unprotected windows.	The external openings of the staircases are less than 6m from other unprotected windows in Slab, Twin Tower and H blocks.
5	12.3	The external wall of a building at any floor should be separated from the external wall at the floor next below by a spandrel of not less 900mm high.	No spandrel of 900mm high is provided in H and Twin Tower blocks.
6	14.3	In any domestic premises with a single exit door, a kitchen adjacent to such door should be separated from the rest of the premises by walls having an FRP of not less than 1 hour and the door should have a FRP of not less than 1/2 hour.	The kitchen doors of PRH do not have the requisite FRP except in Harmony, Concord series and beyond.

Table 3.3 Deviations from the “Code of Practice for the Provision of Means of Access for Firefighting and Rescue Purposes”, (Buildings Department, 2004)

Item	Clause referred	Clause requirements	**Deviations**
1	10.4	No part of the floor served by a fireman’s lift should be more than 60m from the door of the lift lobby measured along actual passages.	-

Table 3.4 Deviations from the "Codes of Practice for Minimum Fire Service Installations and Equipment and Inspection, Testing and Maintenance of Installations and Equipment", (Fire Services Department, 2005)

Item	Clause Referred	Clause Requirements	State of Provision	**Deviations**
1	Clause 4.23: Requirements of Fire Services Installations (FSI) for high-rise domestic buildings (i.e., buildings of which the floor of the uppermost storey exceed 30m above the point of staircase discharge at ground floor level)	Emergency generator	The secondary sources of power supply for old buildings are provided through tapping from the upstream of the incoming circuit breaker.	No emergency generator is provided to PRH except the new block groups of Harmony, Concord series and beyond.
2		Emergency lighting	Provided	-
3		Exit sign	Provided	-
4		Fire alarm system	Provided	-
5		Fire hydrant/hose reel system	Provided	-
6		Fireman's Lift	Provided	-
7		Portable hand-operated approved appliance	Provided	-

3.13 Improvement works carried out by the HKHA

As a caring landlord, HKHA attempts to upgrade the fire safety provisions to bring them up to present day standards as far as practicable subject to site constraints. During the past years, the upgradation works conducted includes the following:

- Wet fire hydrant systems have been retrofitted in some older estates without such provisions.

- Emergency lighting, directional signs and exit signs have been retrofitted in some older estates without such provisions.
- The FSI in the shopping centres and supermarkets have been upgraded as per the Fire Safety (Commercial Premises) Ordinance (Laws of Hong Kong, 2004b).
- The smoke detectors inside those blocks purposely designed for accommodating the elderly have been replaced with standalone smoke detectors. The modification works manifests to be effective in obviating the unwanted building false fire alarms due to burning of incense inside flats, smoking, and cooking etc.
- The entrance doors of dead-end flats are replaced with fire-rated doors.
- Fire collars are provided for the uPVC drain pipes penetrating the floor slabs of the balcony on each floor.

While every endeavours have been taken by HKHA to improve and upgrade the fire safety provisions in its portfolio of buildings from time to time, one have to bear in mind that there may still be some limits because of either site or technical constraints.

3.14 Summary

In this Chapter, the local legislations on building fire safety have been reviewed. It has been criticized that the legislations are generally incremental in a sense that the government is trying to impose additional requirements in response to disastrous fires (Walters and Hastings, 1998b). Although there are stringent requirements on both active and passive fire protection, there are yet little legislative requirements on fire safety management. Although there is a Code of Practice on Building Management and Maintenance issued by the HAD mandating the maintenance of fire safety aspect of communal area, it has no direct sanction effect on the property owner. Fire hazard abatement notice is still to be served by FSD should any breach of the fire safety requirements is reported. A review paper has already been published in the International Journal on Engineering Performance-Based Fire Codes on this topic by the author of this thesis (Yeung, 2007b).

The Chapter continues to introduce the development of the PRH in Hong Kong in the wake of the Shek Kip Mei fire in 1953. During the past decades, PRH of emerging forms and topography has been built to meet the need of the local citizens. Since the PRH stock is constructed across a spectrum of years, it is inevitable that there is a varying degree of deviations of these old PRH buildings against the four current Code books. Despite some major deviations as outlined, the HKHA has endeavoured to carry out fire safety improvement works from time to time subject to feasibility constraints. While the fire safety standard in terms of building construction and provision of FSI is constantly improved, FSM should still be rigorously considered.

CHAPTER 4 Fire Safety Management of HKHA Buildings

4.1 Introduction

In Chapter 3, the major deviations of the PRH against the current fire code books have been discussed. In this Chapter, the fundamental principles of FSM will be explored and the existing practices and procedures within the HKHA will be studied and reviewed. Although the importance of FSM is increasingly revisited, there is still little research on the same especially the organizing and implementation issues of FSM. Later on in Chapter 7, a systemic approach on the development of a fire safety management system for HKHA will be proposed.

4.2 Definition of fire safety management (FSM)

FSM has once been defined as "the application by a manager of policy, standards, tools, information and practices to the task of analyzing, evaluating and controlling fire safety" (Howarth and Kara-Zaitri, 1999). Under the Publicly Available Specification 79: 2007 of the British Standards Institution (BSI), FSM is defined as "the tasks carried out by a defined individuals with appropriate powers and resources to ensure that the fire safety systems, passive, active and procedural, within the building are working properly at all times" (BSI, 2007b). This definition can be viewed as a practical and applied definition of FSM. Normally, such a function is embedded as part of the daily building management responsibilities of the property manager, or the property management agent.

Moreover, the current BSI Code of Practice for fire safety in the design, management and use of buildings (BSI, 2008a) has emphasised that "it is the fundamental assumption that features described in British Standard BS 9999: 2008 will require management and maintenance throughout the life of the building". The statement clearly provides that the fire safety of a building can only be achieved as designed on the premise that it is properly managed and maintained.

4.3 Fire Safety Concepts Tree

In a real world situation, there is no such a thing as absolute safety. Fire safety in buildings is of no exception. Fire safety in buildings depends on numerous factors, be it human, mechanical or environmental.

The National Building Code of Canada (National Research Council, 2005) defines fire safety as "an objective to reduce the probability that a person in or adjacent to a building will be exposed to an unacceptable fire hazard as a result of the design and construction of the building."

Traditionally, a building is considered to be reasonably fire safe if it is designed to the prevailing fire code which reflects the societal tolerability with respect to fire consequence at that time. However, this approach is in lack of a systematic consideration. While there is no absolute solution to building fire safety design, it is more appropriate to have a balanced design through the adoption of a combination of strategies which include:

- Prevent fire ignition
- Control the combustion process
- Control fire by construction

- Detect fire and provide warning
- Automatically suppress the fire
- Manually suppress the fire
- Manage the exposed, either people or property

The National Fire Protection Association (NFPA) has developed a "Fire Safety Concepts Tree" (FSCT) which is reproduced in Figure 4.1 (NFPA, 2007). The FSCT is in essence a logical diagram depicting the various elements of fire safety strategies to assist us in making decisions on a myriad of alternatives. The elements down the tree branches of the pictogram represent the means to achieve the requirements immediately above them. It has to be noted that logic gates are incorporated into the FSCT to indicate those strategies which shall be adopted simultaneously under the "AND" gate; and those strategies which can be applied individually are grouped under the "OR" gate.

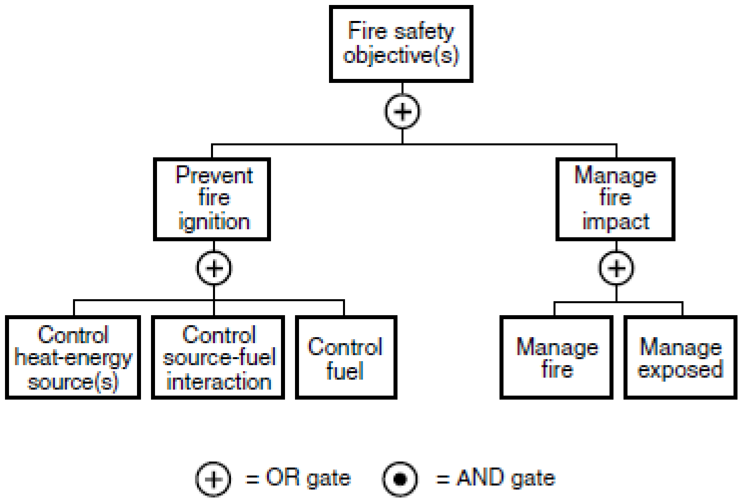


Figure 4.1 Principal Branches of the Fire Safety Concepts Tree (NFPA, 2007)

As shown in Figure 4.1, the “Fire safety objective(s)” can be achieved either by “Prevent fire ignition”; or “Manage fire impact”. Further down the line of the diagram, we can see that “Prevent fire ignition” can be achieved by “Control heat energy source(s)”, “Control source-fuel interactions”; or “Control fuel” as suggested in Figure 4.2.

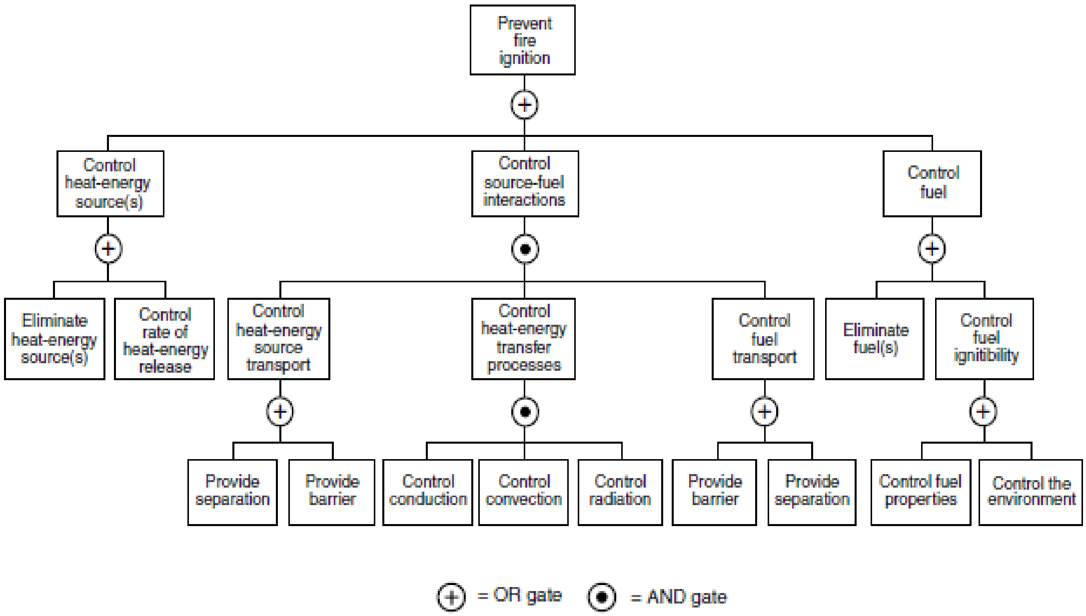


Figure 4.2 Components of the Prevent Fire Ignition Branch of the Fire Safety Concepts Tree (NFPA, 2007)

These three principles are basically predicated upon the “Fire Triangle”; which is a model conventionally used by fire engineers to put forward “Fuel”, “Heat” and Oxygen” as the three ingredients to start combustion. By removing either one of these three ingredients, the combustion process or the fire cannot start.

It is imperative that “Prevent fire ignition” should be taken as the fundamental line of defence. However, should a genuine fire occur, the safety objective can only be achieved by shifting the strategy to “Manage fire impact”; which in turn; can be achieved either by “Manage fire” or “Manage exposed”. In order to “Manage fire”, one can control or suppress the fire. On the other hand, the “Manage exposed” approach can be utilized to protect the people, property, content etc. against the destructive effect of fire through “Limit the exposed” or “Safeguard the exposed” within tenable criteria.

To have a systematic understanding on fire prevention, NFPA has prepared a list of “Fire Prevention Factors” (NFPA, 2003, pp. 2-40) as reproduced in Table 4.1.

Table 4.1 Fire Prevention Factors (NFPA, 2003, pp. 2-40)

1. Heat Sources	a. Fixed equipment b. Portable equipment c. Torches and other tools d. Smoking materials and associated lighting implements e. Explosives f. Natural causes g. Exposure to other fires
2. Forms and Types of Ignitable Materials	a. Building materials b. Interior and exterior finishes c. Contents and furnishings d. Stored materials and supplies e. Trash, lint, and dust f. Combustible or flammable gases or liquids g. Volatile solids
3. Factors That Bring Heat and Ignitable Material Together	a. Arson b. Misuse of heat source c. Misuse of ignitable material d. Mechanical or electrical failure e. Design, construction, or installation deficiency f. Error in operating equipment g. Natural causes h. Exposure
4. Practices That Can Affect Prevention Success	a. Housekeeping b. Security c. Education of occupants d. Control of fuel type, quantity, and distribution e. Control of heat energy sources

Incidentally, the American Society of Safety Engineers also publishes a "Fire Safety Management Handbook" based upon the FSCT. The handbook proposes that a fire safety management programme (Della-Giustina, 1999, pp. 24) should include the following elements:

- Inspections - regular inspections are conducted to detect potential fire hazard, and assure that fire protection systems are operable.
- Education and training - training should be provided in the recognition of fire hazards, use of fire control equipment, and fire code compliance.
- Fire suppression - equipment such as extinguishers and alarms should be provided.

- Emergency service - the fire safety manager should develop fire and emergency response plans for utilising the local fire and police departments.
- Evaluation of fire possibility - the fire safety manager should evaluate the fire possibility through periodic inspections of the building layout and housekeeping/storage practices.
- Fire prevention - it is the incorporation of inspections and educations to prevent fire loss before it occurs.
- Reports and record keeping - report and record can aid senior management in improving fire safety performance. Records should contain inspection and maintenance schedules, fire history and fire investigations.
- Communication - communication should be maintained between all units of the organization to ensure compliance with the programme.

4.4 Role of FSM

It is generally reckoned that FSM has a key role to play in the prevention of fire. Furthermore, it has been pointed out in the literature that "a common factor in many multi-fatality fires is the failure of the occupants of the building, whether management, staff or others, to take the correct action when a fire is discovered or when and alarm is raised" (Her Majesty Stationery Office, 1996). "Even with the most comprehensive fire safety provisions that modern technology can provide, it is essential that there is adequate management of fire safety to ensure that the occupants of a building reach a place of safety in the event of fire and to avert disaster" (CIBSE, 2010, pp. 14-1). If a building is properly managed, it is contemplated that the chance of fire starting is greatly reduced, and the chance of successful evacuation of occupants will increase.

In the scene of Hong Kong where clusters of high-rise buildings are built, the importance of FSM is increasingly revisited (Chow, 2001). However, under the current legislation, there is only the Building Management Ordinance (BMO) (Laws of Hong Kong, 2007a) in place which is relevant to FSM.

4.5 Elements of FSM

As suggested by Malhotra (1987), FSM practice requires the preparation of a Fire Safety Plan which comprises Maintenance Plan, Staff Training Plan, and a Fire Action Plan. Moreover, Her Majesty Stationery Office (1996) further postulates a Fire Prevention Plan which in effect deals with the "Fire Prevention" branch of the FSCT. The Fire Safety Plan can be depicted in Figure 4.3 and details of each of these sub-plans are described as follows:

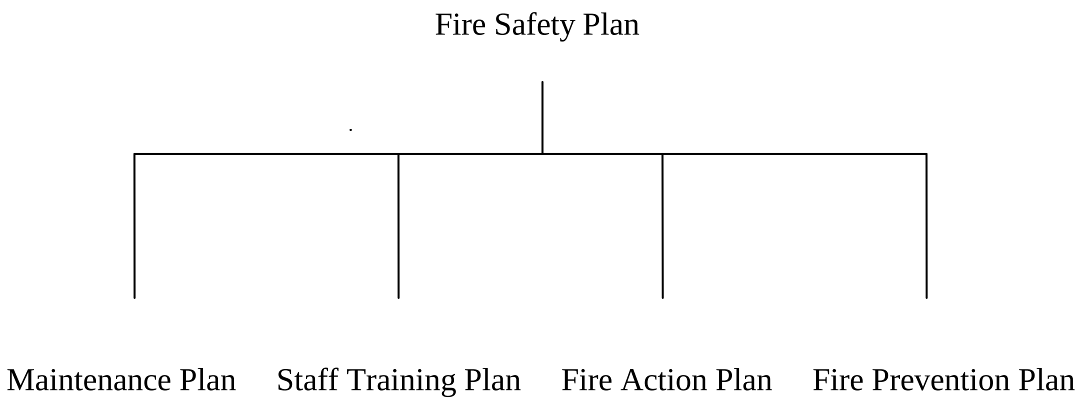


Figure 4.3 Fire Safety Plan

- Maintenance Plan

A Maintenance Plan devises in detail how the passive and active fire services installations (FSI) of the building is regularly checked and tested to verify their functionalities. It is apparent that proper maintenance of FSI helps to assure that the fire safety systems can work as intended in case of fires. For instance, as a minimum, the hose reel system and fire alarm system is mandated to be tested by a Registered Fire Services Installation Contractor (RFSIC) once a year (FSD, 2005). The escape routes are regularly patrolled to ensure that the fire door is not wedged open.

- Staff Training Plan

Staff should be familiar with the various procedures that have to be taken in a fire or similar emergency situation. Ample training to the security guards or other operational staff must be arranged once a building is occupied. Refresher training programme should also be organized from time to time to ensure that the staff are updated with the current procedures and are able to respond promptly and orderly under fire situations. Typical training contents should include the designation of personnel (such as a fire officer) and delineation of their responsibilities; how to raise an alarm; how to guide occupants to a place of safety; how to use first-aid fire-fighting equipment; and how to provide the relevant building information to the fire officers upon their arrival etc.

- Fire Action Plan

The Fire Action Plan will document the actions to be taken by each member of designated staff once a fire is detected. The purpose is to assure that the staff take their roles effectively without panic. What have been learned in the training (such as calling the FSD, evacuation of occupants etc.) will be realized in the Fire Action Plan.

- Fire Prevention Plan

As pointed out before, fire prevention should be accorded the first priority in maintaining building fire safety. Experiences show that "most building fires are started by heat sources and ignitable materials that are brought into the building, not built into it (NFPA, 2003, pp. 2-39)". Therefore, control of the source of ignition and combustible materials is regarded as a first step of fire prevention. Procedures should be established through good housekeeping in the aversion of heat source and combustibles such as proper disposal of cigarette ends; limitation on storage of flammable substance, and regular removal of waste etc. Preventive maintenance of electrical and mechanical equipment should also be stressed as overheating of such equipment is a frequent cause of fire.

On the other hand, education to inculcate occupants on the fire precautionary measures should also be addressed. This may take the form of short classes, posting of posters, and distribution of educational leaflets.

In order to develop a structured Fire Safety Plan, a Fire Safety Manual is recommended (e.g. Porter, 1990). The details of the manual may depend on the complexity of the building concerned. Some typical contents of the Manual include: safety management structure, actions to be taken in an emergency, fire drills, housekeeping, planned maintenance procedures, staff training, continuous control and audit procedures, and security (ISO, 1999).

Besides the procedures in each of the sub-plan, the design assumption and parameters of the fire safety strategies should also be laid down in the manual for the reference of the fire safety personnel. This is particularly important for a building designed on performance based approach. Usually, FSM is dedicated as one of the strategies of fire safety in complex and large buildings where a lot of sophisticated fire engineering systems are installed. In a local example of the Lanham Place, the design consultant has already emphasized the importance of transferring the Manual to the property management company as a fire safety package (Tsui and Luo, 2005).

4.6 Policy and Practice of FSM in HKHA

4.6.1 FSM Procedures

Before a FSM system is put in place, the level of FSM should be specified. According to the British Standard BS 9999:2008, there are three levels of FSM and a total of nine principal factors should be considered in assessing the level required (BSI, 2008a):

- Planning for changes in risk profile
- Resources and authority
- Staffing level
- Fire training
- Work control
- Communication procedures
- Maintenance and testing of fire safety systems
- Liaison with fire and rescue service
- Contingency planning

The HKHA manages a stock of 1,420 rental buildings and Level 1 FSM (which is the highest level) is generally adopted as recommended for residential buildings. The above nine factors are addressed apart from the fact that there is no formal “Permit to Work” system for “hot work”. The various FSM practices and procedures are summarized in Appendix A under the four sub-headings of the Fire Safety Plan, i.e., a full coverage on Fire Prevention Plan, Maintenance Plan, Staff Training Plan, and Fire Action Plan.

4.6.2 Maintenance of Building Services System

As pointed out earlier by NFPA (2003), “mechanical or electrical failure” is one of the fire prevention factors. Proper maintenance of building services plants and equipment is therefore a contributing factor in reducing the likelihood of fires, let alone the enhancement in the system reliability and the reduction in downtime. By recapitulating Figure 1.5, one can see that about 1.99% of fires are due to electrical faults in year 2010.

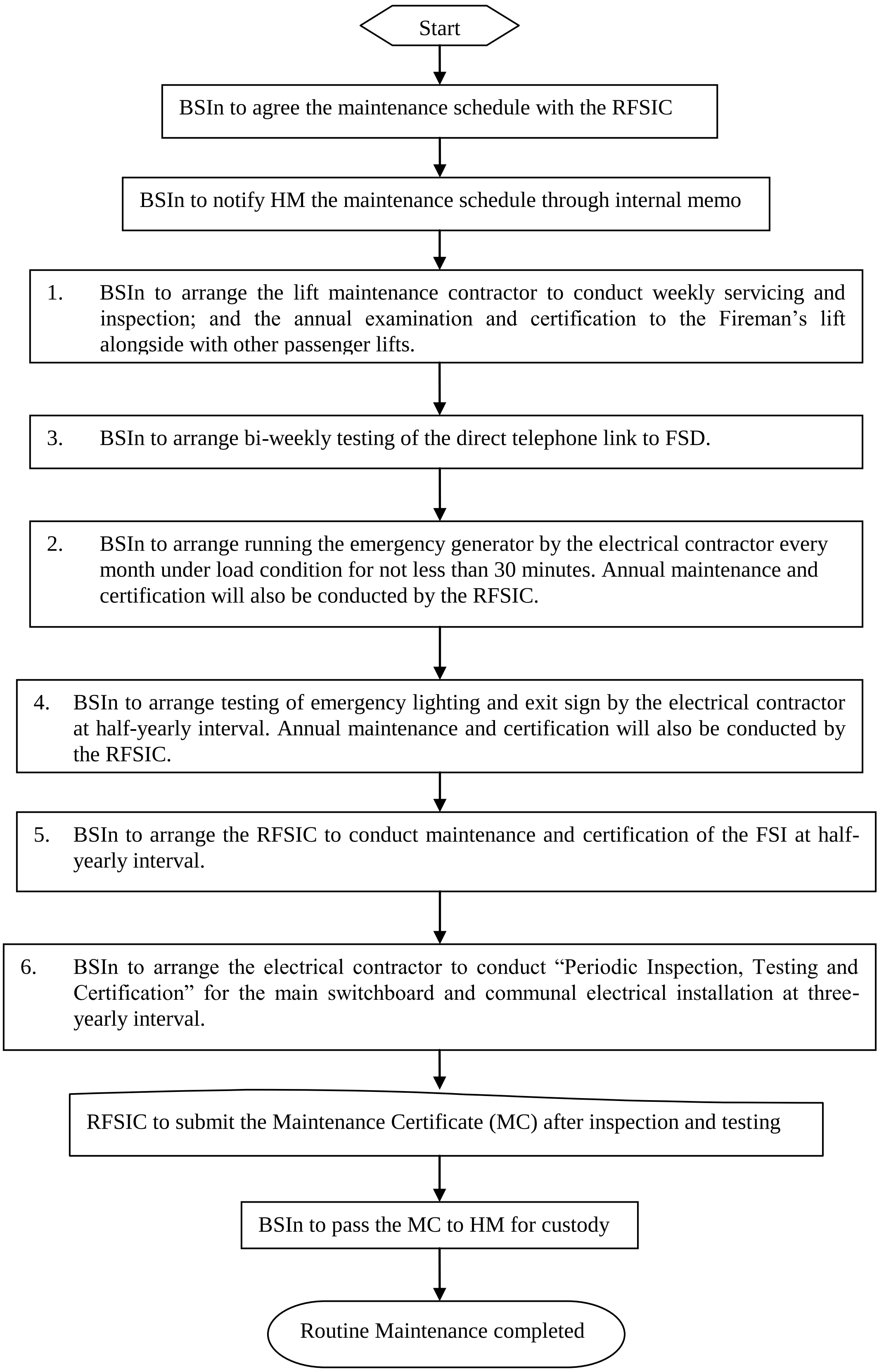
All along, HKHA adopts a preventive maintenance strategy (CIBSE, 2008) in dealing with the maintenance of the communal building services systems. All the plants and equipments in the public area and plant rooms are regularly inspected, checked, tested and repaired as per statutory requirements and plant condition. For instance, the electrical installation is required to be inspected and tested at 5 yearly interval if the design load is more than 400 Amperes (Laws of Hong Kong, 2005a, 2007b). Other core building services improvement programmes such as “Pump Renovation”, “Electrical Reinforcement and Rewiring”, “Lift Modernisation”, “Addition of Addressable Fire Alarm System”, and “Upgradation of Security System” are also executed to bring up the building stock to present day living standard and to uplift the asset value.

On the other hand, HKHA is responsible for the maintenance of the internal services and landlord’s provisions inside flats provided that the installations have not been altered or tampered with by the tenants; and any such defects are attributable to fair wear and tear (HKHA, 2009a). The typical building services inside flats comprise electrical, communal aerial broadcasting distribution, door phone, and gas installations.

Whilst repair works on the in-flat installation are dealt with on a day-to-day basis upon request by tenants, such installation is also replaced and improved as appropriate during vacant flats refurbishment upon moving out of tenants. Moreover, annual appraisal on the condition of internal wiring will be carried out for estates with ages over 20 years. Replacement of internal wiring will be arranged where necessary under the "Rewiring inside Domestic Flat" (RDF) rolling programme (HKHA, 2007b). According to the experience by HKHA during in-flat repairs, the landlord's fixed wiring inside flats is in sound condition[5], while most alteration and fitting-out works on the electrical installation by the tenants are not up to safety standard. The RDF programme will definitely remove the fire hazard incurred by electrical faults due to substandard alteration works by the tenants. Incidentally the number of final circuits and socket outlets have been increased thereby obviating the need to use adaptors.

In order to visualise the routine maintenance and shutdown of FSI in particular, the workflow is indicated in Figure 4.4 and Figure 4.5 respectively.

[5] According to the Fire Protection Research Foundation (FPRF, 2008), thermoplastic insulated (such as PVC) wires which are popular after the 1950 vintage generally continue to perform with excellent results, even after 50 years or more of service in the home. The electrical and mechanical characteristics of these wires appear to be exceeding even the original expectations of performance after aging and normal use. The experience in HKHA appears to tally with the research results from USA.



Legend: BSIn: Building Services Inspector HM: Housing Manager

Figure 4.4 Workflow of routine maintenance to FSI

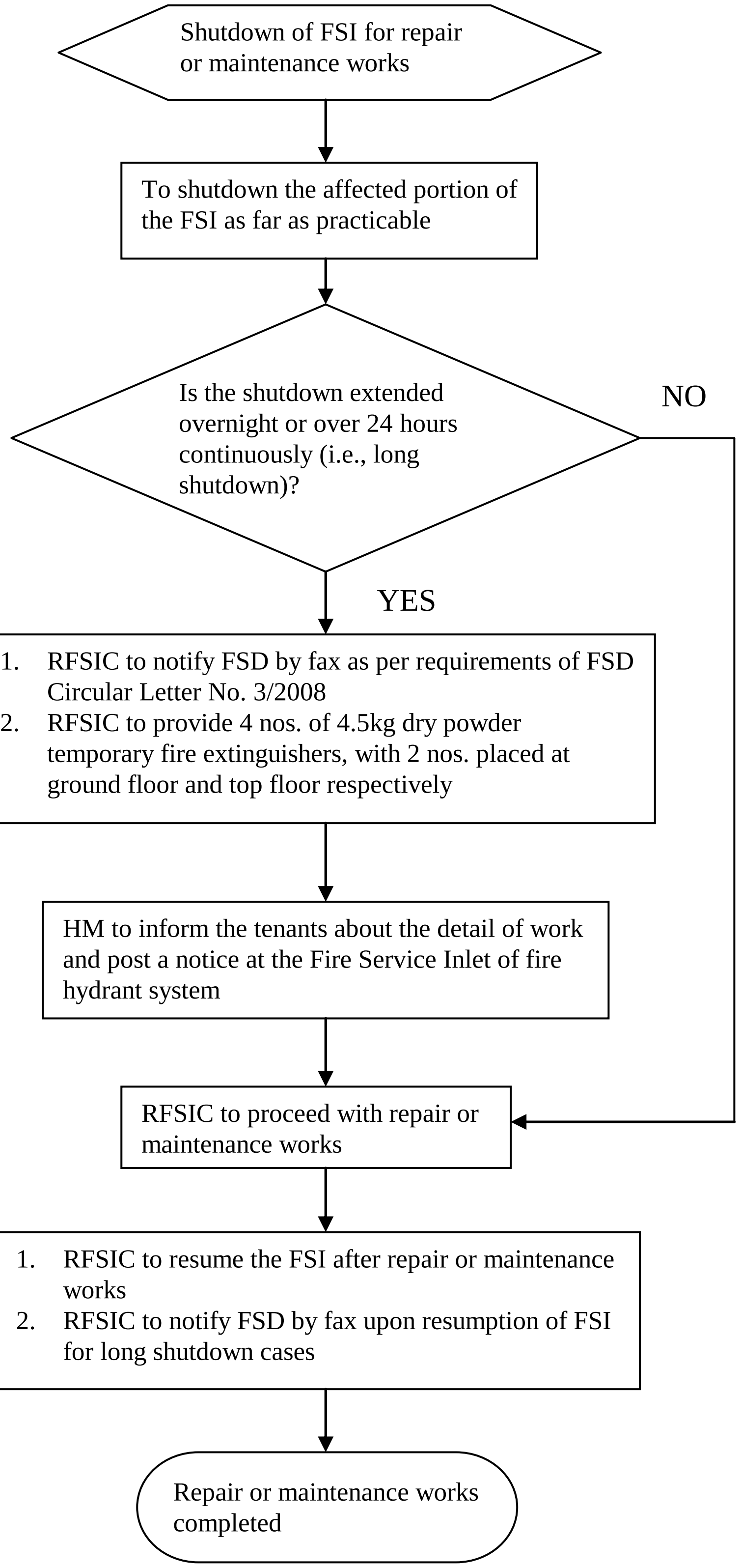


Figure 4.5 Flow chart for shutdown of FSI

4.6.3 Improvement to FSI and building construction

It is HKHA's policy to improve and bring up the standard of the FSI and the building fabric to present day requirements as far as practicable. During the past years, a series of upgradation works on active and passive fire protection features have been carried out as described in Chapter 3. Nevertheless, there are always practical constraints on alteration and additions to existing buildings due to site specific issues. On the other hand, the nuisances caused to residing tenants may sometimes be unacceptable, or else a relatively extensive period is necessary to complete the upgradation works.

A very important consideration before executing any improvement works on FSI should be the reliability and maintainability issues. This is particularly relevant where an improvised installation is proposed (FSD, 2007). For example, Chow, Chong and Wong (1999) have conducted field surveys to 36 old buildings with height over 30m and age over 25 years. In a case study where retrofitted sprinkler installations are provided, they identify that there are many problem areas such as storage of combustible goods up to the false ceiling height; sprinklers are covered with dust etc. They argue that fire safety management of the building is lax and not well developed; and the sprinkler installation may not work as expected should a fire occur. Furthermore, Fong (2000) has conducted a reliability study for a typical improvised sprinkler system with water supply tapping from the fire hydrant tank. By using FTA technique and the reliability data of the system components from other guide book, he estimated that the reliability of the whole system to be very low. He recommended that more frequent proof test on the system is necessary so as to ascertain the reliability.

Arguably, these findings unveil that management and maintenance remain to be critical in terms of fire safety for old existing buildings rather than simply asking for additional FSI. This is more obvious for improvised systems because they are likely to be of a standard somewhat lower than that of new projects which the entire system design can be well planned and coordinated right from the concept feasibility stage.

4.6.4 Education to tenants

HKHA has invested heavily on the publicity and education to tenants on fire safety. This is achieved through the publication of various information brochures and the organizing of a series of fire safety campaigns. Representatives from the Estate Management Advisory Committee (Yip, 2001) are particularly invited with a view to increasing the cohesion and participation of the tenants.

Starting from 1999, HKHA has launched jointly with the FSD the Fire Safety Ambassador scheme to promote a proper fire safety culture amongst the residents. In addition, a “Fire Safety Education Path” has been set up in various estates to inculcate the tenants on awareness and knowledge of fire safety.

In the years 2005 and 2007, HKHA commissioned an independent consultant to conduct survey on fire safety awareness of tenants (HKHA, 2005, 2007a) to gauge the effectiveness of past educational endeavours. In the survey, the consultant adopted the stratified random sampling method to select the buildings with different age. Household members aged over 18 of the selected flat would be interviewed through the telephone. A total of over 1,500 interviews were conducted each time with a response rate of about 70%. The survey results depicted in Table 4.2 below clearly demonstrate that the fire safety knowledge and awareness has significantly increased during the time lapse of just two years.

Table 4.2 Survey Results on Fire Safety Awareness of Tenants in Public Rental Housing

	Survey result in 2005 (a)	**Survey result in 2007 (b)**	**Improvement [(b)-(a)]/(a)**
A. Fire Safety Knowledge			
1. Perceived main causes of fire			
1.1 Leaving stove on when nobody is at home	46.0%	88.3%	91.9%
2. Fire safety awareness of tenants			
2.1 Respondents observed that the smoke doors were being opened in the week before the survey	11.6%	10.2%	12.1%
2.2 Respondents observed that there was obstruction in the corridor or staircase in the week before the survey	10.0%	7.0%	30%
2.3 Respondents are familiar with the location of emergency exit	97.2%	97.7%	0.5%
3. What to do in case of fire			
3.1 To activate the fire alarm	65.8%	70.1%	6.5%
3.2 To bring wet towel for escape	37.2%	40.1%	7.8%
3.3 To use staircase for emergency escape	99.0%	98.7%	-0.3%
B. Effectiveness of Educational Activities			
1. Respondents are aware of educational activities and messages hosted by HKHA	69.2%	71.8%	3.8%
2. Respondents are willing to participate in fire drill	63.2%	68.5%	8.4%
3. Respondents are willing to participate in educational activities	50.0%	63.2%	26.4%
4. Vandalism observed by respondents	3.0%	2.1%	30%

For example, tenants are becoming more aware that “leaving the cooking stove unattended” is a major cause of household fires; and the observation by tenants that there are obstructions in the corridor reduced from 10% in 2005 to 7% in 2007.

4.6.5 Liaison between HKHA and FSD

In view of the high population density residing in PRH, there is a special inter-departmental liaison between the HKHA and FSD. A "Major Disaster Manual" (HKHA, 2009b) has been prepared to outline the overall alerting system and contingency plan in response to different kinds of major disasters including fire and explosion.

The Fire Services Communication Centre (FSCC), which is the centralized Command and Control Centre of the FSD, is responsible for receiving emergency calls and dispatching Fire Services resources to respond to the incidents. In the event of any incidents channeled through the 999 hotline, the FSCC will deal with it and monitor the development of the incident. In case of a Number 3 or higher alarm fire, the relevant District Officer of the HAD will co-ordinate the setting up and operation of an inter-departmental helpdesk at the scene amongst other government departments. Temporary accommodation will also be provided to those rendered homeless arising out of disastrous fire.

4.7 Significance of good FSM

Fire safety in buildings comprises three elements namely passive fire protection, active fire protection, and FSM. The role of FSM has been increasingly re-visited in recent years. Good FSM is considered as fundamental to the design, use and occupancy of buildings. When a building is designed on the principles of Performance-based approach, the contribution of FSM becomes an indispensable part of the design package. The design assumptions and operational conditions must be kept under surveillance to ensure that the safety level is maintained throughout the life cycle of the building according to the design parameters. Actually, proper FSM is a “cradle to crave” business under such circumstances (Brannigan and Spivak, 1999). The effective control on the building fire load and occupant load serves as excellent example on core FSM practice (Chow and Cheung, 2006).

4.8 Summary

In this Chapter, the fundamental principles of FSM have been presented under the backdrop of the NFPA Fire Safety Concepts Tree. The FSM practices and procedures in HKHA have been reviewed by navigating the internal procedure guidelines and manuals. As an overall, the practice is found to be structured and organised. Apart from the fact that there is no formal control mechanism for “hot work” from contractors, the various Fire Prevention Factors are generally addressed. Furthermore, education on fire safety to tenants has been taken seriously. As unveiled by recent Consultancy Reports on “Survey on Fire Safety Awareness of Tenants in Public Rental Housing”, it is found that the fire safety knowledge of tenants have improved in the past years. The educational process is deemed effective.

The FSI are generally maintained at half-yearly interval by RFSIC which is above the statutory requirement of once a year (Laws of Hong Kong, 2004c). The reliability and availability of the active fire fighting systems is greatly assured. The shutdown of FSI is closely monitored under stringent departmental procedures and extra fire extinguishers are provided during the shutdown interim. The communication with the FSD is through special arrangements between FSD and HKHA especially under disasters such as large fire of Number 3 alarm and above. Adequate training is offered to the staff both from within and outside the organization and the roles of individual staff are clearly defined.

HKHA is the landlord of some 1,420 rental building blocks with some “older buildings” aged at 45 years. The “older buildings” constructed many years ago may not comply with present prescriptive fire safety code requirements. Yet there is no compromise on the life safety objective in view of the huge number of residents involved. While endeavors on alteration and improvement works on fire safety provisions are always taken by HKHA, there may still be technical constraints such as locating suitable accommodation space for installing standby generators, space constraint on constructing smoke lobby etc. Moreover, the nuisance caused to the tenants during the extensive period of alteration works may sometimes be politically unpalatable. It is a general acceptance that good FSM plays a key role in elevating the fire safety level of a building as “Fire Prevention” branch of the FSCT is heavily addressed. It is contemplated that the fire safety performance of those “older buildings” managed by HKHA may not be inferior to that of the newly constructed ones because of good management.

A paper presenting the FSM of PRH by the author of this thesis has already been published in the International Journal on Engineering Performance-Based Fire Codes (Yeung, 2007a).

Despite the above, there is yet no formal and systemic FSM system in place to describe the entire FSM development and implementation strategy for the property portfolios with the commitment of the top management, i.e. the Director of Housing. The issue will be discussed in depth in Chapter 7.

CHAPTER 5 Analysis of Fire incidents Statistics in HKHA Buildings

5.1 Introduction

In order to assess the fire safety level of a building, the probability or frequency of fire occurrence is usually taken as one of the parameters. A low frequency of fire occurrence implies that the building has low fire hazard (such as good house-keeping and regular removal of waste materials); or adequate fire preventive measures is in place (such as regular maintenance of electrical system). Implicitly, this is also a reflection of the level of FSM of the building.

While it is not easy to estimate the probability of fire occurrence, very often, the fire statistics can be recalled to provide an indication on the frequency of having fires in a particular building. In this Chapter, the theoretical approach to estimate the fire probability from the literature will be recapped; and the available fire statistics from the year 2006 to 2010 will be retrieved to analyse the fire safety performance of HKHA.

5.2 Probabilistic approach to fire occurrence

Fires can occur anywhere and any time in a building. However, the frequency of such occurrence is low and thus is considered statistically as rare event. Furthermore, the chance and number of fires that occur at any time interval is generally independent of the chance and number of fires that would occur at another time interval in future. A Poisson modeling is therefore very commonly used to model fire occurrence (e.g.

Lin, 2005). LaFleur (2007) also concluded that it is a good choice to adopt Poisson arrival process to model fire occurrence because:

- the distribution of number of fire events depend on length of time interval, but not when the fire occur.
- It is unlikely to have two fires occur simultaneously.

Using the Poisson notation, the probability of having x number of fires at time t, i.e., $P(X = x)$ can be given by the following equation (e.g., Modarres, Kaminskiy and Krivtsov, 2010, pp. 31):

$$P(X = x) = \frac{e^{-\lambda t}(\lambda t)^x}{x!}, \quad x = 0,1,2........etc. \tag{5.1}$$

where λ is the mean fire ignition rate or the average number of fire occurrence per unit time interval, which is usually taken as a year or a day.

The probability of having zero fire incident can therefore be found by putting x =0 into the above equation and thus:

$$P(X = 0) = e^{-\lambda t} \tag{5.2}$$

The probability of having fire incidents in a building can thus be taken as:

$$P(Fire) = 1 - e^{-\lambda t} \tag{5.3}$$

This equation will then be used to estimate the probability of having fires in the PRH buildings in subsequent sections.

5.3 Fire statistics for HKHA buildings

Starting from April 2005, the fire incidents within the HKHA buildings are recorded in the departmental "Fire Incident Report System" (FIRS). The information within the FIRS includes the:

- Estate
- Fire location by flat
- Date of incident
- Time of incident
- Operating condition of the FSI

While the information is very limited, it can be used to analyse the fire situations of the HKHA buildings from the years 2006 to 2010. The incidents records are retrieved and the number of fire incidents for PRH from the years 2006 to 2010 is shown in Figure 5.1

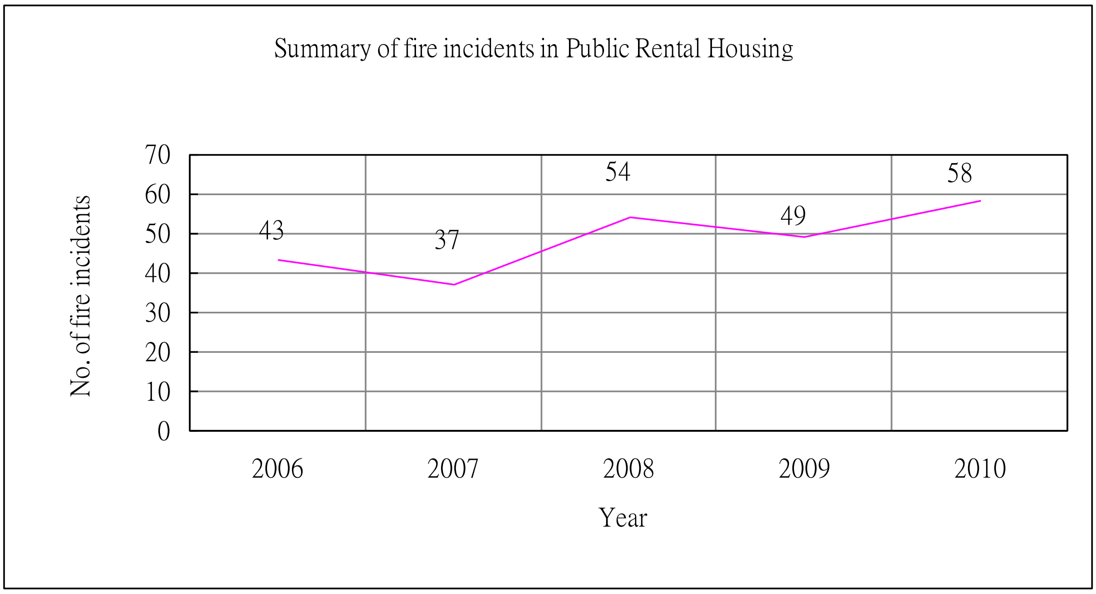


Figure 5.1 Summary of fire incidents in Public Rental Housing

Based on the average return time of the fire incidents, the probability of having fires inside flats from 2006 to 2010 are estimated using the Poisson model and equation (5.3). The estimated probability of fire per day is then averaged over the 5 years and tabulated in Table 5.1. The overall average probability of having fire is in the order of 0.1235 per day.

Table 5.1 Probability of fire per day

Year	**No. of Fires (a)**	**No. of fire incident per day (b) ($=\frac{a}{365}$)**	**Probability of no fire per day (c) ($=e^{-b}$)**	**Probability of fire per day ($=1-c$)**
2006	43	0.1178	0.8889	0.1111
2007	37	0.1014	0.9036	0.0964
2008	54	0.1479	0.8625	0.1375
2009	49	0.1342	0.8744	0.1256
2010	58	0.1589	0.8531	0.1469
			Overall Average	0.1235

5.4 Variation patterns of fire incidents

From the limited data available, attempts are made to gauge the correlations of the frequency of fire incidents (in terms of number of fires per year) against the number of blocks. The number of fires each year versus the number of blocks from the years 2006 to 2010 has been plotted as shown in Figure 5.2.

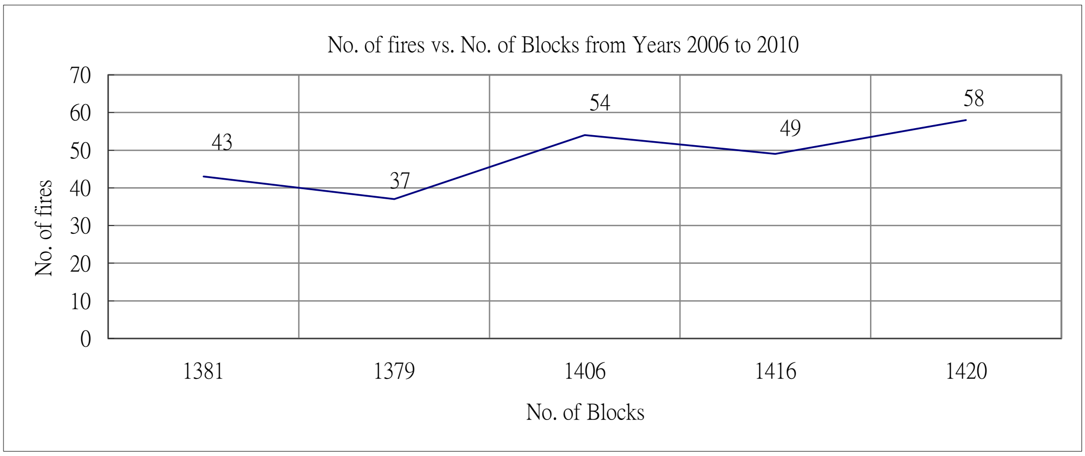


Figure 5.2 No. of fires vs. No. of Blocks

It is generally found that the ignition frequency (i.e. number of fires per year) is positively correlated to the number of blocks throughout the 5 years with a correlation coefficient of 0.8889 as shown in Table 5.2.

Table 5.2 No. of Fires vs. No. of Blocks from 2006 to 2010

Year	**No. of Blocks**	**No. of Fires**
2006	1381	43
2007	1379	37
2008	1406	54
2009	1416	49
2010	1420	58
	Correlation Coefficient	0.8889

Furthermore, the monthly and daily variations of the number of fires for each of the 5 years are plotted in the polar diagrams from Figures 5.3 to 5.12. Owing to the limited statistics available, there is no clearly defined or unique pattern, but more fires tend to occur in winter season around December to February (except in 2009 when most fires occurred around October to December). This may be due to more heating requirements in the winter, and more festive activities are arranged in the home. Additionally, the relative humidity in Hong Kong is quite low during winter which would lead to greater propensity of fires.

On daily basis, it appears that more fires tend to occur around 8 am to 11 am. However, such daily variation behaviour is not obvious in 2007; when the number of fire incidents is only 37 which is also the lowest among the 5 years.

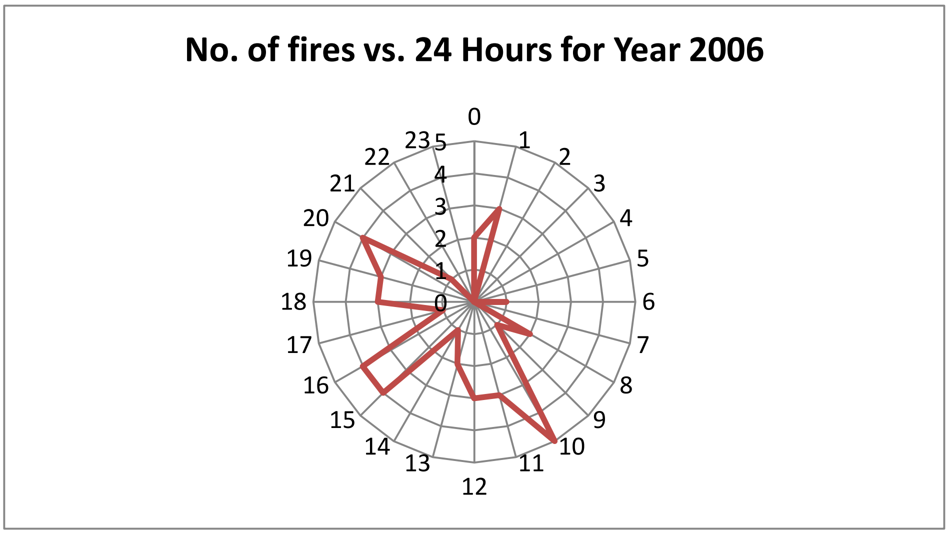


Figure 5.3 No. of fires vs. 24 Hours for Year 2006

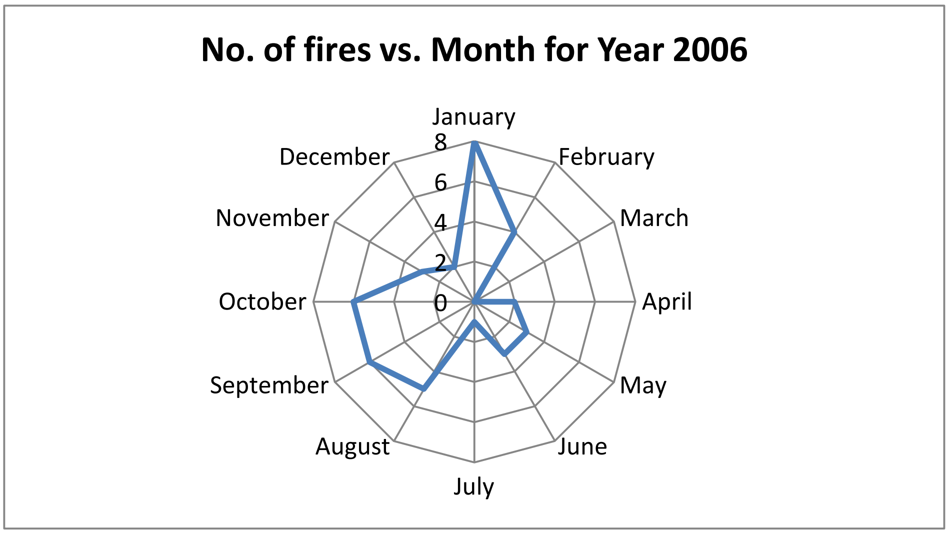


Figure 5.4 No. of fires vs. Month for Year 2006

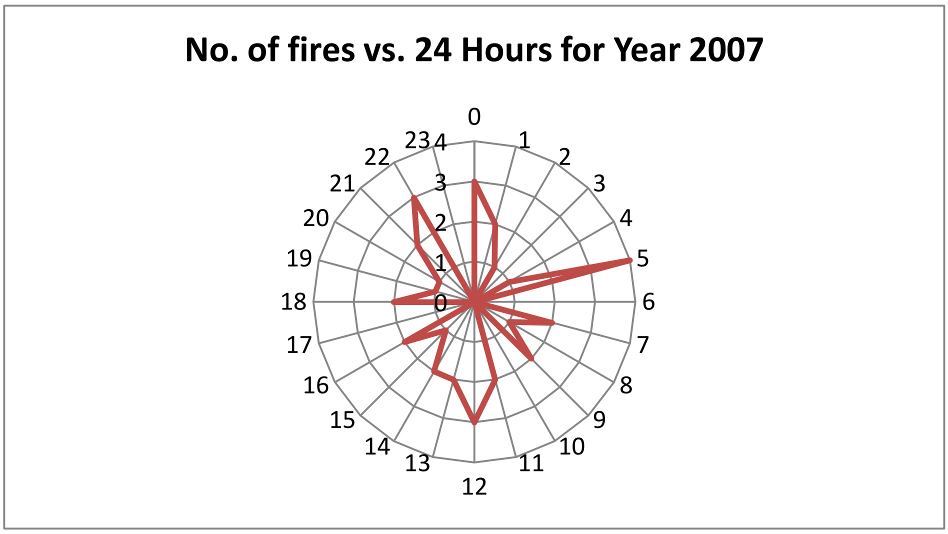


Figure 5.5 No. of fires vs. 24 Hours for Year 2007

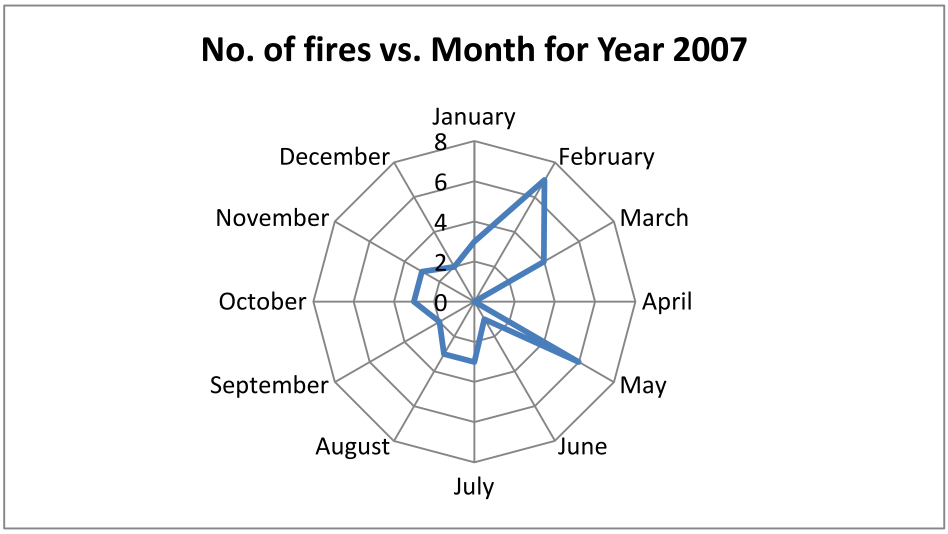


Figure 5.6 No. of fires vs. Month for Year 2007

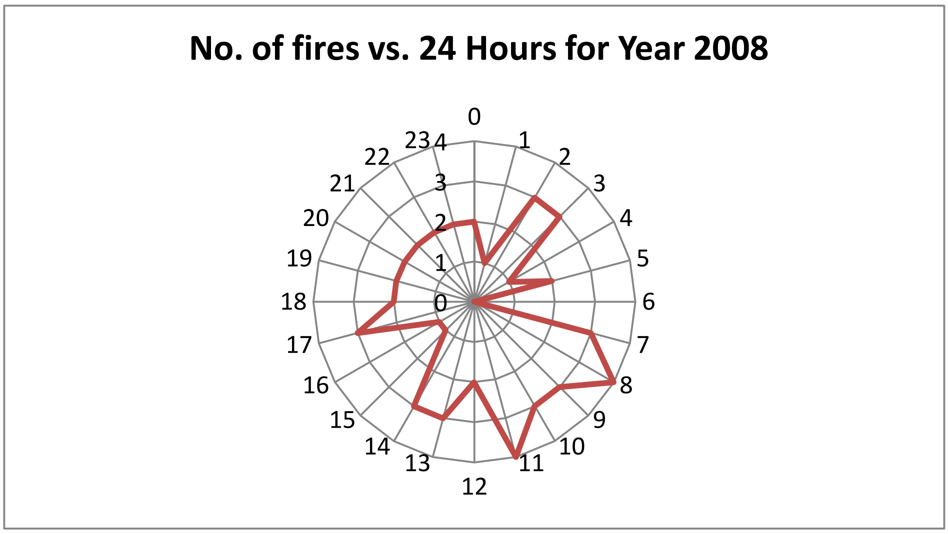


Figure 5.7 No. of fires vs. 24 Hours for Year 2008

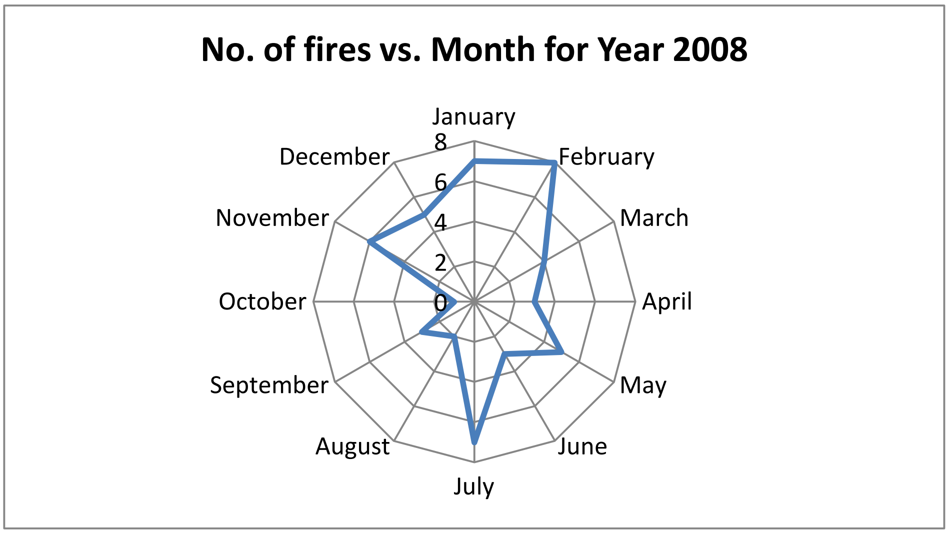


Figure 5.8 No. of fires vs. Month for Year 2008

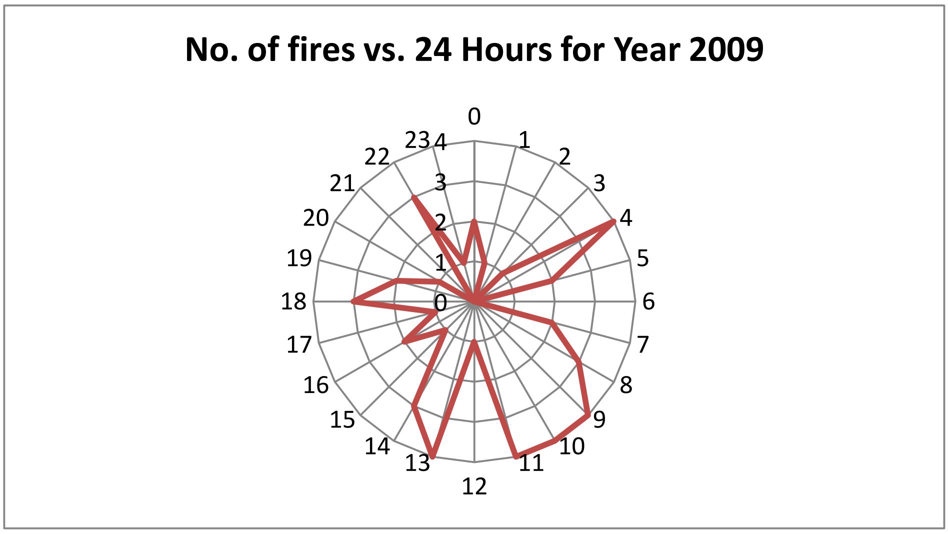


Figure 5.9 No. of fires vs. 24 Hours for Year 2009

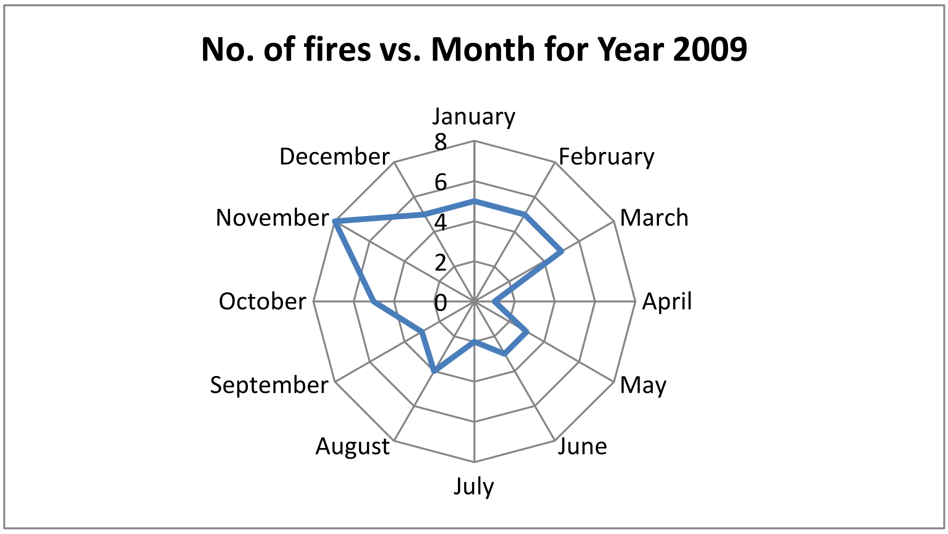


Figure 5.10 No. of fires vs. Month for Year 2009

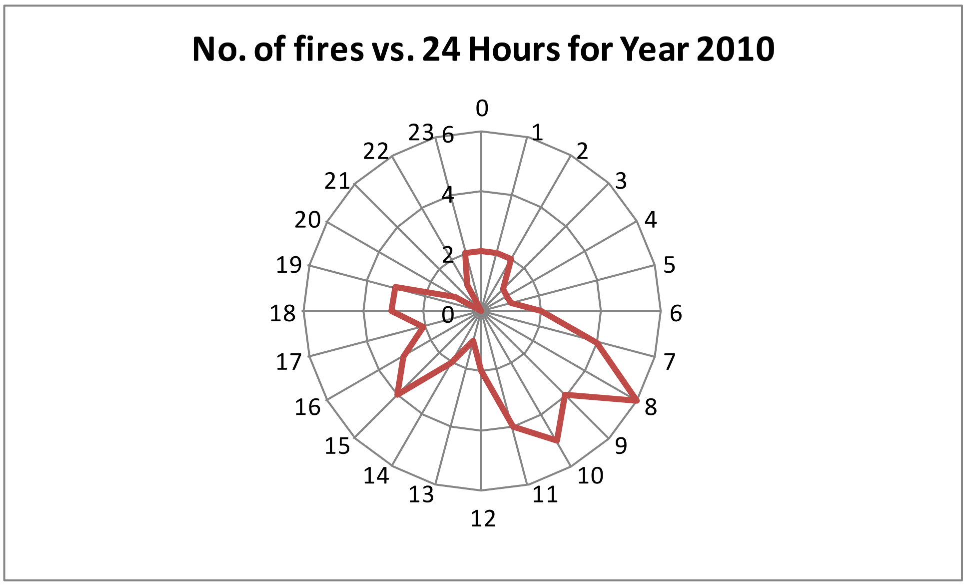


Figure 5.11 No. of fires vs. 24 Hours for Year 2010

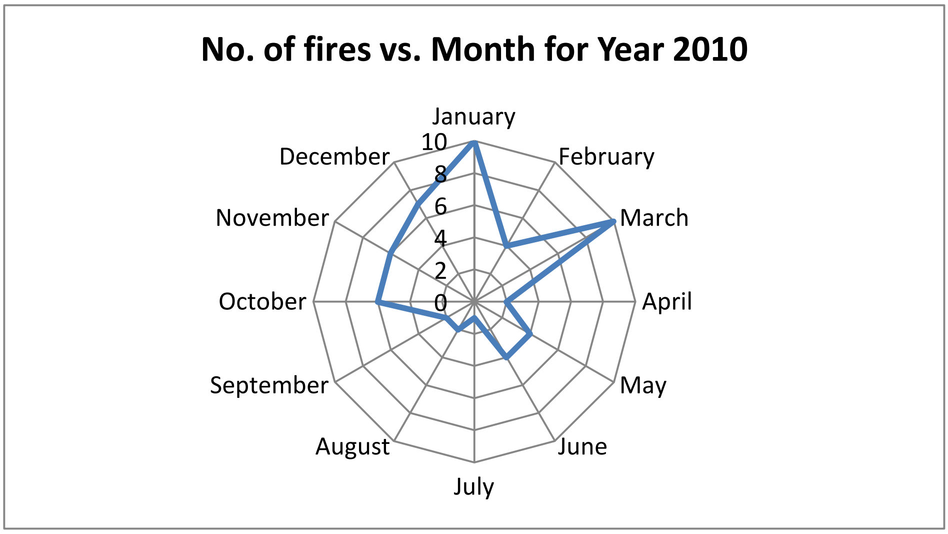


Figure 5.12 No. of fires vs. Month for Year 2010

5.5 Variation patterns of fire incidents in other countries

In China, the fire statistics is very limited due to difficulties in obtaining the data. Yang et al. (2002) have analysed the data from the Fire Service Bureau of the Ministry of Public Security for the year 1998. They find that the fire frequency is higher in spring than other seasons. The number of fires in January shows the highest percentage (12.3% of the total). This can be attributed to the heating requirements by means of radiator etc. in winter time which may result in more fires.

In terms of daily variations, they observe that fires occur more often between 8 am to 8 pm; and the frequency of fires between 6 pm to 10 pm is higher than the average in the whole day. They suggest that it is likely due to more people staying at home after work. On the other hand, they note that death cases between 2 am to 4 am are much more than other times of the day. It is the period of deep sleep and people may not be awakened early enough and evacuate speedily.

In Finland, Rahikainen and Keski-Rahkonen (2004) had plotted the distribution of alarming times for 5,514 building fires during 1994-1995. Since in Finland, 90% of the number, or 67% of the floor area of the buildings are residential buildings, they only categorized the building stocks into residential and non-residential buildings. On the monthly cycle, they found that more fires occurred in Christmas time when there would be more celebrating events. On the other hand, more fires occurred from 3 pm to 8 pm. This time period is generally where there are more people with home activities. They also compared with the cases in UK and Japan and concluded that the variation patterns are roughly similar despite national differences in the cycle.

The situation is quite different in Taiwan. According to Chi et al. (2004), most of the fires occur between 0 am to 8 am before dawn based on the statistics of 311 large or congregation fires from 1985-2004. However, this phenomenon is not explained in his paper.

In US, the US Fire Administration (USFA) publishes very exhaustive information on fire statistics via the National Fire Incidents Reporting System (NFIRS), which is a state-based voluntary fire data collection system. With over half of the fire departments nationwide reporting the incidents, the large sample size provides a very good estimate of the fire situation in US. In particular, the “Residential Structure and Building Fires” (USFA, 2008) addresses residential structure fires over the 10 year period from 1996 to 2005. As revealed in the report, there is a slight down trend on the number of fire incidents from 428,000 in 1996 to 396,000 in 2005. The figures throughout the ten years are fitted and the number of residential structures fires, deaths, and injuries are seen to decline by 1.2, 18.1 and 28.9 percents respectively.

According to the NFIRS, residential structures refer to all built structures on residential properties, and structures include buildings and other non-building structures such as fences, bridges etc. Furthermore, residential structures comprise 1&2 family structures, multi-family structures (similar to multi-storey domestic buildings in Hong Kong), and other structures such as hotels and dormitories. Overall speaking, residential building fires represent 95% of the aggregate residential structure fires. Since about 73% of the US population lives in 1&2 family housing, it is not surprising that the 1&2 family residential structures account for 66% of residential structure fires in 2005, whereas multi-family residential structures account for 28% for the same year. While there may be differences in the statistics of the category of multi-family structures from that of overall residential class, we would take the fire statistics of multi-family residential buildings from the report for comparison purposes.

In terms of the alarm time, multi-family residential buildings have more fires occurring at evening cooking hours from 5 pm to 8 pm, and at the lowest point from 4 am to 7 am when most people are in deep sleep. This time pattern is quite similar to that of 1&2 family houses. During the early morning from 1 am to 4 am, it is the most dangerous period when most fatal fires occur. Fires with injuries are spread quite even in the day time.

On monthly variations, more fires in multi-family buildings tend to occur in winter time from December to January due to heating, and the greater propensity of people to stay indoors. Again, such pattern resembles closely to that of 1&2 family residential buildings.

In UK, the Department for Communities and Local Government (2010) has compiled a full statistics on fires attended by the Fire and Rescue Service across the nation. For example, the publication in 2010 provides a detailed analysis of fires and their causes for year 2008. Buildings occupied by domestic households are usually termed as dwellings in UK.

According to the above statistics, there is a declining trend in dwelling fires since 1999. The number of dwelling fires in UK totaled 49,600 in 2008, which accounts for 64% of all building fires. At the same time, it represents 15% of all fires in that period. However, 75% of deaths come from dwelling fires, and 83% of non-fatal casualties occur in dwelling fires. Again, it is manifested that domestic fires still worth our attention in order to reduce the casualties.

In terms of the accidental dwelling fires in 2008, 36% of them occur between midday (12:00 noon) and 6 pm, and 33% of them occur between 6 pm and midnight. The corresponding fire casualties in these periods are 27% and 33% of the total number of casualties. It is believed that cooking may be the factor for the higher percentages of fires in the day time. Moreover, more fires are noted to occur in winter months.

As suggested by the variation patterns of fire occurrence in China, Finland, US, UK and Hong Kong, it is generally noted that there is a general tendency to have more fires in winter time, likely due to more festive activities and higher propensity of people to stay indoors in that period. In terms of daily patterns, it is more likely to have fires during day time, possibly due to preparation of meals or cooking.

5.6 Analysis of the ignition frequency for different PRH types

As the building configuration design of PRH is changing throughout the years, the extent of deviations of the fire safety features from the current code books also varies. The major deviations have been outlined in Tables 3.1 to 3.4.

It is understandable that the newer buildings will have a lesser degree of deviations from the current codes. However, the ignition frequency may not totally depend on the building configuration design. The ignition frequency of each building design has been studied empirically based on the fire statistics for the five years from 2006 to 2010.

Although there may be slight variation in the building block design, the buildings can be classified into 19 Block Groups as follows:

Table 5.3 Building Block Groups of PRH

	Building Block Design	Block Group	No. of Blocks at year end of 2010
1.	Harmony Series	HAR	424
2.	New/Old Slab	SL	272
3.	Trident Series	TR	190
4.	H, Double H, Triple H	H	123
5.	Linear 1,3 & Liner L	LR	87
6.	Non Standard	NST	63
7.	New Cruciform Block	NCB	62
8.	Twin Tower	TWT	61
9.	Small Household Block	SHB	36
10.	Concord	C1	23
11.	Single I & Triple I	I	16
12.	Single Aspect Building	SAB	14
13.	Cruciform	CRF	12
14.	Housing for Senior Citizen	HSC	10
15.	Ancillary Facilities Block	AFB	7
16.	Linear B	LRB	6
17.	Ziggurat	ZIG	6
18.	Single Tower	SGT	5
19.	Mark IV	IV	3
		Total	**1420**[6]

[6] It includes all rental housing blocks located inside estates of Public Rental Housing (PRH), Tenant Purchase Scheme (TPS), Home Ownership Scheme (HOS), Buy or Rent (BRO) & Interim Housing (IH).

The Harmony Series are generally becoming the current design paradigm of PRH. Obviously, more concentration should be put on those Block Groups with a larger number of building stocks, i.e., Harmony Series, New/Old Slab, Trident Series, H Series, Linear Series, Non Standard, New Cruciform, as well as Twin Towers. It has to be noted that the remaining “Linear B” blocks in So Uk Estate will be demolished in year 2012 for subsequent redevelopment. Mark IV buildings are of obsolete design and are likely to be redeveloped in the foreseeable future.

The ignition frequency of each Block Group within the 5 years is counted and plotted in the histograms of Figures 5.13 to 5.17. The Y-axis shows the number of fires in that year in a descending manner with the X-axis shows the corresponding Block Group. It is observed that the ignition frequency generally increases with the number of buildings of that particular Block Group design, with the exception of Trident series and Linear series, which always exhibit lower ignition frequencies throughout the 5 years.

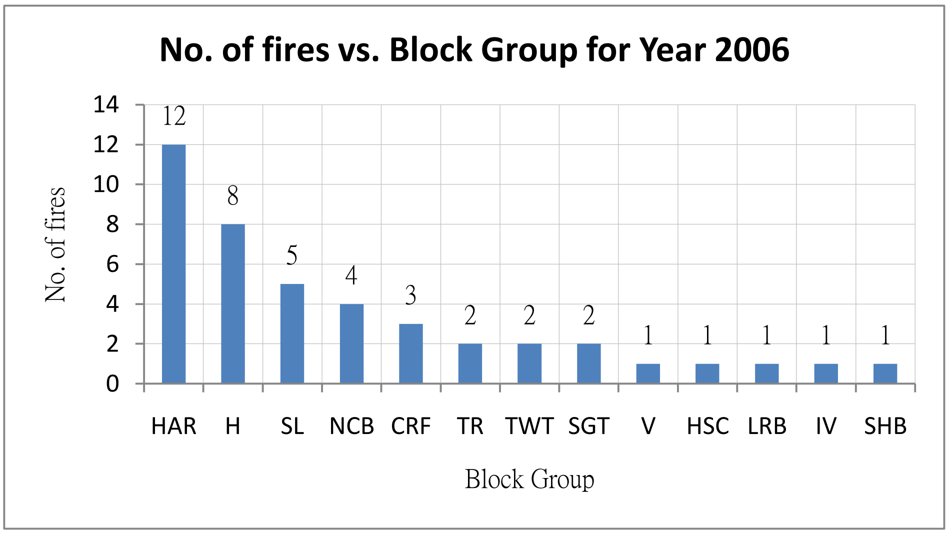


Figure 5.13 No. of fires vs. Block Group for Year 2006

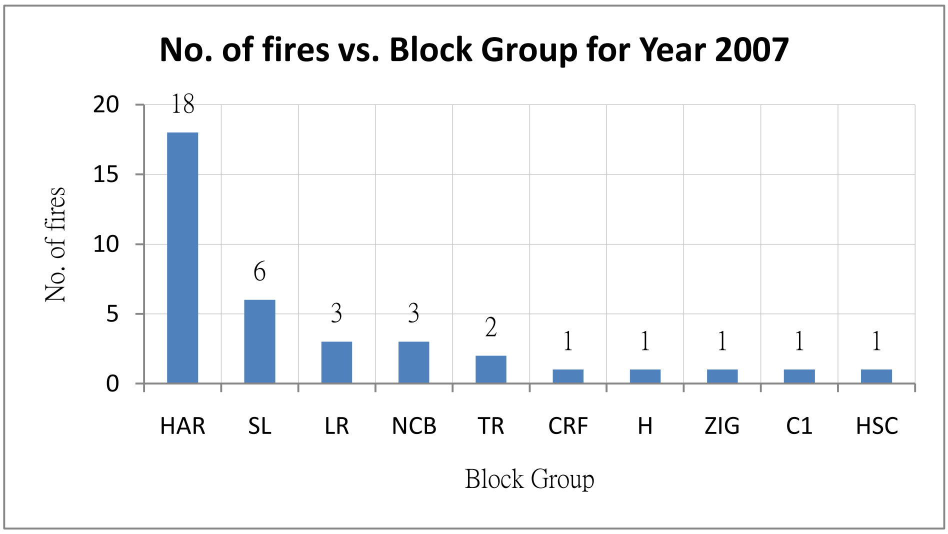


Figure 5.14 No. of fires vs. Block Group for Year 2007

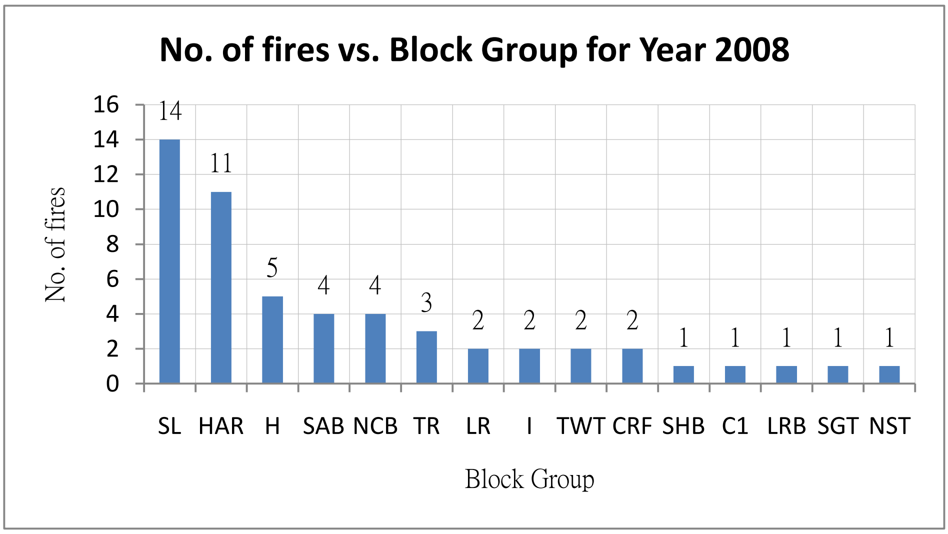


Figure 5.15 No. of fires vs. Block Group for Year 2008

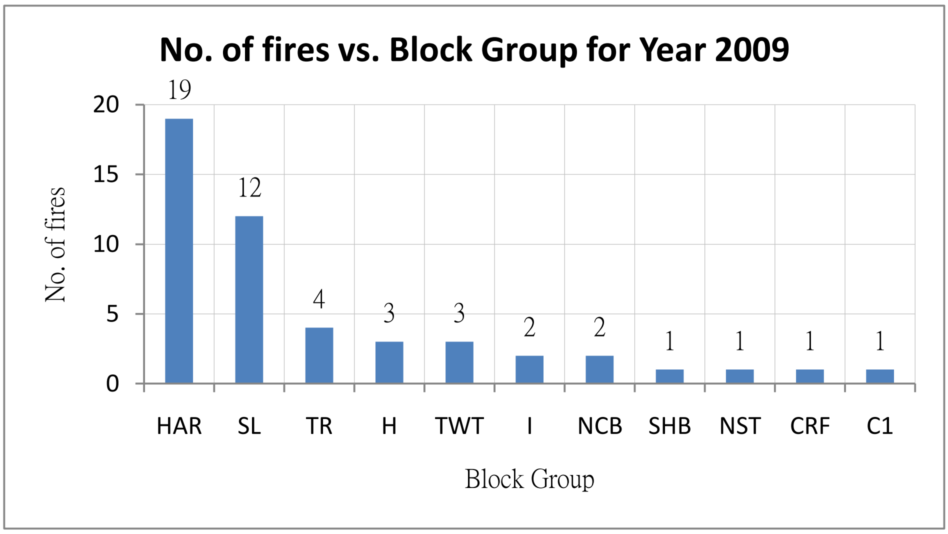


Figure 5.16 No. of fires vs. Block Group for Year 2009

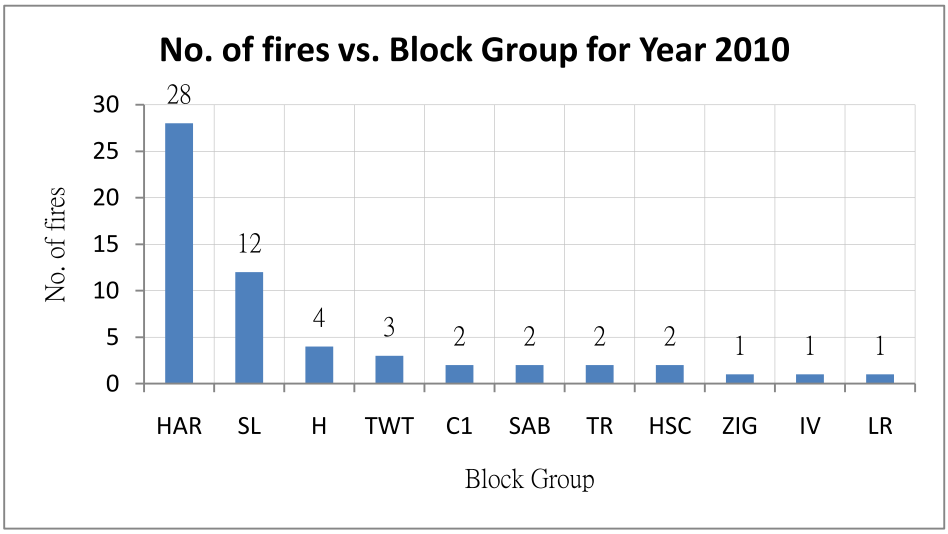


Figure 5.17 No. of fires vs. Block Group for Year 2010

In order to compare the number of fires occurring in each Block Group against the number of buildings belonging to that particular design, the normalised histograms are plotted as shown in Figures 5.18 to 5.22.

It has to be borne in mind that the exact number of blocks within each year is moving or changing; because a particular block may be demolished; or a new block is taken up by prospective tenants during that year. For analytical purpose, the cumulative number of fires at the year end would be counted against the number of buildings at the associated year end to arrive at the "No. of fires per block" in each year. In addition, these values will be averaged out over the 5 years to give the "Average no. of fires per block per year" and is plotted against the Block Group in Figure 5.23.

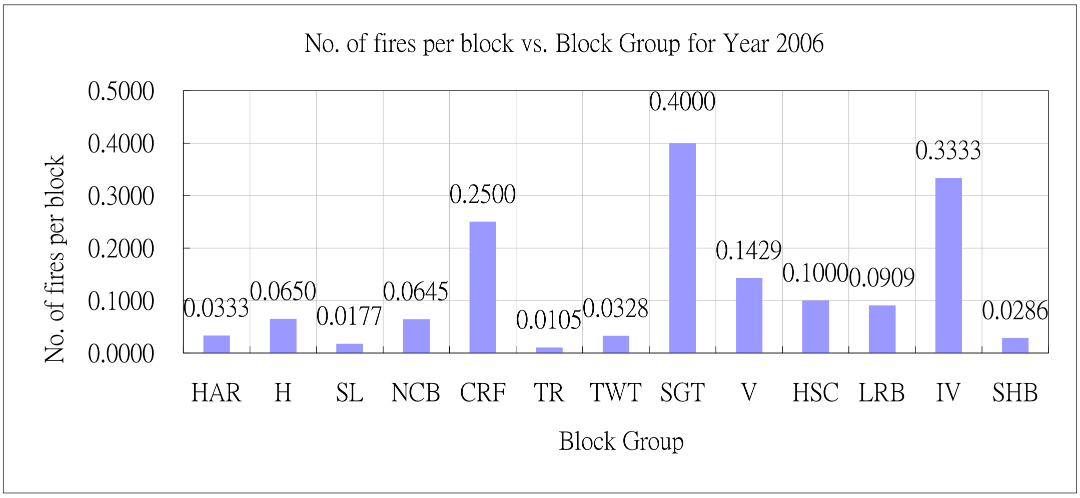


Figure 5.18 No. of fires per block vs. Block Group for Year 2006

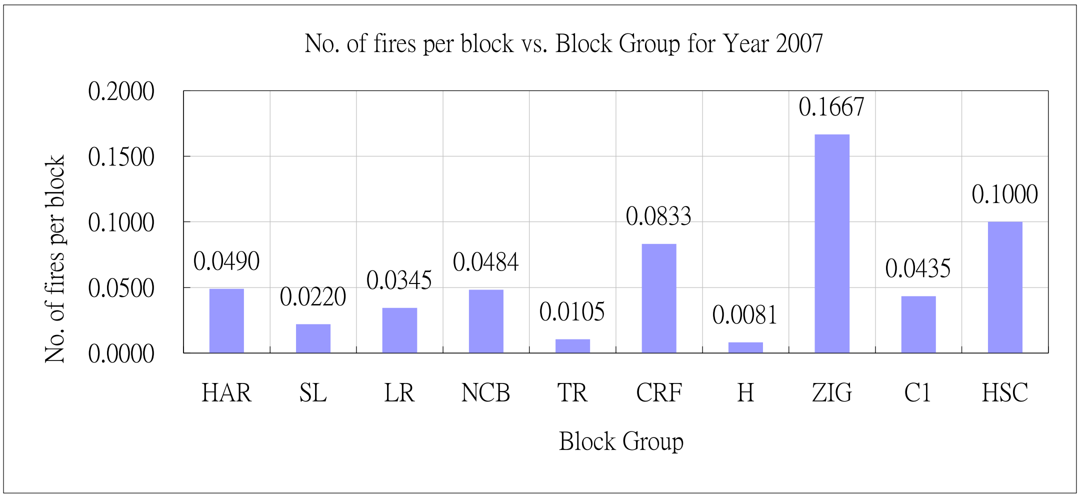


Figure 5.19 No. of fires per block vs. Block Group for Year 2007

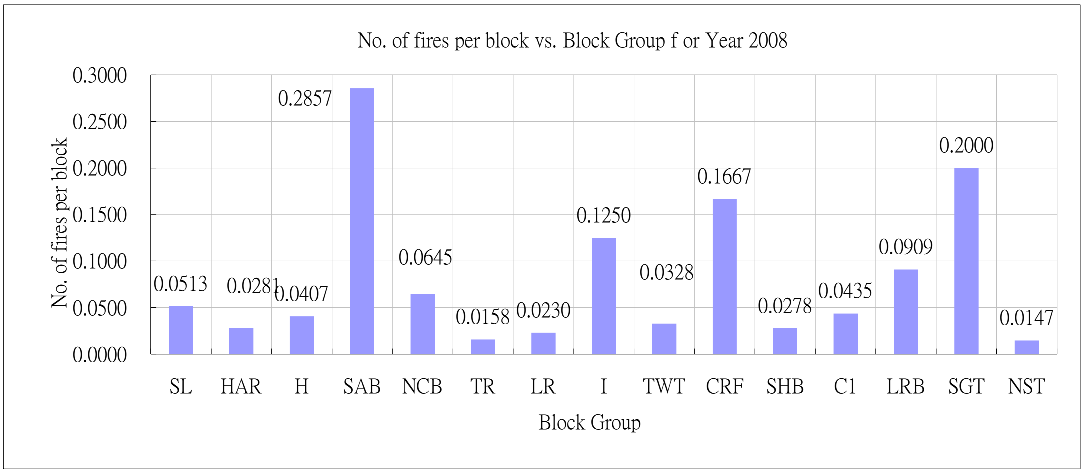


Figure 5.20 No. of fires per block vs. Block Group for Year 2008

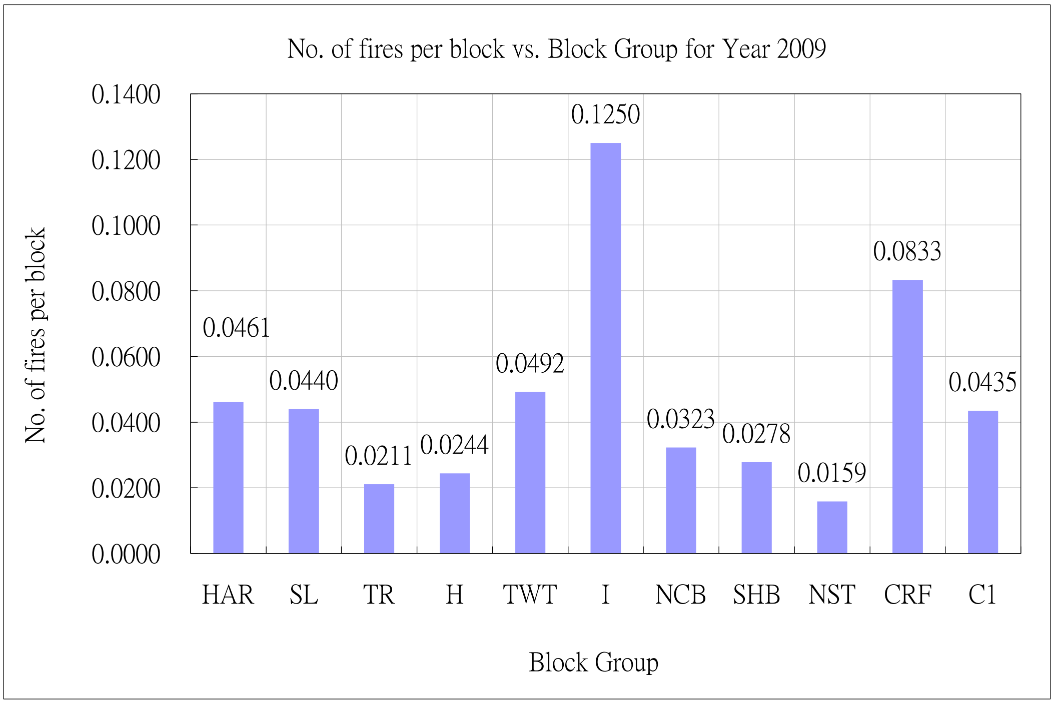


Figure 5.21 No. of fires per block vs. Block Group for Year 2009

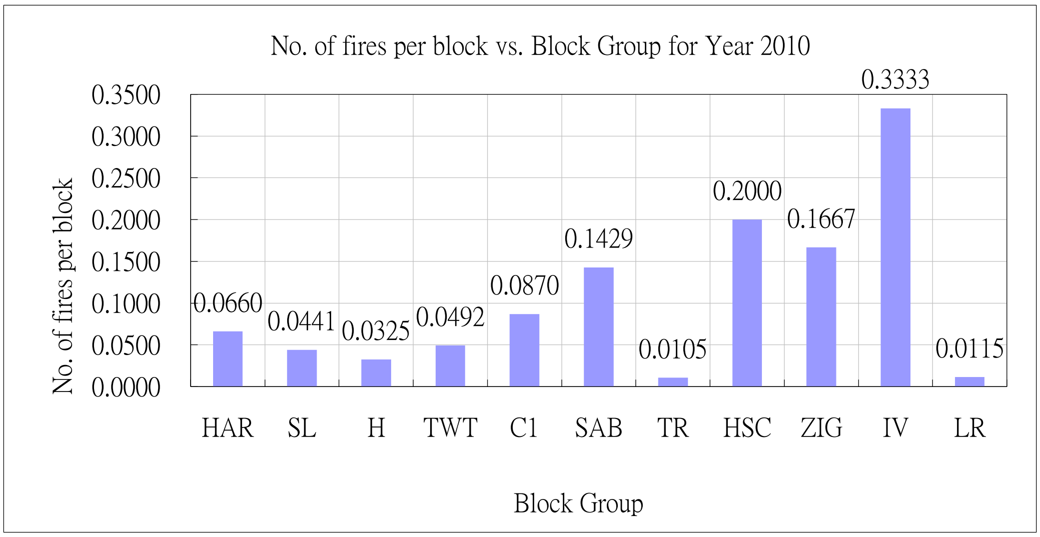


Figure 5.22 No. of fires per block vs. Block Group for Year 2010

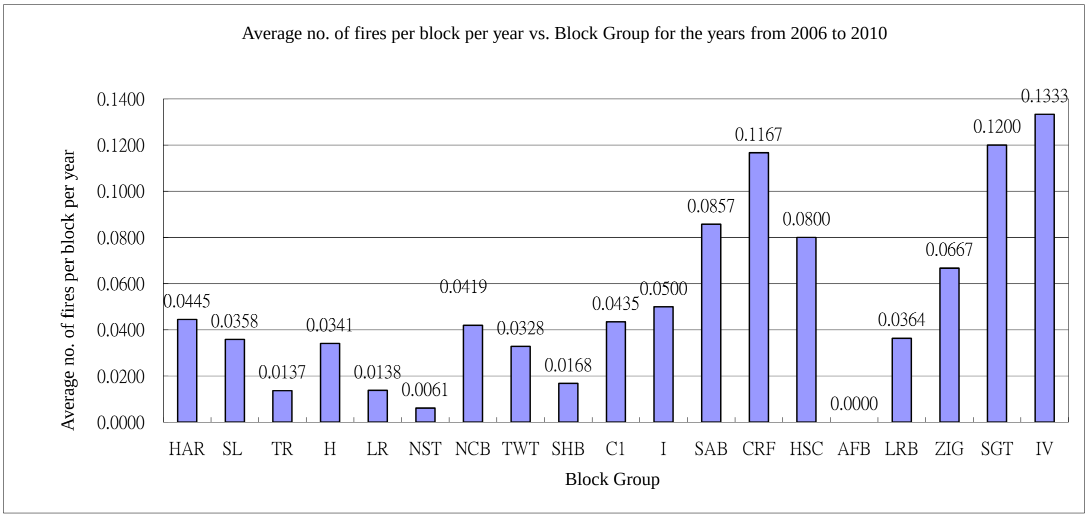


Figure 5.23 Average no. of fires per block per year vs. Block Group for the Years from 2006 to 2010

From the normalized histograms, there is no empirical evidence to suggest that those buildings of older design (such as Slab, H, and Twin Tower) have a higher frequency of fire occurrence. When we look at Figure 5.23, it is observed that the average number of fires per block per year for most Block Groups (HAR, SL, H, NCB, TWT) is in the region of 0.03 to 0.04. As highlighted previously, the ignition frequencies for Trident and Linear series are relatively low. There are spikes in some Block Groups such as CRF, SGT, and IV. This can be attributed to the relatively small number of building stocks of such design which cause “noises” in the statistical rates of fires.

5.7 Discussion

The number of fire incidents in the PRH buildings has been analysed empirically based on the fire incident record from 2006 to 2010. The ignition frequency of buildings is the fundamental parameter for fire risk analysis. It is observed that the fire frequency in PRH is quite low. The number of fire incidents ranges from 43 to 58 with the number of blocks ranging from 1,381 to 1,420 in the years from 2006 to 2010.

At the same time, the number of fires per block in each Block Group remains almost in similar order of magnitude. The fire risk level in terms of the chance of occurrence can be considered to be equivalent amid the different design regimes across older and modern housing blocks. While some may raise that the chance of having similar ignition frequencies in these buildings may be attributed to the similar living habits or life styles of the tenants in PRH, this is not necessarily true because the living habits may change with time, and the awareness of tenants may rise with more education. The improvement in design and provisions of the newer blocks may also modify the life styles of the tenants as well. On the other hand, a possible explanation on the similar ignition frequencies amongst the different Block Groups could be due to the organized FSM system in place. Nevertheless, the consequence of fires such as fatality or injury rate cannot be reviewed due to the limited information available from the database.

In future, it is highly recommended that the FIRS be enhanced to embrace information on:

- Room of fire origin (RFO)
- Items first ignited
- Spread of fire beyond RFO
- Number of fatality and injuries

The database can be built up in the coming years such that more detail empirical analysis can be made with regard to the fire risk in PRH. Only when more detail statistical information is available can more robust analysis be carried out (e.g. Richardson, 2001). The analytical results can manifest the aspects of risk factors that warrant special attention and the management tactics to mitigate the hazard. Design of new buildings in future can be improved through addressing the deficiency if found. While it may be quite tedious in the beginning, a concerted effort can be shared between the HKHA and the FSD as a long term goal.

5.8 Summary

This Chapter provides an introduction to the Poisson modeling of fire occurrence in buildings. An analysis on the fire incidents in HKHA buildings based on the fire incident records from 2006 to 2010 is also conducted. The annual ignition frequency is found to correlate well with the number of HKHA building stocks, i.e., ignition frequency increases with the number of blocks.

It seems that the chance of having a fire will increase with human activities. For example, there are more fires in winter time in PRH when there are likely to have more festive activities and a greater propensity of people to stay indoors. On daily basis, more fire incidents would occur in day time, possibly due to cooking. Such characteristics are quite similar to other countries like China, Finland, US and UK.

In addition, the ignition frequency of each Block Group of PRH is analysed empirically and is found to increase with the number of blocks of that particular design. On the other hand, there is no observed overall significant variation in the number of fires per block for each Block Group within the 5 years; despite those older blocks may not be designed as per the current fire codes in comparison with those newer design blocks. One of the possible reasons is due to the high standard of FSM system in place amongst all the estates managed by HKHA. With very good management and fire prevention measures, the chance of having fire to start is effectively reduced.

CHAPTER 6 Fault Tree Analysis of Fire Safety Level of HKHA Buildings

6.1 Introduction

In Chapter 2, the fire risk assessment methods have been reviewed and the quantitative method is chosen as a suitable method for estimating the contribution of FSM on the reduction of fire risk. In this Chapter, the fundamentals of Fault Tree Analysis as a quantitative risk assessment technique will be discussed. Subsequently, the technique will be deployed to study conceptually the reduction in risk level of the PRH buildings with organized FSM in place.

6.2 Principles of Fault Tree Analysis (FTA) and Event Tree Analysis (ETA)

Fault Tree Analysis (FTA) was developed in 1962 by the Bell Telephone Laboratories for the US air force for the purpose of determining the possibilities of an inadvertent launch of a minuteman missile and of an inadvertent arming of a nuclear device (Walter, 1987). Nowadays, it is frequently used for the reliability and risk analysis of various engineering process and systems. It is a “top down” or deductive process which starts with a postulated event, namely the top event, and works downwards until all the causes of the top event are identified. The results of the FTA procedures will culminate in a diagram showing the combinations of procedural or equipment failures that lead to the top event; which is a fire in this context.

Usually, the analysis will be presented in the form of a logical diagram with typical AND, OR, INHIBIT, and TRANSFER gates etc. and down to the basic events. The diagrams are usually presented in a vertical format with graphical symbols as per international standard (BSI, 1991) as shown in Figure 6.1.

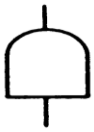
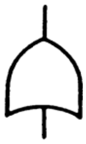
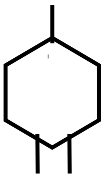
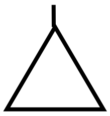
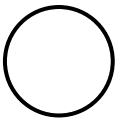
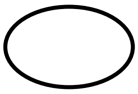
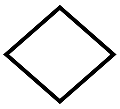
Symbol	**Function**	**Description**
	AND gate	Event occurs only if all the input events occur simultaneously.
	OR gate	Event occurs if any of the input events occur, either alone or in any combination.
	Exclusive-OR gate	Event occurs only if one of the input events occurs alone (used typically with two input events).
	INHIBIT gate	Event occurs only if both input events occur. One of the input events represents a conditional event. It is actually a special case of AND gate.
	TRANSFER gate	It indicates that this part of the fault tree is developed in different part of the diagram.
	Basic Event	Event which cannot be subdivided.
	Conditional Event	Event that is a qualifying condition before the input can produce the output. It is mainly used in conjunction with the INHIBIT gate.
	Undeveloped Event	Event which is yet to be developed.

Figure 6.1 Fault Tree Symbols (BSI, 1991)

FTA may be used to identify the causes and pathway that will lead to the occurrence of the top event. It will provide a qualitative analysis of a system to project the minimal cut sets which are defined as sets that contain the minimum events causing the top event to occur. If an event is removed from the minimal cut set, the remaining events will not cause the top event to occur on their own. These critical events within the minimal cut sets provide the analyst an insight into the failure structure and focus can be put on the associated critical basic events for detail analysis. Alternatively, a quantitative approach can be adopted to input the various probabilities of the basic events so as to calculate the probability of occurrence of the top event.

Contrary to FTA, the Event Tree Analysis (ETA) is a “bottom up” or inductive process. ETA seeks to identify the ultimate consequence of an initiating event such as the extent of damage or fatality following a fire. The ETA starts with an initiating event and develops the possible outcomes through a network of branches. At each branch, a question is raised describing a further event that is intended to result in a “Yes” or “No” answer. A succession of the inductive process builds up an overall event tree with a set of probable outcomes.

ETA can be used qualitatively for modeling different incident scenarios following the initiating event, and how the outcomes affected by the introduction of various treatment or control measures designed to mitigate the undesired outcomes. If the conditional probabilities of each branch events are known, the probabilities of the outcomes can be found accordingly. The quantitative analysis can assist to identify the effectiveness of the mitigation measures or to consider the acceptability of the controls by checking the outcome probabilities against tolerance thresholds.

6.3 Mathematics of FTA

As a quantification process for finding the probability of the top event, Boolean algebra and probability theory are applied (Modarres, Kaminskiy, and Krivtsov, 2010). The mathematical details of FTA manipulation are discussed in the "Fault Tree Handbook with Aerospace Applications Version 1.1" by National Aeronautics and Space Administration of USA (NASA, 2002).

Consider that X_1, X_2, X_3,………., X_n are the input events to an AND gate, the output event X_o is given by:

$$X_o = X_1 \cap X_2 \cap X_3 \cap \ldots\ldots\ldots\ldots\ldots \cap X_n \tag{6.1}$$

where the symbol $\cap$ represents the intersection of the events.

If the same events are input to an OR gate, the output event Y_o is given by:

$$Y_o = X_1 \cup X_2 \cup X_3 \cup \ldots\ldots\ldots\ldots\ldots \cup X_n \tag{6.2}$$

where the symbol $\cup$ represents the union of the events.

In order to obtain the top event probability, the following formulas can be used in conjunction with the laws of probability. For an AND gate with statistically independent events X_1, X_2, X_3,……., $X_{n,}$, the top event probability is given by:

$$P(X_1 \cap X_2 \cap X_3 \cap \ldots \cap X_n) = P(X_1)xP(X_2)xP(X_3)x\ldots xP(X_n) \qquad (6.3)$$

The probability of occurrence of an output event for an OR gate is obtained from the additive law of probability. Consider an OR gate with two statistically independent input events X_1 and X_2, the top event probability is given by:

$$P(X_1 \cup X_2) = P(X_1) \cup P(X_2) - P(X_1) \cap P(X_2) \qquad (6.4)$$

For n inputs of X_1, X_2, X_3,……., X_n ,

$$P(X_1 \cup X_2 \cup X_3 \cup \ldots\ldots \cup X_n) =$$

$$\sum_{i=1}^{n} P(X_i) - \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} P(X_i \cap X_j) + \sum_{i=1}^{n-2} \sum_{j=i+1}^{n-1} \sum_{k=j+1}^{n} P(X_i \cap X_j \cap X_k) \ldots + (-1)^n P(X_1 \cap X_2 \cap \ldots . \cap X_n) \qquad (6.5)$$

Where Σ is the summation sign.

If we ignore the cases of any two or more of the events X_i occurring simultaneously, the above equation can be reduced to:

$$P(X_i \cup X_2 \cup \ldots . \cup X_n) = \sum_{i=1}^{n} P(X_i) \qquad (6.6)$$

For simple to medium size fault trees, it is possible to carry out hand calculation to find out the probabilities and cut sets. However, for large fault trees, it is very tedious to perform hand calculation and arithmetic errors may easily be introduced. Under the circumstances, it is more efficient to deploy software packages because they work faster and are capable of offering more in-depth analysis such as sensitivity analysis through computing resources.

6.4 Procedures for construction of fault tree

The construction of a fault tree requires that the analyst be highly familiar with the concerned system and process and the intervening events be presented rationally. The steps of constructing the fault tree are shown as follows (e.g., USNRC, 1981):

- The top event to be analysed is first defined. This may be a failure of a system or an outcome of the failure.
- Starting from the top event, the immediate causes leading to the top event are identified.
- Each of the immediate cause is analysed to identify the failure mode or further immediate causes.
- The above procedure is repeated and followed to a lower system until the causes cannot be broken down further. In a hardware engineering system, this is usually the component level; whereas in an engineering process, this is usually the root cause of the undesirable outcome. The events at the lowest possible level of the system are then the basic events.
- Probabilities can be assigned to the basic events to evaluate the probability of the top event.

6.5 Advantages and limitations of FTA

FTA is frequently deployed for risk analysis in various disciplines such as chemical industry and fire safety engineering. It has numerous advantages as follows:

- It is highly systematic but sufficiently flexible to allow analysis of a myriad of factors.
- It is especially useful for analyzing systems with many interfaces and interactions.
- The pictorial presentation allows us to understand and visualize the system behaviour and the intervening process. For complex system, computer software can be utilized to assist in analysis.
- The analysis and the identification of the minimal cut sets serve as a tool to sort out the critical events and pathways leading to the occurrence of the top event, which would otherwise be overlooked in complex systems.

On the other hand, there are some limitations of FTA which should be considered at the same time.

- Uncertainties in the basic events can lead to uncertainties in the top event. Therefore, sensitivity analysis should be conducted if the probabilities of the basic events are not exactly known.
- In some situations, the casual events may not have been included in the analysis and hence the pathway to the top event may be restricted.
- FTA is a static model and would not address time interdependencies.

- FTA is a model which is not an absolute fidelity of the actual system. The result of analysis is relative.

6.6 Application of the software from Isograph

ISOGRAPH was founded in 1986 and is now one of the world's leading companies in the development and provision of integrated Reliability, Availability, Maintainability and Safety software products. The company has offices near Manchester, UK; and Irvine, California. The company has developed the "Fault Tree+" software which is a specialised yet user-friendly software for fault tree and event tree analysis operating on a Microsoft window environment (Isograph, 2008). The software is capable of solving large and complex fault trees in the order of 20,000 gates and 20,000 basic events; and producing the full minimal cut set representation for top event and event tree consequence. Alongside with that, the programme can provide importance analysis, uncertainty and sensitivity analysis facilities. Since this research project aims to compare the quantitative effect of organized FSM towards the reduction of fire risk in residential buildings using FTA approach, version 11.2 of the "Fault Tree+" software is deemed suitable for the purpose and will be utilized as an analytical tool.

6.7 Causes of fires

Before constructing the fault tree for fire risk assessment, it would be assumed that the undesirable outcome, i.e. the top event, is "A flat on fire". The causes of fires in various countries have been studied previously in the literatures and are described as below.

6.7.1 Study of causes of fires in China

China is the largest developing country in the world and the bourgeoning economy has brought about more fire incidents and hence more research on fire science. The fire situation is not too clear in China due to difficulty of obtaining the data. Yang et al. (2002) have analysed the statistical information for the year 1998 with a total of 142,326 fire incidents (excluding forest fires, grass fires and military fires) reported. It is noted that the fire frequency is related to the economic situation of different regions, where fire per million persons occur more often in more developed regions such as East China in comparison with less prosperous regions such as the Northwest area. They observe that the share of fires in dwelling houses is about 40% of the total and the percentage of death is 57%. Additionally, the major causes of fires are as follows:

Table 6.1 Causes of fires in China in 1998

Causes of fires	**Percentage (%)**
Electricity	**27.5**
Improperly using fire in daily life	**25.5**
Smoking	**9.5**
Disregarding safety rules	7.1
Play with fire	6.5
Arson	6.1
Spontaneous combustion	1.4
Thunder strike	0.3
Others	8.0
Unknown	7.9

The table reveals that “Electricity” and “Improperly using fire in daily life” are the major causes. It has to be noted that the traditional Chinese custom of setting fireworks in festive occasions are also classified as “Improperly using fire in daily life”, which is a notable cause of accidental fires.

With regard to fatal fires, the major causes differ slightly as reproduced in Table 6.2.

Table 6.2 Causes of fatal fires in China in 1998

Causes of fatal fires	**Percentage (%)**
Improperly using fire in daily life	**27.0**
Electricity	**17.8**
Disregarding safety rules	**14.3**
Arson	10.9
Smoking	9.7
Unknown	7.5
Others	7.1
Play with fire	4.4
Spontaneous combustion	1.0
Thunder strike	0.0

By and large, the leading causes of fatal fires are “Improperly using fire in daily life" (27.0%), “Electricity” (17.8%) and “Disregarding safety rules” (14.3%). In China, the classification of “Disregarding safety rules” refers to human errors. It appears that more education and training to improve the skills of operators and the fire safety knowledge of the public are necessary in order to shoot down this casual factor resulting in fire death.

6.7.2 Study of causes of fires in Japan

In a bid to learn from other developed countries on the experiences in mitigating the life loss due to accidental fires, Sekizawa (1994) has collected the fire data of Japan from the year 1985 to 1989 and compared with the statistical figures in US and UK. He found that residential fires in Japan accounts to 51.5% of all fire incidents; and the share of residential fire deaths accounts to 89.4% of all fire deaths. The major causes of residential fires and the associated causes of fatal fires are shown in Table 6.3 and Table 6.4 respectively. It is noted that cooking is the most significant cause that contributes to 31.1% of the number of fire incidents in Japan. On the other hand, cooking in the US and UK counterparts contribute to 21.3% and 39.6% of the fire incidents. Regarding fire death patterns in the three countries, they are broadly similar, with higher death rates in Japan for the elderly. The pattern is particularly serious as the share of residential fire deaths for adults over 65 years is 47.0%. This can be attributed to the lesser escape capability of older or sick people. Fire preventive measures to tackle the high death rate for the elderly are particularly relevant in an aging society of Japan.

Table 6.3 Causes of fires for residential buildings in Japan from 1985 to 1989

Causes of fires	**Percentage (%)**
Cooking	31.1
Smoking	13.3
Heaters	12.7
Matches	7.2
Electric	6.4
Playing	6.4
Others	22.9

Table 6.4 Causes of fatal fires for residential buildings in Japan from 1985 to 1989

Causes of fatal fires for residential buildings	**Percentage (%)**
Smoking	27.7
Heaters	27.3
Matches	17.7
Others	16.9
Cooking	10.4

In another paper, Notake et al. (2007) attempt to study the effectiveness of residential fire safety measures by the types of houses (either single house or apartment) and their construction (either fire resistant or wooden) from 1995 to 2001. Since more people live in single houses, the fire frequency for this type of dwelling is higher. On the building construction, fire frequency rate per unit of dwelling is highest for wooden single house as expected. When aggregating together, they note that the major causes of residential fires are still “cooking appliance”, then followed by “cigarette” and “heating equipment”. Although the fire statistics from Sekizawa is a little out of date, the leading causes of residential fires appear to be unchanged as revealed by the paper from Notake et al. However, the daily or monthly variation patterns of fire incidents have not been reported in this paper.

6.7.3 Study of causes of fires in UK

In UK, Holborn et al. (2004) have analysed the fire incidents in London from 1996 to 2000 based on fire investigation results from London Fire Brigade Library. The distribution of fire damage size, fire growth rate, fire brigade arrival time were studied to find out the fire growth rate and fire damage area vs. (i) occupancy, (ii) source of ignition, (iii) effect of first-aid fire fighting by the occupants, and (iv) item first ignited. A total sample of 2,044 residential dwelling fires and 464 “other building type” fires were taken as part of the analysis. Regarding the “other building types”, they could be further classified into:

- Care homes
- Factories
- Colleges of higher education
- Hospitals
- Licensed premises
- Offices

- Public buildings
- Retails
- Schools
- Warehouses

They observed that both the frequency histograms of fire damage area and fire growth rate for residential dwellings and “other building types” fitted closely to a log-normal distribution.

As far as residential dwellings are concerned, they estimated that the fire damage areas (within 1,991 dwelling fires) from various sources of ignition are as follows:

Table 6.5 Fire damage areas of residential dwellings in UK from 1996 to 2000

Source of ignition	**Expected fire damage area (m^2)**
Home electrical appliances such as refrigerator and washing machine	3
Cooking appliances	4
TV and Hi-Fi equipment	5
Heating appliances	6
Candles	7
Smoking materials	7
Naked flame	8
Electrical supply and lighting	9

It is a bit surprising that the fire damage area arising from electrical supply and lighting is even higher than naked flame. One of the possible explanations is that fires of electrical nature may take longer time for detection. This gives us a hint that electrical installation should be accorded more attention in fire safety.

On the other hand, they also found that fire growth parameter is related to the source of ignition and the first item ignited within 481 dwelling fires as reproduced in Table 6.6 and 6.7.

Table 6.6 Fire growth parameter of residential dwellings vs. source of ignition in UK from 1996 to 2000

Source of ignition	**Estimated fire growth parameter (kW/s^2)**
Home electrical appliances such as refrigerator and washing machine	0.002
TV and Hi-Fi equipment	0.002
Candles	0.005
Smoking materials	0.005
Naked flame	0.005
Electrical supply and lighting	0.005
Cooking appliances	0.006
Heating appliances	0.012

Table 6.7 Fire growth parameter of residential dwellings vs. first item ignited in UK from 1996 to 2000

First item ignited	**Estimated fire growth parameter (kW/s^2)**
Electrical insulation	0.003
Curtain	0.004
Clothing	0.004
Bedcloth	0.005
Cooking oil	0.005
Paper and cardboard	0.006
Rubbish and packaging	0.008
Upholstered furniture	0.012
Flammable liquid	0.023

As revealed in Table 6.6, it is noted that the fire growth parameters for all heat sources are almost the same other than heating appliances. In addition, they concluded that flammable liquid was usually the first item ignited and it also gave a high fire growth rate. In residential dwellings, the fire growth rate is usually taken as "medium" with a typical value of 0.012 kW/s^2 (e.g., BSI, 2003a); whereas the threshold for "slow" fire is 0.0029 kW/s^2. Thus the statistical data manifested that the "medium" criterion is a good guidance for design purpose. Upholstered furniture which is a basic provision in home should therefore warrant our special attention; because it also gives a high fire growth rate.

As regards the major causes of 49,600 dwelling fires in 2008, the summary table 2 from the Department for Communities and Local Government UK (2010) is referred and converted into causes by percentages as shown in Table 6.8.

Table 6.8 Causes of fires for dwellings in UK in 2008

Causes of fires for dwellings	**No. of fires**	**Percentage (%)**
Playing with fires	300	0.60
Unspecified cause	600	1.21
Faulty fuel supplies	1700	3.43
Other accidental	4100	8.27
Careless handling of fire or hot substances	4200	8.47
Placing articles too close to heat	4200	8.47
Chip/fat pan fires	**4800**	**9.68**
Faulty appliances and leads	**7300**	**14.72**
Deliberate	8300	16.73
Misuse of equipment or appliances	**14200**	**28.63**

It is quite clear that the leading causes of accidental dwelling fires are misuse of equipment or appliances (28.63%), faulty appliances and leads (14.72%), and chip/fat pan fires (9.68%). Other major causes include careless handling of fire or hot substances (8.47%), and placing articles too close to heat (8.47%).

At the same time, dwelling fires deaths in 2008 account for 78% of all deaths from fire incidents. The major causes of the fatal fires for dwellings are also extracted from the Department for Communities and Local Government (2010) publication table 10 as shown below.

Table 6.9 Causes of fatal fires for dwellings in UK in 2008

Causes of fatal fires for dwellings	**No. of fires**	**Percentage (%)**
Playing with fires	2	0.57
Unspecified cause	18	5.10
Faulty fuel supplies	2	0.57
Other accidental	**40**	**11.33**
Careless handling of fire or hot substances (e.g. careless disposal of cigarettes)	**113**	**32.01**
Placing articles too close to heat	**30**	**8.50**
Chip/fat pan fires	19	5.38
Faulty appliances and leads	**30**	**8.50**
Deliberate	**59**	**16.71**
Misuse of equipment or appliances	28	7.93
Person too close/fell on fire	12	3.40

Again, the leading cause of fatal accidental dwelling fires is “careless handling of fire or hot substances” (32.01%) with mostly on careless disposal of cigarettes. It is then followed by other known causes of “placing articles too close to heat” (8.5%) and “faulty appliances and leads” (8.5%).

6.7.4 Study of causes of fires in US

In US, the National Fire Protection Association (NFPA) has estimated that, while residential structure fires account for 25% of the fires in the country, they account for 83% of fire deaths and 77% of fire injuries in 2005 (NFPA, 2006). Residential fires continue to be the focus on fire safety concern.

To understand the causes of fires in US, the report from the US Fire Administration “Residential Structure and Building Fires” (USFA, 2008) has been reviewed. In particular, the sections on 1&2 family and multi-family residential buildings will be taken for study as they represent 66% and 28% of the total number of residential structure fires in 2005. The general causes of fires for such building types in 2005 are further reported in Table 6.10 and 6.11 as follows:

Table 6.10 Causes of fires for 1&2 family residential buildings in US in 2005

Causes of fires for 1&2 family residential buildings	**Percentage (%)**
Playing with heat source	0.7
Arson	0.7
Other equipment	1.1
Smoking	1.7
Natural	1.9
Exposure	1.9
Appliances	2.1
Equipment Mis-operation	3.8
Intentional	4.3
Other heat	4.3
Open flame	5.7
Other Unintentional	5.8
Electrical malfunction	**7.8**
Heating	**12.9**
Unknown	21.7
Cooking	**23.4**

Table 6.11 Causes of fires for multi-family residential buildings in US in 2005

Causes of fires for multi-family residential buildings	**Percentage (%)**
Natural	0.4
Arson	0.4
Playing with heat source	0.5
Exposure	1.1
Appliances	1.3
Other equipment	1.9
Smoking	2.1
Intentional	2.7
Other heat	2.8
Equipment Mis-operation	2.8
Electrical malfunction	2.9
Other Unintentional	3.5
Open flame	**3.7**
Heating	**6.1**
Unknown	13.8
Cooking	**54.2**

It is noted that cooking (23.4%), heating (12.9%), and electrical malfunction (7.8%) are the major causes of fires in 1&2 family buildings. For multi-family buildings, the major causes of fires are cooking (54.2%), heating (6.1%) and open flame (3.7%). Fires caused by electrical malfunction become 2.9% probably due to better maintenance of the electrical installation in multi-family apartments. Generally, the causes of fires in residential buildings mainly comes from cooking, heating, open flame and electrical malfunction.

As far as fatal residential fires for 1&2 family buildings are concerned, the major causes are smoking (10.1%), unintentional and careless in the use of products (9.3%) and electrical malfunction (6.5%). For fires involving injuries, the major causes are cooking (16.5%), open flame (10.1%), unintentional and careless in the use of products (10.1%), and electrical malfunction (7.6%).

On the other hand, for fatal residential fires in multi-family buildings, the major cause are smoking (17.9%), open flame (7.4%), electrical malfunction (5.6%), and unintentional and careless in the use of products (5.6%). For fires involving injuries, the major causes are cooking (27.8%), unintentional and careless in the use of products (9%), and open flame (8.5%).

6.7.5 Study of causes of fires in Taiwan

In Taiwan, Chi et al. (2004) has analysed 311 large fire incidents or conflagrations in Taiwan from 1985 to 2004 comprising 40 fire cases in residential buildings, 68 fire cases in business buildings, 185 fire cases in factory buildings and 18 fire cases in other buildings. They determined to take these fire cases with greater loss because it is more worthy of study into the causes and analysis of the weight value. The fire hazard level of large fire or conflagration is based on the research by Yang et al. (2002) and is reproduced in Table 6.12.

Table 6.12 Ranking Standard of Fire Hazard Levels

Fire damage ranking	**Death (person)**	**Badly injured (person)**	**Death and Badly injured (person)**	**Damaged residence**	**Direct property loss (thousand NT Dollars)**
Conflagration	≧10	≧20	≧20	≧50	≧4000
Large fire	≧3	≧10	≧10	≧30	≧1200
Ordinary fire	＜3	＜10	＜10	＜10	＜1200

Based on the statistical analysis, they found that the major causes of the fires in the 40 cases of residential buildings as per Table 6.13. It is identified that misuse of gas and electricity; and damaged electrical appliances are the two major causes. They further concluded that these causes generally apply to almost all types of buildings.

Table 6.13 Causes of fires for residential buildings in Taiwan from 1985 to 2004

Causes of fires for residential buildings	**No. of fires**	**Percentage (%)**
Malfunctioned or damaged electric appliances and machinery	12	30.0
Inaccurate usage of fire, gas, and electricity	11	27.5
Inaccurate usage of public hazardous materials	5	12.5
Arson	11	27.5
Unidentified reason	1	2.5

Regarding the causes leading to fatality in residential fires, Hsiung, Chien and Wu (2007) have analysed the fire records of the Taipei City Fire Department from 2003 to 2006 and found that the leading causes of 21 fatal residential fires in this period as follows.

Table 6.14 Causes of fatal fires for residential buildings in Taipei from 2003 to 2006

Causes of fatal fires	**No. of fires**	**Percentage (%)**
Unintentional		
Electrical fault and defects	8	38
Discarded cigarette	6	28
Careless construction	1	5
Candles	1	5
Deliberate		
Suicide	3	14
Arson	2	10

The first two causes of electrical fault (38%) and discarded cigarette (28%) are generally in line with the situation in US.

Having reviewed the leading causes of fires in various countries from the literatures, it is noted that there are some similarities in the causes of residential fires although the studies are under different years. The leading causes are invariably related to "Cooking", "Smoking" or "Electrical" activities as shown below. Therefore, it is necessary to pay more concentration on such issues when dealing with education to the public on fire prevention.

Table 6.15 Summary of causes of residential building fires in various countries/region

Country/Region	**Major causes of residential fires**		
China	Electricity (27.5%)	Improperly using fire in daily life (25.5%)	Smoking (9.5%)
Japan	Cooking (31.1%)	Smoking (13.3%)	Heaters (12.7%)
UK	Misuse of equipment or appliances (28.63%)	Faulty appliances and leads (14.72%)	Chip/fat pan fires (9.68%)
US (Multi-family residential buildings)	Cooking (54.2%)	Heating (6.1%)	Open flame (3.7%)
Taiwan	Malfunctioned or damaged electric appliances and machinery (30.0%)	Inaccurate usage of fire, gas, and electricity (27.5%)	Inaccurate usage of public hazardous materials (12.5%)

Table 6.16 Summary of causes of fatal residential building fires in various countries/region

Country/Region	**Major causes of fatal residential fires**		
China	Improperly using fire in daily life (27.0%)	Electricity (17.8%)	Disregarding safety rules (14.3%)
Japan	Smoking (27.7%)	Heaters (27.3%)	Matches (17.7%)
UK	Careless handling of fire or hot substances (e.g. careless disposal of cigarettes) (32.01%)	Placing articles too close to heat (8.50%)	Faulty appliances and leads (8.50%)
US (Multi-family residential buildings)	Smoking (17.9%)	Open flame (7.4%)	Electrical malfunction (5.6%), Careless in the use of products (5.6%)
Taipei	Electrical fault and defects (38.0%)	Discarded cigarette (28.0%)	Careless construction (5%)

By comparison among the leading causes of fatal residential fires in several countries, it is noted that smoking (usually the careless disposal of cigarettes) is the most critical cause. This is reaffirmed by the statement emphasizing on the fire problem relating to smoking: “There is no substitute for prevention when a victim is “intimate with ignition”. For a victim recorded as “intimate with ignition,” the fire begins so close to him or her that it is very difficult to survive long enough for active or passive fire protection to save him or her (USFA and NFPA, 2006, pp. 5)”.

6.8 Identification of the causes of fires for the PRH through questionnaire

As revealed by the fire statistics by FSD in Chapter 1, the major causes of fire in Hong Kong in 2010 are:

- Food stuff (stove overcooking) (4.42%)

- Careless handling or disposal of cigarette ends, matches and candles (3.84%)
- General electrical fault (1.99%)
- Careless disposal of joss sticks, joss paper and candles etc. (0.45%)
- Over-heating of engines, motor and machinery (0.23%)
- Sparks from welding and oxygen acetylene cutting (0.14%)
- Children playing with matches (0.13%)
- Control burning (0.005%)

For a domestic household fire, only 6 causes are considered directly relevant. These 6 causes will therefore become the first level of causes of the fault trees, namely:

- Cooking
- Cigarette disposal
- Electrical fault
- Joss stick disposal
- Overheating of electrical appliance
- Children playing with fire

In order to further identify the sub-causes of these major causes and the underlying events, a questionnaire has been prepared and distributed to various professionals working in the property management and maintenance sector to seek their professional opinions as described below.

6.8.1 Elicitation of expert opinions by means of questionnaires

The expert opinion elicitation process is defined as a formal heuristic process of gathering information and data or answering questions on issues or problems of concern (Ayyub, 2001, pp. 234). This is particularly useful when there is a lack of information at the current state of knowledge. Although there is no universal definition of expert, Shields et al. (1987) suggests that experts should be from persons who are involved in the area of study and possess some formal qualifications such as membership of a professional body. Ayyub (2001, pp. 98) describes an expert as “a very skillful person who had much training and has knowledge in some special field. Someone can become an expert in some special field by having the training and knowledge to a publicised level that would make him or her recognized by others as such.” Common protocols for good practice of expert opinion elicitation are also suggested in the literature (Yoe, 2012, pp. 376).

In the present research, the purpose of the elicitation process is to get an estimate on the quantitative contribution of FSM on the reduction of likelihood and consequence of fires in residential buildings. Professionals including Building Services Engineers (BSE), Building Surveyors (BS) and Estate or Facility Managers (EM) are identified as appropriate persons for eliciting their expert views. For instance, a BSE is usually engaged in the design, specification, installation and maintenance of various electrical and mechanical services in buildings including fire protection systems. A BS is an expert on building and fire safety ordinances, building construction planning, design and maintenance of the building fabric. In the case of HKHA, a BS who is deployed in the maintenance and improvement works of building fabric and structure is deployed as a maintenance surveyor. On the other hand, EM is the professional responsible for the day to day property and facility management issues such as housekeeping, safety and security; as well as tenancy matters. In general, the professional activities of these practitioners embrace the maintenance and management of active and passive fire safety systems of buildings, and property management as a whole. Hence they will be the target professionals for being the respondents.

6.8.2 Design and construction of the questionnaire

Questionnaires are frequently used in quantitative research in social science. When properly designed, they are valuable tools to gather a wide range of information from a large number of individuals. In this research project, a questionnaire is constructed to obtain the experts' opinions regarding the quantitative contribution of FSM towards the reduction of fire probability and consequence.

The questionnaire is divided into 4 Parts. Part 1 will request the interviewees to fill in the background information about their professions, working experiences, business nature and type of property being managed etc. Such information provides a general profile of the respondents.

Part 2 of the questionnaire will seek to understand the degree of awareness of the professionals on the causes of fires happening inside residential units; and these 6 common causes are primarily as recorded by the Hong Kong Fire Services Department after putting out the fires. To this end, a 5 point Likert Scale[7] ranging

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[7] Likert Scale is a psychometric scale developed by a psychologist Rennis Likert (e.g., Clark-Carter, 1997). It is a widely adopted approach to scale response in survey and research.

from “Fully Aware”, “Very Aware”, “Aware”, “Slightly Aware” and “Not Aware” has been designed. While a scale of 1-10 can be used, the 5-point scale is by far the most popular one because it is relatively simpler to use yet with sufficient degree of reliability. Recent research has shown that a 5 or 7-point scale may produce a slightly higher mean scores relative to the highest possible attainable in comparison with those obtained from a 10-point scale (Dawes, 2008). However, the purpose here is merely to gauge the general knowledge level on fire safety of the professionals with an ordinal scale (i.e. the relative position of items) and hence a 5-point scale would suffice. Based on the common causes identified, this Part of the questionnaire continues to elicit the experts on the probable underlying sub-causes and the basic events which will lead to the occurrence of residential fires.

The questionnaire is further designed in way to elicit the experts’ opinions on the expected percentage reduction in the likelihood of a fire from occurring, or the consequence of a fire incident as a result of the organized and enhanced FSM system being put in place. The enhanced FSM is basically the practice of the Hong Kong Housing Authority which is considered to be above the basic requirements of relevant legislations, e.g., the increase in the frequency of checking for the fire fighting systems. These views or engineering judgements from the experts will be recorded in Parts 3 and 4 respectively. These two Parts of the questionnaire are central to the analysis because they will be applied for estimating the reduction in the risk level as a result of organized FSM later on. In order to obtain a better understanding on the expected percentages, the ratio scale (i.e. the scale will indicate the magnitude of difference and there is a fixed zero point) should be seriously considered. It is quite difficult for the respondents to decide on the expected percentage if it is designed on a scale with a wide magnitude of difference. A split of 10% in the percentage interval is considered optimum in the application and the interviewees can enter their expected percentage accordingly. This 10-point scale will provide a reasonable degree of information for analysis while not overburdening the respondents.

Finally, the interviewees will be invited to give their overall comments on issues relating to FSM in residential buildings. A sample of the questionnaire is attached in Appendix B.

6.8.3 Approach of sampling the respondents

Unlike ordinary opinion research survey where the sample size can be estimated given the tolerable sampling error and the level of confidence required (e.g., Fellows and Liu, 1997, pp. 124), there is no precise indication on the number of experts to be involved in an elicitation exercise. It hinges on the degree and depth of information required, as well as the availability of experts. Sometimes, the questions cover a wide spectrum of knowledge and experts from different areas of expertise are necessary. Take the case of traditional Delphi technique, some literatures just suggest that the minimum size of the panel of experts to be no less than 10 members (Mitchell, 1991).

In this expert opinion elicitation exercise through questionnaires, the interviewing process of the respondents is arranged in two batches. Firstly, 31 returns from the respondents are collected. This is served as the test-out of the questionnaire and to assess whether the views of the respondents are independent of their training background. Later on, an additional 70 respondents are invited making a total of 101 questionnaire returns. It is expected that the total sample size is reasonable and manageable.

In order to verify whether the opinions from these 2 batches of samples are generally consistent, a statistical mean *t*-test is further conducted. An independent two sample mean *t*-test is commonly used to compare the values of the means from two samples and test whether there is significant difference in mean values between them (e.g., NIST, 2012). For a *t*-test with 2 samples of unequal sizes and variances, the test statistic can be evaluated from the following equation.

$$t = \frac{Y_1 - Y_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}} \quad (6.7)$$

where N_1 and $N2$ are the size of the two samples,

Y_1 and Y_2 are the means of the two samples, and

S_1^2 and S_2^2 are the variances of the two samples.

Furthermore, the degrees of freedom *df* (i.e. the number of values in the final calculation of a statistic that are free to vary) can be calculated as follows:

$$df = \frac{(\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2})^2}{\frac{(S_1^2/N_1)^2}{N_1 - 1} + \frac{(S_2^2/N_2)^2}{N_2 - 1}} \quad (6.8)$$

Once the *t*-statistic is determined, it can be compared with the critical value obtained from statistical tables under a selected confidence level, e.g. at 95%. If the *t* value is below the critical value, it can be inferred that the difference in the mean values of the 2 samples are statistically insignificant.

In the present research, the mean values of the expected percentages of reduction in the likelihood and consequence of fires from the 2 batches of questionnaire returns will be tested to see whether there is a significant difference in the views from the 2 batches of respondents. If their views are statistically consistent, the overall averages of the 101 questionnaires will then be adopted for the subsequent analysis by FTA technique.

6.8.4 Administration of the interview

Since the professionals are likely to be busy in their workplace, a prior telephone appointment would be made with them for the interview which is expected to last not more than one hour. While every reasonable endeavour is made to maximise the number of respondents participating in the interview, their rights to decline involvement are fully respected.

Before the interview starts, an introductory note will be given to the interviewees to outline the objectives of the research, i.e., to study the contribution of organized FSM towards the reduction of fire risk in residential buildings. In addition, it is intended to elicit the experts' opinions on the quantitative effect of organized FSM on the reduction in probability and likelihood of fire incidents by means of the questionnaire. It has to be highlighted that only life safety will be concerned in the study and property protection is not considered. A brief outline of the questionnaire design is then verbally communicated to the interviewees in order for them to have a general understanding and to facilitate their completion of each item without difficulty.

They are then encouraged to put down overall comments on FSM in the last session of the questionnaire. Some of the interviewees may be committed with other contingent appointment and they may elect to email the questionnaire upon completion afterwards.

The interviewees are acknowledged for their support and assistance in the interview. They will be kept anonymous that the information and opinions will only be used for academic purpose and will not be disclosed in other occasions.

6.9 Analysis of the returned questionnaires

6.9.1 Analysis of the first batch of samples

A total of 31 returns from the first batch of questionnaire sheets have been received from 14 BSE, 10 BS and 7 EM professionals. Amongst all the respondents, 24 professionals (77 %) are highly experienced with over 15 years in their professional practices. In addition, most of them (74%) are working in government organizations. The profiles and descriptive statistics of the respondents are summarized in Table 6.17.

Table 6.17 Profiles of the first batch of respondents

Profession	Years of experience	No. of respondents			
			Nature of organisation		
			Government	Public Utilities	Private
Building Services Engineer	10-15	3	8	3	3
	15-20	1			
	Over 20	10			
Building Surveyor	10-15	2	9	NIL	1
	15-20	5			
	Over 20	3			
Estate Manager	Below 5	1	6	NIL	1
	10-15	1			
	15-20	3			
	Over 20	2			
Total no. of respondents with over 15 years of experiences is 24 (i.e. 24/31=**77%**). Total no. of respondents working in government organization is 23 (i.e. 23/31=**74%**).					

With regard to the degree of awareness of the 31 respondents on the causes of fires, the summary is shown in Table 6.18 to 6.20. It is noted that the percentages of the respondents with the degree of awareness above the level of “Aware” are 86.9%, 91.7% and 90.5% respectively for the 3 professions of BSE, BS and EM. This means that all the professionals have a strong understanding on the causes of fire irrespective of their training background. When the number of respondents within each profession is taken into account, the overall weighted average of the percentage of awareness above the level of “Aware” becomes 89%.

Table 6.18 Awareness of the first batch of respondents (BSE) on the causes of fires in residential buildings

		No. of respondents				
Profession	**Causes of fires**	**Fully Aware (FA)**	**Very Aware (VA)**	**Aware (A)**	**Slightly Aware (SA)**	**Not Aware (NA)**
Building Services Engineer	Careless disposal of cigarette ends	7	4	3	NIL	NIL
	Cooking	5	5	3	1	NIL
	Electrical fault	9	2	3	NIL	NIL
	Careless disposal of joss sticks and candles	7	NIL	5	2	NIL
	Children playing with matches	6	NIL	2	5	1
	Overheating of machinery	5	4	3	2	NIL
No. of answers with “Aware” and above is 73, and the total no. of possible answers is 84 (14 respondents vs. 6 causes of fires). The percentage of answers with “Aware” and above is **86.9%** (i.e. 73/84).						

Table 6.19 Awareness of the first batch of respondents (BS) on the causes of fires in residential buildings

		No. of respondents				
Profession	**Causes of fires**	**Fully Aware (FA)**	**Very Aware (VA)**	**Aware (A)**	**Slightly Aware (SA)**	**Not Aware (NA)**
Building Surveyor	Careless disposal of cigarette ends	3	2	4	1	NIL
	Cooking	5	5	NIL	NIL	NIL
	Electrical fault	6	3	1	NIL	NIL
	Careless disposal of joss sticks and candles	3	2	4	1	NIL
	Children playing with matches	4	2	3	1	NIL
	Overheating of machinery	3	4	1	2	NIL
No. of answers with "Aware" and above is 55, and the total no. of possible answers is 60 (10 respondents vs. 6 causes of fires). The percentage of answers with "Aware" and above is **91.7%** (i.e. 55/60).						

Table 6.20 Awareness of the first batch of respondents (EM) on the causes of fires in residential buildings

		No. of respondents				
Profession	**Causes of fires**	**Fully Aware (FA)**	**Very Aware (VA)**	**Aware (A)**	**Slightly Aware (SA)**	**Not Aware (NA)**
Estate Manager	Careless disposal of cigarette ends	3	1	2	1	NIL
	Cooking	2	1	3	1	NIL
	Electrical fault	NIL	3	4	NIL	NIL
	Careless disposal of joss sticks and candles	NIL	5	1	1	NIL
	Children playing with matches	4	2	NIL	1	NIL
	Overheating of machinery	1	4	2	NIL	NIL
No. of answers with "Aware" and above is 38, and the total no. of possible answers is 42 (7 respondents vs. 6 causes of fires). The percentage of answers with "Aware" and above is **90.5%** (i.e. 38/42)						
Overall weighted average of the percentage of awareness with "Aware" and above for 31 respondents $= \frac{86.9 \times 14 + 91.7 \times 10 + 90.5 \times 7}{31}$ = **89%**						

An analysis of the "Expected percentage of reduction in the likelihood of fire due to FSM" and the "Expected percentage of reduction in the consequence of fire due to FSM" is further conducted. It is revealed that all respondents consider that FSM strategies are very critical to fire safety.

The responses from the experts are essentially categorical data. The mid-range value of each "Expected percentage" (e.g. 15 will be taken as the representative value for 10-20%) can be taken as the categorical value against the associated opinion in the form of a contingency table. In order to evaluate whether the opinions on FSM from the experts hinge on their background training and profession, a non-parametric chi-square test (USFA, 2004) is constructed on the 10 representative values of FSM attributes vs. the 3 different professions, i.e., with 9x2=18 degrees of freedom (*df*). According to statistical tables, the critical chi-square value of 18 *df* analysis under 5% level of significance is 28.87. The result of the Total Chi-square Value is calculated to be ***4.4223***.

Since the calculated value is far below the critical value, it is unveiled that the opinions on good FSM in the reduction of fire risks is independent of the professions and background of the respondents. The summary of the response and calcuation is shown in Table 6.21.

Table 6.21 Summary of views on FSM from the first batch of respondents and calculation of Total Chi Square Value

		Fire safety education	**Control of tenant's fit-out works**	**Increased frequency of checking for communal electrical installations**	**Planned rewiring of domestic flats**	**Regular fire drill**	**Speedy removal of obstruction items in MOE**	**Regular patrol to ensure no smoke door is wedged open**	**To prepare a list of vulnerable tenants for quick reference of firemen**	**Increased frequency of checking for fire alarm and hose reel**	**Increased frequency of checking for exit sign**	
Actual Average % of reduction in likelihood or consequence based on questionnaire	BSE	55.00	43.75	45.71	56.43	57.14	62.86	63.57	47.14	55.71	51.43	*538.74*
	BS	63.00	49.00	47.00	63.00	56.00	72.00	66.00	58.00	58.00	52.00	*584.00*
	EM	49.29	40.71	39.29	56.67	45.00	67.86	70.71	45.00	52.14	47.86	*514.52*
		167.29	*133.46*	*132.00*	*176.10*	*158.14*	*202.72*	*200.28*	*150.14*	*165.85*	*151.29*	*1637.26*
Overall Average % of reduction in likelihood or consequence based on questionnaire		56.29	45.00	44.68	58.67	54.03	*66.94*	*65.97*	50.16	55.65	50.81	
Expected Average % of reduction in likelihood or consequence based on calculation	BSE	55.05	43.92	43.43	57.94	52.04	66.70	65.90	49.40	54.57	49.78	
	BS	59.67	47.61	47.08	62.81	56.41	72.31	71.44	53.55	59.16	53.96	
	EM	52.57	41.94	41.48	55.34	49.70	63.71	62.94	47.18	52.12	47.54	

Table of Chi Square Values

		Fire safety education	**Control of tenant's fit-out works**	**Increased frequency of checking for communal electrical installations**	**Planned rewiring of domestic flats**	**Regular fire drill**	**Speedy removal of obstruction items in MOE**	**Regular patrol to ensure no smoke door is wedged open**	**To prepare a list of vulnerable tenants for quick reference of firemen**	**Increased frequency of checking for fire alarm and hose reel**	**Increased frequency of checking for exit sign**
	BSE	0.0000	0.0006	0.1194	0.0396	0.5007	0.2215	0.0826	0.1037	0.0237	0.0546
	BS	0.1859	0.0408	0.0001	0.0006	0.0029	0.0013	0.4142	0.3691	0.0227	0.0714
	EM	0.2053	0.0360	0.1162	0.0318	0.4439	0.2706	0.9600	0.1010	0.0000	0.0021
	Total Chi Square Value	**4.4223**	Critical Value	28.87	Degree of freedom 9x2=18		Level of significance=0.05				

Since the Total Chi Square Value is less than the Critical Value, there is no relationship between the profession and their views on FSM.

6.9.2 Analysis of the second batch of samples

The test-out in the first batch of returns manifests that the respondents are generally aware of the research problem and are able to answer the questions without much difficulty; despite that some respondents need the clarification from the author on the meaning of the "underlying sub-causes of fires in question 7".

After collecting an extra 70 returns of the questionnaire sheets from 36 BSE, 17 BS and 17 EM as the second batch of samples, a similar analysis is carried out. The profiles and descriptive statistics of the respondents are summarized in Table 6.22.

Table 6.22 Profiles of the second batch of respondents

		No. of respondents			
Profession	**Years of experience**		**Nature of organisation**		
			Government	**Public Utilities**	**Private**
Building Services Engineer	5-10	3	15	9	12
	10-15	6			
	15-20	4			
	Over 20	23			
Building Surveyor	Below 5	2	12	NIL	5
	10-15	7			
	15-20	1			
	Over 20	7			
Estate Manager	Below 5	1	12	1	4
	10-15	2			
	15-20	3			
	Over 20	11			
Total no. of respondents with over 15 years of experiences is 49 (i.e. 49/70=**70%**). Total no. of respondents working in government organization is 39 (i.e. 39/70=**55.71%**).					

With regard to the degree of awareness of the 70 respondents on the causes of fires, the summary is shown in Table 6.23 to 6.25. It is noted that the percentages of the respondents with the degree of awareness above the level of "Aware" are 90.3%, 90.2% and 96.1% respectively for the 3 professions of BSE, BS and EM. When the number of respondents within each profession is taken into account, the overall weighted average of the percentage of awareness above the level of "Aware" becomes 91.7%.

Table 6.23 Awareness of the second batch of respondents (BSE) on the causes of fires in residential buildings

		No. of respondents				
Profession	**Causes of fires**	**Fully Aware (FA)**	**Very Aware (VA)**	**Aware (A)**	**Slightly Aware (SA)**	**Not Aware (NA)**
Building Services Engineer	Careless disposal of cigarette ends	11	18	6	1	NIL
	Cooking	9	20	7	NIL	NIL
	Electrical fault	18	12	6	NIL	NIL
	Careless disposal of joss sticks and candles	7	11	11	7	NIL
	Children playing with matches	8	8	11	5	4
	Overheating of machinery	6	12	14	4	NIL
No. of answers with "Aware" and above is 195, and the total no. of possible answers is 216 (36 respondents vs. 6 causes of fires). The percentage of answers with "Aware" and above is **90.3%** (i.e. 195/216).						

Table 6.24 Awareness of the second batch of respondents (BS) on the causes of fires in residential buildings

		No. of respondents				
Profession	**Causes of fires**	**Fully Aware (FA)**	**Very Aware (VA)**	**Aware (A)**	**Slightly Aware (SA)**	**Not Aware (NA)**
Building Surveyor	Careless disposal of cigarette ends	5	2	9	1	NIL
	Cooking	4	7	4	2	NIL
	Electrical fault	5	8	2	1	1
	Careless disposal of joss sticks and candles	4	4	7	2	NIL
	Children playing with matches	3	2	10	1	1
	Overheating of machinery	5	5	6	1	NIL
No. of answers with "Aware" and above is 92, and the total no. of possible answers is 102 (17 respondents vs. 6 causes of fires). The percentage of answers with "Aware" and above is **90.2%** (i.e. 92/102).						

Table 6.25 Awareness of the second batch of respondents (EM) on the causes of fires in residential buildings

		No. of respondents				
Profession	**Causes of fires**	**Fully Aware (FA)**	**Very Aware (VA)**	**Aware (A)**	**Slightly Aware (SA)**	**Not Aware (NA)**
Estate Manager	Careless disposal of cigarette ends	8	5	4	NIL	NIL
	Cooking	9	7	1	NIL	NIL
	Electrical fault	10	4	3	NIL	NIL
	Careless disposal of joss sticks and candles	6	5	5	1	NIL
	Children playing with matches	8	3	4	2	NIL
	Overheating of machinery	8	6	2	1	NIL
No. of answers with "Aware" and above is 98, and the total no. of possible answers is 102 (17 respondents vs. 6 causes of fires). The percentage of answers with "Aware" and above is **96.1%** (i.e. 98/102)						
Overall weighted average of the percentage of awareness with "Aware" and above for 70 respondents $= \frac{90.3\times 36+90.2\times 17+96.1\times 17}{70}$ = **91.7%**						

A non-parametric chi-square test is again conducted as shown in Table 6.26. The result reveals that there is no relationship on the views of the respondents and their professional background.

Table 6.26 Summary of views on FSM from the second batch of respondents and calculation of Total Chi Square Value

		Fire safety education	**Control of tenant's fit-out works**	**Increased frequency of checking for communal electrical installations**	**Planned rewiring of domestic flats**	**Regular fire drill**	**Speedy removal of obstruction items in MOE**	**Regular patrol to ensure no smoke door is wedged open**	**To prepare a list of vulnerable tenants for quick reference of firemen**	**Increased frequency of checking for fire alarm and hose reel**	**Increased frequency of checking for exit sign**	
Actual Average % of reduction in likelihood or consequence based on questionnaire	BSE	61.67	52.71	45.83	50.28	45.56	60.28	57.50	42.50	44.44	41.94	502.71
	BS	52.65	47.35	49.71	51.47	40.29	52.65	55.00	40.88	45.00	39.71	*474.71*
	EM	61.47	62.65	63.24	62.06	50.88	66.18	69.71	60.29	64.41	62.06	*622.94*
		175.78	*162.71*	*158.77*	*163.81*	*136.73*	*179.10*	*182.21*	*143.68*	*153.86*	*143.71*	*1600.36*
Overall Average % of reduction in likelihood or consequence based on questionnaire		59.43	53.84	51.00	53.43	45.57	59.86	59.86	46.43	49.43	46.29	
Expected Average % of reduction in likelihood or consequence based on calculation	BSE	55.22	51.11	49.88	51.46	42.95	56.26	57.24	45.13	48.33	45.14	
	BS	52.14	48.26	47.10	48.59	40.56	53.13	54.05	42.62	45.64	42.63	
	EM	68.42	63.34	61.80	63.76	53.22	69.72	70.92	55.93	59.89	55.94	

Table of Chi Square Values										
	Fire safety education	**Control of tenant's fit-out works**	**Increased frequency of checking for communal electrical installations**	**Planned rewiring of domestic flats**	**Regular fire drill**	**Speedy removal of obstruction items in MOE**	**Regular patrol to ensure no smoke door is wedged open**	**To prepare a list of vulnerable tenants for quick reference of firemen**	**Increased frequency of checking for fire alarm and hose reel**	**Increased frequency of checking for exit sign**
BSE	0.7530	0.0502	0.3275	0.0270	0.1579	0.2869	0.0012	0.1535	0.3124	0.2266
BS	0.0049	0.0172	0.1446	0.1709	0.0017	0.0043	0.0168	0.0707	0.0089	0.2003
EM	0.7066	0.0075	0.0332	0.0455	0.1029	0.1796	0.0209	0.3412	0.3416	0.6696
Total Chi Square Value	**5.3852**	Critical Value	28.87	Degree of freedom 9x2=18		Level of significance=0.05				
Since the Total Chi Square Value is less than the Critical Value, there is no relationship between the profession and their views on FSM.										

The *t*-statistic of the two batches of samples is further computed using equations (6.7) and (6.8) as summarised below.

Table 6.27 Summary of *t* statistic calculation

FSM attribute	**Mean value of batch 1**	**Mean value of batch 2**	***df***	***t*-statistic**	**Critical value at 5% significance level (NIST, 2012)**
Fire safety education	56.29	59.43	54.9101	-0.6756	1.674
Control of tenant's fit-out works	45.00	53.84	52.1496	-1.7035	1.675
Increased frequency of checking for communal electrical installations	44.68	51.00	51.7135	-1.1544	1.675
Planned rewiring of domestic flats	58.67	51.43	63.3130	1.1698	1.669
Regular fire drill	54.03	45.57	58.2974	*1.8994*	1.672
Speedy removal of obstruction items in MOE	66.94	59.86	68.8246	1.4390	1.668
Regular patrol to ensure no smoke door is wedged open	65.97	59.86	80.0499	1.2975	1.664
To prepare a list of vulnerable tenants for quick reference of firemen	50.16	46.43	61.3775	0.7240	1.670
Increased frequency of checking for fire alarm and hose reel	55.65	49.43	66.2728	1.2181	1.668
Increased frequency of checking for exit sign	50.81	46.29	65.8133	0.8720	1.669

Since the *t* statistic of the 2 samples for all the 10 FSM attributes (with the exception of “Regular fire drill”) are generally below the critical values, it can be inferred that there is no significant difference in the mean values of the opinions collected in the 2 batches of questionnaires. The overall average values of the percentage reductions will therefore be adopted in the FTA analysis subsequently.

6.9.3 Overall analysis of all samples

The returns from the two batches are now aggregated together and a total of 101 questionnaire sheets have been received from 50 BSE, 27 BS and 24 EM professionals. The profiles and descriptive statistics of the respondents are summarized in Table 6.28.

Table 6.28 Profiles of all the respondents

		No. of respondents			
Profession	**Years of experience**		**Nature of organisation**		
			Government	**Public Utilities**	**Private**
Building Services Engineer	5-10	3	23	12	15
	10-15	9			
	15-20	5			
	Over 20	33			
Building Surveyor	Below 5	2	21	NIL	6
	10-15	9			
	15-20	6			
	Over 20	10			
Estate Manager	Below 5	2	18	1	5
	10-15	3			
	15-20	6			
	Over 20	13			
Total no. of respondents with over 15 years of experiences is 73 (i.e. 73/101=**72.3%**). Total no. of respondents working in government organization is 62 (i.e. 62/101=**61.4%**).					

With regard to the degree of awareness of the 101 respondents on the causes of fires, the summary is shown in Table 6.29 to 6.31. It is noted that the percentages of the respondents with the degree of awareness above the level of "Aware" are 89.3%, 90.7% and 94.4% respectively for the 3 professions of BSE, BS and EM. This means that all the professionals have a strong understanding on the causes of fire irrespective of their training background. When the number of respondents within each profession is taken into account, the overall weighted average of the percentage of awareness above the level of "Aware" becomes 90.9%.

Table 6.29 Awareness of all the respondents (BSE) on the causes of fires in residential buildings

		No. of respondents				
Profession	**Causes of fires**	**Fully Aware (FA)**	**Very Aware (VA)**	**Aware (A)**	**Slightly Aware (SA)**	**Not Aware (NA)**
Building Services Engineer	Careless disposal of cigarette ends	18	22	9	1	NIL
	Cooking	14	25	10	1	NIL
	Electrical fault	27	14	9	NIL	NIL
	Careless disposal of joss sticks and candles	14	11	16	9	NIL
	Children playing with matches	14	8	13	10	5
	Overheating of machinery	11	16	17	6	NIL
No. of answers with "Aware" and above is 268, and the total no. of possible answers is 300 (50 respondents vs. 6 causes of fires). The percentage of answers with "Aware" and above is **89.3%** (i.e. 268/300).						

Table 6.30 Awareness of all the respondents (BS) on the causes of fires in residential buildings

		No. of respondents				
Profession	**Causes of fires**	**Fully Aware (FA)**	**Very Aware (VA)**	**Aware (A)**	**Slightly Aware (SA)**	**Not Aware (NA)**
Building Surveyor	Careless disposal of cigarette ends	8	4	13	2	NIL
	Cooking	9	12	4	2	NIL
	Electrical fault	11	11	3	1	1
	Careless disposal of joss sticks and candles	7	6	11	3	NIL
	Children playing with matches	7	4	13	2	1
	Overheating of machinery	8	9	7	3	NIL
No. of answers with “Aware” and above is 147, and the total no. of possible answers is 162 (27 respondents vs. 6 causes of fires). The percentage of answers with “Aware” and above is **90.7%** (i.e. 147/162).						

Table 6.31 Awareness of all the respondents (EM) on the causes of fires in residential buildings

		No. of respondents				
Profession	**Causes of fires**	**Fully Aware (FA)**	**Very Aware (VA)**	**Aware (A)**	**Slightly Aware (SA)**	**Not Aware (NA)**
Estate Manager	Careless disposal of cigarette ends	11	6	6	1	NIL
	Cooking	11	8	4	1	NIL
	Electrical fault	10	7	7	NIL	NIL
	Careless disposal of joss sticks and candles	6	10	6	2	NIL
	Children playing with matches	12	5	4	3	NIL
	Overheating of machinery	9	10	4	1	NIL
No. of answers with "Aware" and above is 136, and the total no. of possible answers is 144 (24 respondents vs. 6 causes of fires). The percentage of answers with "Aware" and above is **94.4%** (i.e. 136/144)						
Overall weighted average of the percentage of awareness with "Aware" and above for 101 respondents $= \frac{89.3\times 50+90.7\times 27+94.4\times 24}{101}$ = **90.9%**						

Lastly, a chi square test on the views of all the respondents again confirms that there is no relationship between their views and there professional background as summarized in Table 6.32.

Table 6.32 Summary of views on FSM from all the respondents and calculation of Total Chi Square Value

		Fire safety education	**Control of tenant's fit-out works**	**Increased frequency of checking for communal electrical installations**	**Planned rewiring of domestic flats**	**Regular fire drill**	**Speedy removal of obstruction items in MOE**	**Regular patrol to ensure no smoke door is wedged open**	**To prepare a list of vulnerable tenants for quick reference of firemen**	**Increased frequency of checking for fire alarm and hose reel**	**Increased frequency of checking for exit sign**	
Actual Average % of reduction in likelihood or consequence based on questionnaire	BSE	59.80	51.53	45.80	52.00	48.80	61.00	59.20	43.80	47.60	44.60	*514.13*
	BS	56.48	47.96	48.70	55.74	46.11	59.81	59.07	47.22	49.81	44.26	*515.19*
	EM	57.92	56.25	56.25	60.65	49.17	66.67	70.00	55.83	60.83	57.92	*591.49*
		174.20	*155.74*	*150.75*	*168.39*	*144.08*	*187.48*	*188.27*	*146.86*	*158.25*	*146.78*	*1620.80*
Overall Average % of reduction in likelihood or consequence based on questionnaire		58.47	51.70	49.06	55.00	48.17	62.03	61.73	47.57	51.34	47.67	
Expected Average % of reduction in likelihood or consequence based on calculation	BSE	55.26	49.40	47.82	53.42	45.70	59.47	59.72	46.58	50.20	46.56	
	BS	55.37	49.50	47.92	53.53	45.80	59.59	59.84	46.68	50.30	46.65	
	EM	63.57	56.84	55.02	61.45	52.58	68.42	68.71	53.59	57.75	53.56	

Table of Chi Square Values										
	Fire safety education	**Control of tenant's fit-out works**	**Increased frequency of checking for communal electrical installations**	**Planned rewiring of domestic flats**	**Regular fire drill**	**Speedy removal of obstruction items in MOE**	**Regular patrol to ensure no smoke door is wedged open**	**To prepare a list of vulnerable tenants for quick reference of firemen**	**Increased frequency of checking for fire alarm and hose reel**	**Increased frequency of checking for exit sign**
BSE	0.3735	0.0916	0.0853	0.0375	0.2099	0.0393	0.0046	0.1663	0.1344	0.0824
BS	0.0223	0.0480	0.0129	0.0917	0.0022	0.0008	0.0099	0.0063	0.0047	0.1229
EM	0.5029	0.0060	0.0277	0.0104	0.2214	0.0448	0.0243	0.0937	0.1646	0.3538
Total Chi Square Value	**2.9964**	Critical Value	28.87	Degree of freedom 9x2=18		Level of significance=0.05				
Since the Total Chi Square Value is less than the Critical Value, there is no relationship between the profession and their views on FSM.										

6.10 Views of the respondents on contribution of Fire Safety Management (FSM)

Besides providing the views on the "percentages" relating to the contribution of FSM, some respondents have made the following comments which are worthy of consideration.

- Fire safety education should be continuous and regular.
- FSM is a practical tool to elevate fire safety of old buildings, and the research is constructive to fire safety improvement.
- Upgradation of fire services installations and training on fire fighting skills by FSD should also be considered.
- FSM is effective for fire safety, but the cost incurred may need to be considered.
- Appointment of a qualified Fire Safety Manager should be considered for highly-populated residential properties.
- Adequate professional knowledge of the manager on fire safety issues is very important in planning the FSM system.
- Organized FSM can be adopted as a label for "safe" or "quality" buildings in par with "green" buildings.
- The property management office should provide fire extinguishers to the contractors during renovation works.
- FSM should be a mandatory provision under the Deed of Mutual Convenant. Government should provide incentive and educational support

to property management agents and/or owner's corporations in providing and enforcing FSM in domestic buildings.

- Installation of smoke detectors may be considered for residential buildings to reduce fire risk.
- The tenants should be encouraged to equip themselves with simple-to-use breathing masks for fire escape purpose.

6.11 Example case study of FTA for deriving the probability of a fire incident

In this section, an example case study of estimating the probability of "A flat on fire" by the FTA will be demonstrated. We will take an example under the following scenario:

- Building Block Design: H block
- Building Age: 30 years old
- Passive fire safety provision: smoke door at staircase
- Active fire safety provision: break glass unit and manual fire alarm, fire hydrant and hosereel system, exit sign and emergency light

Standard FSM for such building is taken as the base case. The various causes of fires as suggested by the FSD are further broken down into sub-causes and the fundamental basic events as tabulated in Table 6.33. The associated fault tree diagram is constructed by using the "Fault Tree+" software and depicted in Figure 6.2. The aim is to estimate the probability of "A flat on fire" in the target building.

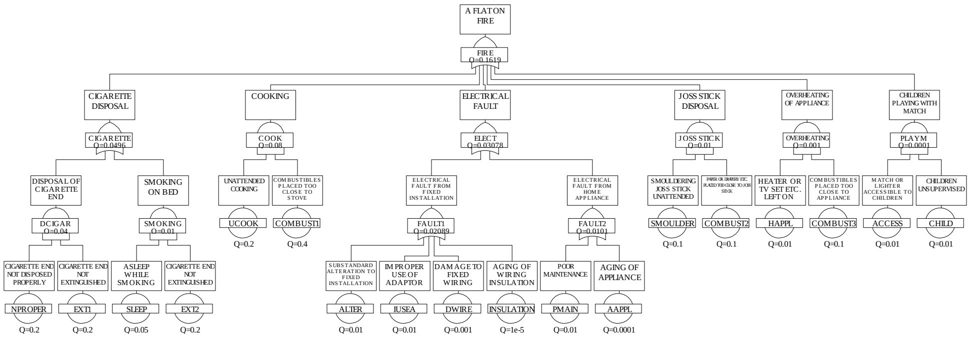


Figure 6.2 Fault tree diagram of “A flat on fire”

6.12 Assignment of probabilities to basic events

In order to calculate the probability of the top event, it is necessary to assign the probabilities to the basic events. This is the most difficult task of the entire process. The historical data for basic events are usually scarce, trivial and limited. Even though the data are available from some handbooks or statistical sources, it may not be readily applicable to a particular situation. Expert judgement is necessary for adjustment of the relevant data to suit an individual organization or setting. Although some people may challenge on the credibility of individual probability values, it is still a pragmatic approach as the data can be refined later on through Bayesian mathematics when more and more data are collected. As commented by NFPA, "Treating probability as a degree of belief, as the subjectivists purport to do, raises the question of why anyone should attach any credibility to anyone else's estimate of probability. It suggests that everyone is free to select their own probability and that there is no point of comparison to revise or challenge those selections. For this reason, a pure subjectivist is rare, and a convincing fire risk analysis openly based on pure subjectivism is even rarer. A more broadly credible version of subjectivism holds that a probability estimate is an expression of all the knowledge one has regarding the underlying process that leads to the event or does not." (NFPA, 2003, pp. 3-118). Provided that the expert judgements are built upon logical arguments and properly documented, it can provide a good analysis especially on a comparative basis.

The estimation on the probabilities for FSM issues such as success and failure of evacuation planning, training and drills is particularly difficult. Yung (Yung, 2008, pp. 156) suggests that “these probability values should be agreed upon by fire safety engineers and authorities having jurisdiction”.

For comparative analysis purpose, the probabilities of the events have been estimated by engineering judgement and inserted in Table 6.33. The probability of “A flat on fire” in the H block is calculated by the software “Fault Tree+” to be **0.1619**. This value is generally in par with the probability of 0.1235 as estimated by the Poisson modeling of fire statistics in Table 5.1.

Table 6.33 Basic events of the fault tree and the estimated probability

Event No.	Event Name	Event	Probability	Remark
1	NPROPER	Cigarette end not disposed properly	0.2	Engineering Judgement[8]
2	EXT1	Cigarette end not extinguished	0.2	Engineering Judgement
3	SLEEP	Asleep while smoking	0.05	Engineering Judgement
4	EXT2	Cigarette end not extinguished	0.2	Engineering Judgement
5	UCOOK	Unattended cooking	0.2	Engineering Judgement
6	COMBUST1	Combustibles placed too closed to stove	0.4	Engineering Judgement
7	ALTER	Substandard alteration to fixed installation	0.01	Engineering Judgement
8	IUSEA	Improper use of adaptor	0.01	Engineering Judgement
9	DWIRE	Damaged to fixed wiring	0.001	Engineering Judgement
10	INSULATION	Aging of wiring insulation	0.00001	The life expectancy of PVC insulated cable can exceed 50 years (e.g., CIBSE, 2005). Therefore the chance of aging is very low, and is estimated to be 0.00001.
11	PMAIN	Poor maintenance	0.01	Engineering Judgement
12	AAPPL	Aging of appliance	0.0001	Engineering Judgement
13	SMOULDER	Smouldering joss sticks unattended	0.1	Engineering Judgement
14	COMBUST2	Paper or drapery etc. placed too close to joss stick	0.1	Engineering Judgement
15	HAPPL	Heater or TV set etc. left on	0.01	Engineering Judgement
16	COMBUST3	Combustibles placed too close to appliance	0.1	Engineering Judgement
17	ACCESS	Match or lighter accessible to children	0.01	Engineering Judgement
18	CHILD	Children unsupervised	0.01	Engineering Judgement

[8] Engineering judgement is defined as the process exercised by a professional who is qualified by way of education, experience and recognized skills to complement, supplement, accept or reject elements of a quantitative analysis (BSI, 1999; Australia Building Code Board, 2005).

Alternatively, under structured and enhanced FSM in the setting of HKHA, the probabilities of some of the basic events leading to a fire can be reduced. The overall average percentage improvement above the base case provided by the questionnaires is used in estimating the improved probabilities as shown in Table 6.34.

Table 6.34 Improved probabilities of basic events due to structured FSM

Event No.	Event Name	Event	Improved Probability	Remark
1	NPROPER	Cigarette end not disposed properly	0.08306	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.2x0.4153=0.08306
2	EXT1	Cigarette end not extinguished	0.08306	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.2x0.4153=0.08306
3	SLEEP	Asleep while smoking	0.05	Unchanged since it depends very much on personal factor
4	EXT2	Cigarette end not extinguished	0.08306	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.2x0.4153=0.08306
5	UCOOK	Unattended cooking	0.08306	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.2x0.4153 =0.08306
6	COMBUST1	Combustibles placed too closed to stove	0.16612	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.4x0.4153=0.16612
7	ALTER	Substandard alteration to fixed installation	0.00483	Based on the result of the questionnaire, the control of tenant’s fit-out works will bring about 51.7% (0.517) improvement in this aspect, and the new probability becomes 0.01x0.483=0.00483
8	IUSEA	Improper use of adaptor	0.004153	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.01x0.4153=0.004153
9	DWIRE	Damaged to fixed wiring	0.00045	Based on the result of the questionnaire, the planned rewiring of domestic flat will bring about 55% (0.55) improvement in this aspect, and the new probability becomes 0.001x0.45=0.00045
10	INSULATION	Aging of wiring insulation	0.0000045	Based on the result of the questionnaire, the planned rewiring of domestic flat will bring about 55% (0.55) improvement in this aspect, and the new probability becomes 0.00001x0.45=0.0000045

11	PMAIN	Poor maintenance	0.004153	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.01x0.4153=0.004153
12	AAPPL	Aging of appliance	0.00004153	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.0001x0.4153=0.00004153
13	SMOULDER	Smouldering joss sticks unattended	0.04153	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.1x0.4153=0.04153
14	COMBUST2	Paper or drapery etc. placed too close to joss stick	0.04153	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.1x0.4153=0.04153
15	HAPPL	Heater or TV set etc. left on	0.004153	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.01x0.4153=0.004153
16	COMBUST3	Combustibles placed too close to appliance	0.04153	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.1x0.4153=0.04153
17	ACCESS	Match or lighter accessible to children	0.004153	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.01x0.4153=0.004153
18	CHILD	Children unsupervised	0.004153	Based on the result of the questionnaire, fire safety education will bring about 58.47% (0.5847) improvement in this aspect, and the new probability becomes 0.01x0.4153=0.004153

The revised fault tree diagram is shown in Figure 6.3. After assigning the improved probabilities to the basic events, the probability of “A flat on fire” for an H Block drops significantly from **0.1619** to **0.03974** only. This represents a **75%** [(0.1619-0.03974)/0.1619] reduction in the probability of having a fire inside flat.

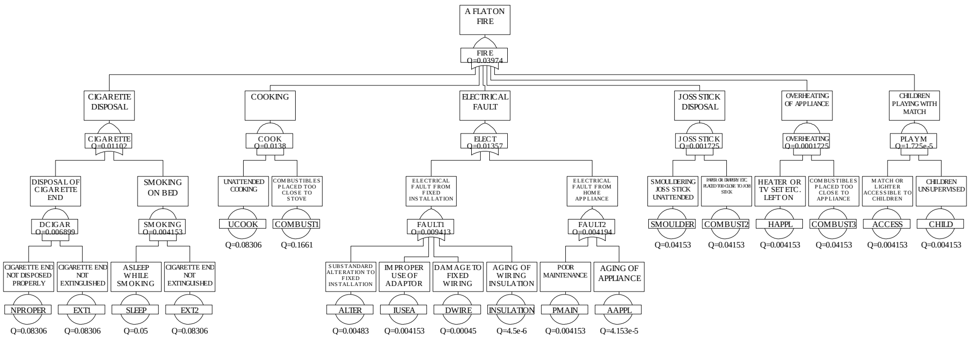


Figure 6.3 Fault tree diagram of “A flat on fire” with improved probabilities of basic events

6.13 Consequence of fires

Consider that there is a flat on fire in the H block. The subsequent consequences are usually property damage, or casualty which is our concern. However, we can also describe the consequence on the positive side, i.e., the success of escape. Assuming that the tenant is unable to put out the fire and the fire spreads beyond the fire flat, the tenants in the flat and the fire floor will start to evacuate. The chance of successful or effective evacuation largely depends on the positive fire safety factors namely, proper functioning of the break glass units, hose reels, exit signs, closing of fire doors, and no obstruction in the staircases. The events leading to successful escape are therefore:

1. Break glass unit and alarm bell are functional
2. Hose reel is functional
3. Exit sign is functional
4. Smoke lobby door is closed properly
5. No obstruction item is present in staircase

Such events can be depicted as shown in the event tree in Figure 6.4. The ultimate consequence of a fire is described with a dichotomous variable of either having "Successful evacuation" (i.e. no injury or fatality) or "Unsuccessful evacuation" (i.e. some injuries or casualties).

The resultant consequence will depend on the possibility of the intervening events which have created a favourable escape environment and reflect some degrees of untenabilities. For the sake of analysis; the resultant consequence will be described as the "Effectiveness of evacuation" in the consequence event tree diagram. The probabilities of the contributing events are estimated as shown in Table 6.35. Most of the values are taken from the British Standard PD 7974-7: 2003.

Table 6.35 Probabilities of the events in the event tree "A flat on fire"

Events	Probability	Remark
Break glass unit and alarm bell are functional	0.95	According to PD 7974-7: 2003 Table A.17, the "reliability of alarm box, wiring and sounders is 0.95". Therefore the probability of "break glass unit and alarm bell are functional" is taken as 0.95.
Hose reel is functional	0.9	According to PD 7974-7: 2003 Table A.17, the "probability of successful operation of automatic fire suppression system" is 0.9. Therefore the probability of "hose reel is functional" is taken as 0.9.
Exit sign is functional	0.95	The probability value is considered to be similar to other electrical items such as alarm bell and is therefore taken as 0.95.
Smoke lobby door is closed properly	0.7	According to PD 7974-7: 2003 Table A.17, the "probability of fire doors being blocked open" is 0.3. Therefore the probability of "smoke lobby door is closed properly" is taken as (1-0.3), i.e., 0.7.
No obstruction item is present in staircase	0.8	Although there is seldom reported case on obstruction items in the means of escape in PRH, to play safe, the probability of "no obstruction item is present in staircase" is taken as 0.8. Such estimate is based on engineering judgement.

By taking the probability of the initiating event "A flat on fire" to be 0.1619 as per the base case; the result of analysis by the "Fault Tree+" software is shown in Figure 6.4. Since we are conducting a comparative analysis on the effect of structured FSM on the overall risk, it is not necessary to evaluate the absolute risk level of the scenarios. The resultant risk of the base case can be taken as **0.1619 units**.

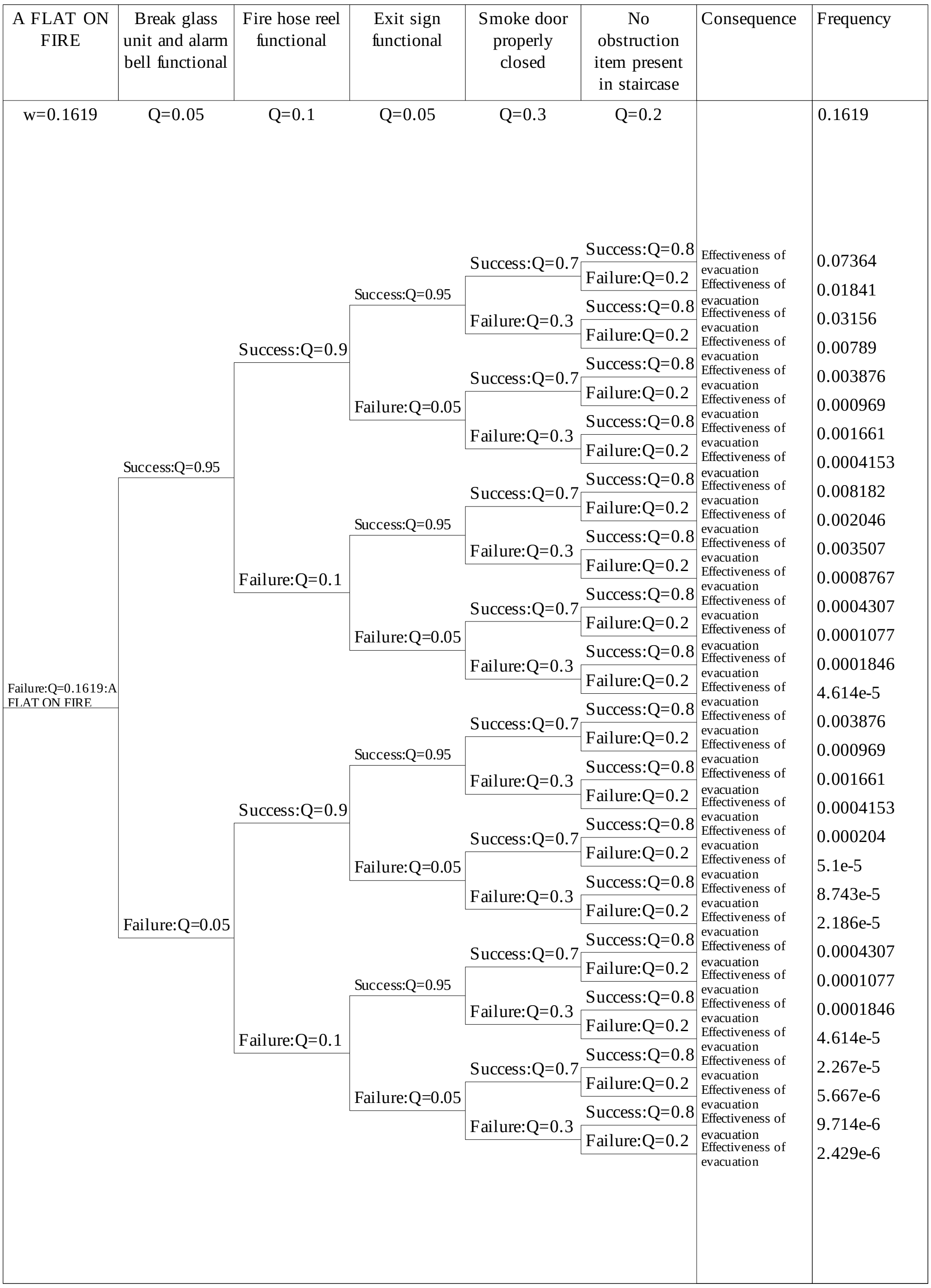


Figure 6.4 Consequence event tree of “A flat on fire”

6.14 Residual risk due to structured FSM

Now, suppose a structured and organized FSM system is in place, some of the risk factors can be mitigated as shown in Table 6.36.

Table 6.36 Mitigation measures of fire risk through Fire Safety Management (FSM)

Fire Safety Sub-systems	**Fire Safety Provisions in PRH**	**Mitigation measures of fire risk through FSM**	**Reduction in the likelihood of fire incidents**	**Reduction in the consequence of fire incidents**
Ignition	-	1. Education 2. Control of occupancy 3. Control of combustible 4. Control of fit-out works 5. Regular inspection and testing of communal electrical installations 6. Planned rewiring of electrical installations inside flats	YES	-
Smoke Spread	1. Compartmentation	1. Education 2. Regular patrol to ensure smoke door is properly closed	-	YES
Fire Spread beyond Room of Fire Origin	1. Compartmentation 2. Fire hydrant/hose reel system	1. Education 2. Regular testing of FSI	-	YES
Detection of Fire and Activation of Fire Fighting Systems	1. Fire alarm system	1. Regular testing of all FSI	-	YES
Evacuation	1. Means of escape (MOE) 2. Fire alarm 3. Exit sign 4. Emergency lighting	1. Fire drill 2. Removal of obstruction items in MOE promptly 3. Preparation of a list of vulnerable	-	YES

		tenants for handy reference of the firemen during rescue operations 4. Regular testing of fire alarm, exit sign and emergency lighting		
Fire Service Intervention	1. Means of access for fire-fighting and rescue (MOA) 2. Direct telephone link to FSD 3. Firemen's lift	1. Regular patrol and removal of obstruction items in MOA promptly 2. Regular testing of direct telephone link 3. Regular testing of Firemen's lift	-	YES

The risk level is expected to be lowered and the resultant risk is termed as the residual risk. We can calculate the residual risk due to the impact of the fire protection measures of enhanced FSM by using a residual consequence multiplier (Yung, 2008, pp. 59).

The contribution from the increase in the frequencies of checking the fire services installations can best be described by the improvement in reliabilities of the installations. The improved probabilities or reliabilities are estimated as shown in Table 6.37.

Table 6.37 Improved reliabilities of the FSI due to increase in the frequencies of checking

Events	**Improved Reliability**	**Remark**	**Improvement Multiplier in Reliability**
Break glass units and alarm bells are functional	0.974	Applying the theory on dormant failure, if the interval of inspection is reduced from 1 year to half year, the probability is approximately $\sqrt{0.95}$, i.e., 0.974.	0.95/0.974 =0.9754
Hose reels are functional	0.948	Applying the theory on dormant failure, if the interval of inspection is reduced from 1 year to half year, the probability is approximately $\sqrt{0.9}$, i.e., 0.948.	0.9/0.948 =0.9494
Exit signs are functional	0.974	Applying the theory on dormant failure, if the interval of inspection is reduced from 1 year to half year, the probability is approximately $\sqrt{0.95}$, i.e., 0.974.	0.95/0.974 =0.9754

On the other hand, the Improvement Multiplier from the proper closing of the smoke door and the clearance of obstructions in the escape staircase can be estimated from the return of the questionnaires. Based on Table 6.32, the overall average percentage of reduction in consequence for “Regular patrol to ensure no smoke door is wedged open” and “Speedy removal of obstruction items in MOE” are 61.73% and 62.03% respectively. Therefore the Improvement Multipliers for “Smoke door properly closed” and “No obstruction item present in staircase” are taken to be 0.3827 (i.e., 1-0.6173) and 0.3797 (i.e., 1-0.6203) respectively. The consequence multipliers for individual contributing events are listed and the overall consequence multiplier is estimated as shown in Table 6.38. The overall consequence multiplier is treated as a null event and input into the “Fault Tree+” software for calculation of the residual risk.

Table 6.38 Overall consequence multiplier with structured FSM

Event	**Break glass units and alarm bells are functional**	**Hose reels are functional**	**Exit signs are functional**	**Smoke lobby door is closed properly**	**No obstruction item is present in staircase**	**Overall Consequence Multiplier**
Basic Consequence Multiplier	0.9754	0.9494	0.9754	0.3827	0.3797	
ET1	0.9754	0.9494	0.9754	0.3827	0.3797	**0.1313**
ET2	0.9754	0.9494	0.9754	0.3827	1.0000	**0.3457**
ET3	0.9754	0.9494	0.9754	1.0000	0.3797	**0.3430**
ET4	0.9754	0.9494	0.9754	1.0000	1.0000	**0.9033**
ET5	0.9754	0.9494	1.0000	0.3827	0.3797	**0.1346**
ET6	0.9754	0.9494	1.0000	0.3827	1.0000	**0.3544**
ET7	0.9754	0.9494	1.0000	1.0000	0.3797	**0.3516**
ET8	0.9754	0.9494	1.0000	1.0000	1.0000	**0.9260**
ET9	0.9754	1.0000	0.9754	0.3827	0.3797	**0.1382**
ET10	0.9754	1.0000	0.9754	0.3827	1.0000	**0.3641**
ET11	0.9754	1.0000	0.9754	1.0000	0.3797	**0.3612**
ET12	0.9754	1.0000	0.9754	1.0000	1.0000	**0.9514**
ET13	0.9754	1.0000	1.0000	0.3827	0.3797	**0.1417**
ET14	0.9754	1.0000	1.0000	0.3827	1.0000	**0.3733**
ET15	0.9754	1.0000	1.0000	1.0000	0.3797	**0.3704**
ET16	0.9754	1.0000	1.0000	1.0000	1.0000	**0.9754**
ET17	1.0000	0.9494	0.9754	0.3827	0.3797	**0.1346**
ET18	1.0000	0.9494	0.9754	0.3827	1.0000	**0.3544**
ET19	1.0000	0.9494	0.9754	1.0000	0.3797	**0.3516**
ET20	1.0000	0.9494	0.9754	1.0000	1.0000	**0.9260**
ET21	1.0000	0.9494	1.0000	0.3827	0.3797	**0.1380**
ET22	1.0000	0.9494	1.0000	0.3827	1.0000	**0.3633**
ET23	1.0000	0.9494	1.0000	1.0000	0.3797	**0.3605**
ET24	1.0000	0.9494	1.0000	1.0000	1.0000	**0.9494**
ET25	1.0000	1.0000	0.9754	0.3827	0.3797	**0.1417**
ET26	1.0000	1.0000	0.9754	0.3827	1.0000	**0.3733**
ET27	1.0000	1.0000	0.9754	1.0000	0.3797	**0.3704**
ET28	1.0000	1.0000	0.9754	1.0000	1.0000	**0.9754**
ET29	1.0000	1.0000	1.0000	0.3827	0.3797	**0.1453**
ET30	1.0000	1.0000	1.0000	0.3827	1.0000	**0.3827**
ET31	1.0000	1.0000	1.0000	1.0000	0.3797	**0.3797**
ET32	1.0000	1.0000	1.0000	1.0000	1.0000	**1.0000**

In this circumstance of structured and enhanced FSM, we will adopt the consequence of the initiating event “A flat on fire” in the H block to be **0.1619 units** as the base case. The residual risk of “A flat on fire” with enhanced FSM is found to be **0.04217 units** as per Figure 6.5. The overall risk level with enhanced FSM has been reduced from 0.1619 to 0.04217 units, i.e., a **74%** [(0.1619-0.04217)/0.1619] reduction in the consequence. The improvement due to enhanced FSM is demonstrated to be substantial.

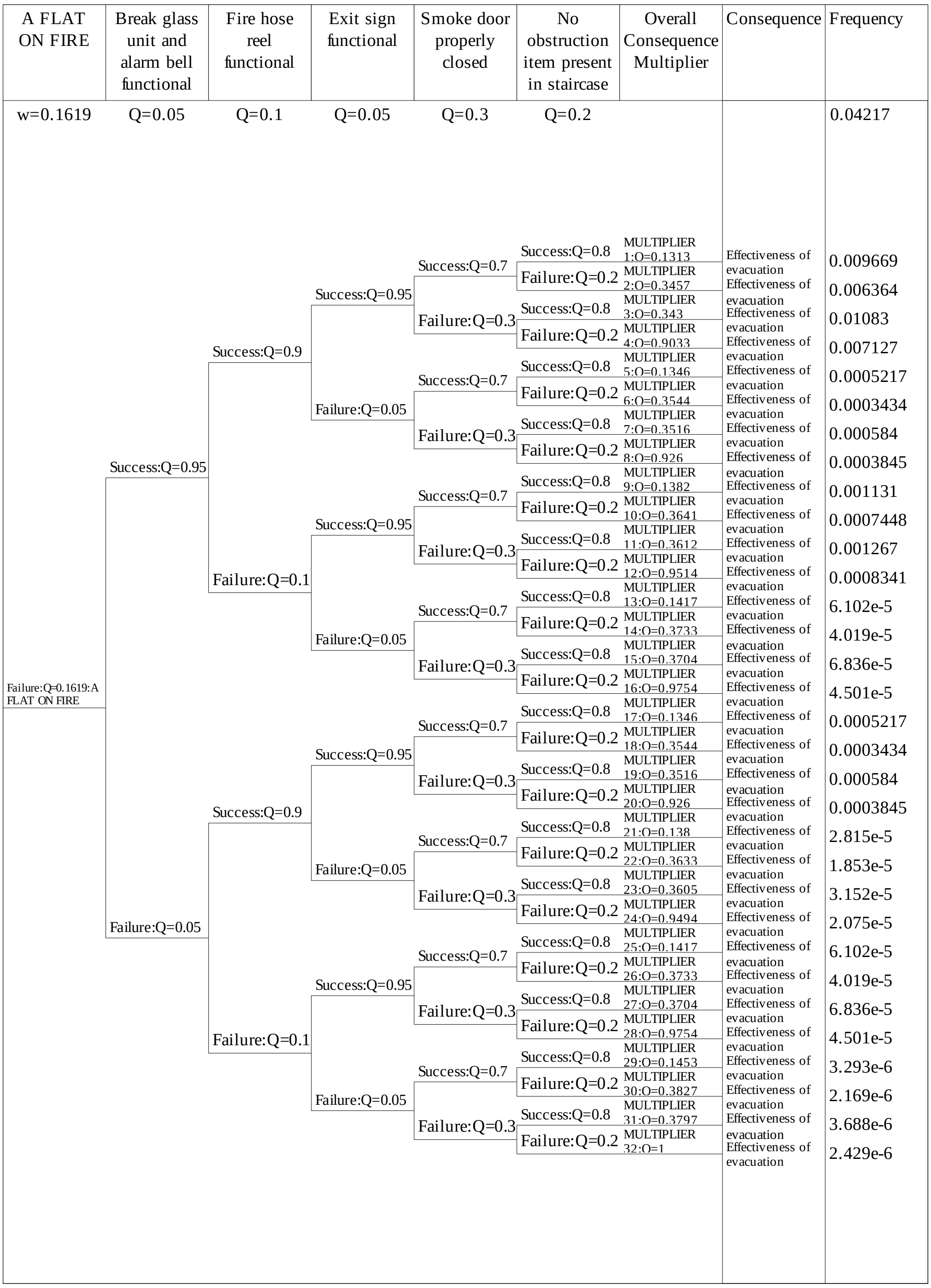


Figure 6.5 Consequence event tree of “A flat on fire” with structured FSM

6.15 Summary

This Chapter provides a review on the principles of FTA and ETA techniques, which will be adopted for quantitative fire risk analysis in evaluating the contribution of organized FSM on a conceptual basis. The advantages and limitations are also discussed. Firstly, the causes of fires in China, Japan, UK, US and Taiwan are reviewed from the literatures. The general causes of fires in Hong Kong are also reviewed based on the information from the local FSD. A questionnaire is used to solicit the opinions of the professionals (including Building Services Engineers, Building Surveyors, and Estate Managers) on the causes as well. In particular, the views from the professionals on the probable "reduction in the percentages of likelihood and consequence of a fire due to structured FSM" are also elicited.

It is found that the local professionals consider that FSM is very significant towards the reduction of fire incidents and the associated consequence irrespective of their professional background.

By taking the top event to be "A flat on fire" in a "H" block building as the example case, the fault tree diagrams and consequence event tree diagrams with and without structured FSM in place are constructed. The estimated probabilities of the various events under the above two scenarios are further assigned to the diagrams to evaluate the likely possibilities and consequences of the fire incidents by utilizing the software "Fault Tree+". The probability of having "A flat on fire" is estimated to reduce from **0.1619** to **0.03974** with enhanced FSM, i.e. an improvement of about **75%**. On a comparison of the risk levels in terms of "Effectiveness of evacuation", it is found that the overall risk level of "A flat on fire" reduces from **0.1619** to **0.04217 units** at the same time. This represents a substantial improvement of **74%** and demonstrates the contribution of structured and enhanced FSM in the reduction of fire risk in buildings.

Despite that such study is conceptual and not an evaluation of the absolute risk level, it does give an indication on the likely contribution of FSM towards the reduction of fire risk on a comparative basis. The reduction of 74% on the risk level is generally in par with the questionnaire return of Table 6.32; where the overall average percentage reduction in consequence arising from “Regular patrol to ensure no smoke door is wedged open” and “Speedy removal of obstruction items in MOE” are both over 60%. A more reliable result may be obtained through a larger scale of questionnaire survey including fire officers as they can offer their views evidenced from their fire scene attendance experiences.

CHAPTER 7 Development and Implementation of a FSM System in HKHA

7.1 Introduction

In Chapter 4, the existing FSM system in HKHA has been reviewed and outlined through studying the procedure manuals and internal guidelines. The FSM procedures are found to be well organized and laid down in the quality manuals. While there is a "Health and Safety Policy" from HKHA, yet there is no formal FSM system installed and a clear "Fire Safety Policy" within the organization with the commitment from the highest management, i.e. the Director of Housing.

As suggested in the literature, major conflagration disasters are due to inadequate fire safety management (Beard and Santos-Reyes, 1999). According to Santos-Reyes and Beard (2001), there are two kinds of failures which would lead to disasters. These kinds of failures include active failures, which are human errors having an immediate impact on the integrity of a system. Secondly, there is also latent failure or organizational errors, which are due to design, management, communication, and deficiencies in the structure of the organization. In general, a fire loss is a result of the interactions among the human and organizational aspects of the organization as a whole. The crux of FSM is based on the setting of safety goals within the organization and is a proactive process especially where continual improvements are envisaged.

They further opined that a FSM system must be systemic in order for it to be effective. According to their concepts, "systemic means to look upon events as products of systems, and system is understood as an interaction of a number of entities called parts of the system or organization". On the other hand, systematic simply means something which is organized, tidy and procedural. Clearly, "systemic" will be a macroscopic approach over and above systematic.

To assure fire safety in PRH, and to bring up the fire safety standard of the existing buildings in particular, it is necessary to construct a FSM system in the setting of the HKHA, and to explore the implementation issues in a systemic manner. In the following sessions, a brief review will be made on the principles of management, and then a FSM model for HKHA will also be proposed.

7.2 Principles of Management

Management is an established social science discipline on the application of organizational culture and resources to complete a mission. In the business context, it is the act of getting people together to accomplish desired goals and objectives using available resources efficiently and effectively.

Historically, the practice of management evolves as a result of the desire to acquire higher productivity during industrial expansion. In early 1900s, the application of scientific principles to management began to emerge as a classical school of management (Montana and Charnov, 2008). For example, Frederick W. Taylor who is regarded as the founder of scientific management advocated that the worker's job could be broken down into smaller tasks and the most efficient way to perform each task could be determined to arrive at a maximum productivity of the entire job. Although the industrial productivity could be improved, there is resent from workers' union because the approach may lead to higher chance of consequent lay-off due to earlier work completion. In addition, the human aspect is largely ignored simply due to the measurement of work performance by scientific means. Later on, another classical management theorist Mary Parker Follet put her focus on conflict resolution in the workplace and suggested a collaborative approach to problem solving and that manager should not over-manage the work force. Such idea can be considered as the foundation of modern management because human element has been taken into account.

While the scientific management principles developed by Taylor is mainly restricted to factory environment for enhancing productivity, Henri Fayol who is regarded as the father of Administrative Theory did assert that management should stress more on general administration of the organization as a whole and the human aspect should be taken as well. According to Fayol, management comprises 5 basic functions of planning, organizing, commanding, co-coordinating and controlling. A diagrammatic approach to depict the typical management functions is shown in Figure 7.1.

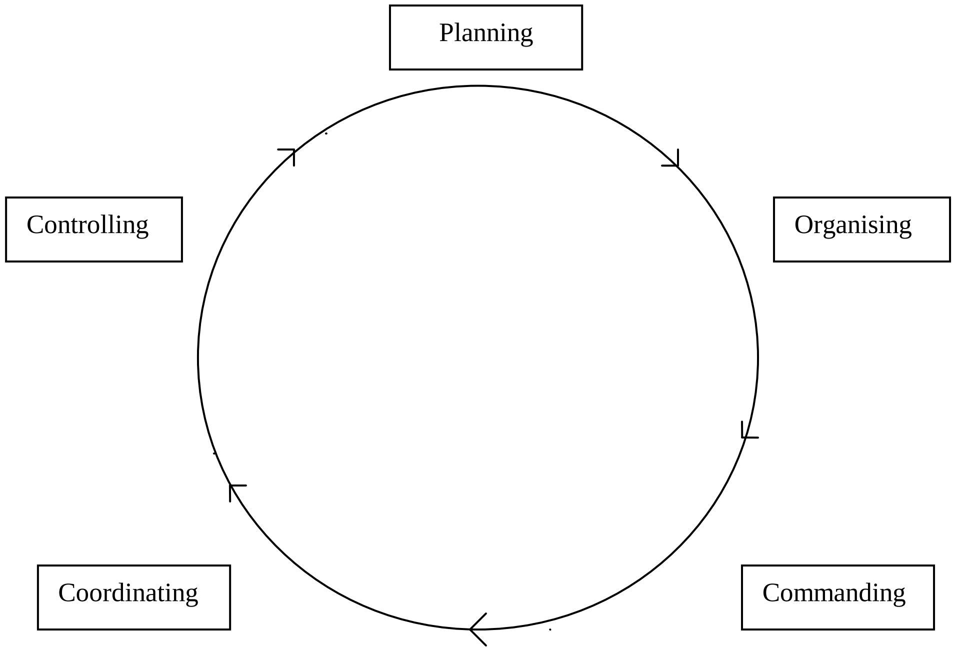


Figure 7.1 Functions of Management

In the diagram, it can be seen that the five functions of management are arranged in the clockwise sequence to indicate the order of the functions. Each of the functions can be further described as follows.

- Planning - Planning is a systematic thinking about the ways and means to accomplish a pre-determined goal. It is a higher level of management function to decide upon the future course of action and to properly arrange the resources to achieve the goal.
- Organising - It is the process of bringing together the requisite financial, physical and human resources and developing the productive and operational relationships among them in order to achieve the task. The

authority and responsibility of the management and work force will also be established.

- Commanding - It is the process of developing and directing the staff to meet with the need of the organization. Despite advancement in technology, staffing is becoming increasingly important because of the increase in size of organization, complexity in business structure, and the change in human behaviour. Managing function of commanding involves the communication, direction, supervision, and development of personnel to fill the various job duties of the organization.
- Coordinating - Coordinating is the effort of unifying, integrating and synchronising the individual members of the organization to pursue the common goal. This is considered as the essence of successful management because the organization can only be an efficient and effective one with the various activities being carried out in harmony and integration.
- Controlling - It is the measurement and correction of performance of activities in order to ensure that the performance follows and fulfills the plan. It involves the setting of standards, predicting and checking of performance; and take remedial actions should deviations occur.

While there may be some slight differences in the classification of functions of management from different gurus or experts, the objective of management is fundamentally the same, i.e. to secure the maximum output within the available resources.

7.3 Application of management principles to Safety Management

Safety Management System (SMS) is an emerging trend in business which refers to a comprehensive business management system designed to manage occupational safety and health aspects in the workplace. It can be defined as "a systematic, explicit and comprehensive process for managing safety risks" (e.g. Wikipedia, 2011).

Traditionally, organizations have little understanding on workplace health and safety until a worker is injured. They learn by experience and incorporate health and safety activities into their operation and address the problems that have occurred in the past. At some points, the organizations begin to realize the likely contravention of legislations and institute a program of activities to satisfy due diligence requirements. Apart from concern on legal requirements, there are also concerns on ethical and humanity aspects; as well the huge financial loss incurred either directly or indirectly due to various incidents.

Since the quality management (BSI, 2008b) bandwagon in the 1990s, organizations begin to recognize that continual improvement which is not explicitly spelt out in conventional management principles; is one of the success factors in order to remain in business competition. Building on the quality process of Plan-Do-Check-Act, organizations establish systems to manage and control quality. This quality management cycle was further incorporated into an environmental management system through ISO 14001 (BSI, 2004). Later on, such concept was further evolved in the health and safety management discipline, culminating in the establishment of workplace occupational health and safety management systems (OHSAS).

At present, there is no international standard on OHSAS. In 2001, the International Labour Organisation published the ILO-OSH 2001 "Guidelines on Occupational Health and Safety Management Systems" (ILO, 2001). The document provides a framework for integrating health and safety into the corporate culture and management systems within an organization. On the other hand, the British Standards Institution's Occupational Health and Safety Assessment Series (e.g. BS EN OHSAS 18001) rapidly gains its place and becomes a model for international specification on Safety Management System (BSI, 2007a). Developed to be compatible with the ISO 9001 and ISO 14001, BS EN OHSAS 18001 has been accepted in many jurisdictions as a technical specification for an SMS. It is expected that the document will form the basis of an international standard in the near future.

7.4 Safety Management System Model

7.4.1 ILO Safety Management Model

Both the ILO-OSH 2001 and BS EN OSHAS 18001 build on a common model of a continual improvement cycle. The ILO model includes elements of Policy, Organizing, Planning and Implementation, Evaluation and Action for Improvement. The entire cycle is supported by a system audit requirement. Each of the elements is described as below.

- Policy - The Policy statement defines the requirements of the organization in terms of resources, management commitment, and safety targets.
- Organizing - It will define the organization structure, the responsibilities and accountabilities of the hierarchy of personnel.

- Planning and Implementation - It will define the legislations and standards that apply to the organization, and how the objectives are assessed and managed.
- Evaluation - It provides the process of measuring safety performance, and the arrangement of an internal and external audit procedure to review the management system.
- Action for Improvement - It provides for the preventive and corrective actions to ensure the continual improvement process, which is the essence of the entire system.

The model can also be depicted by the diagram in Figure 7.2

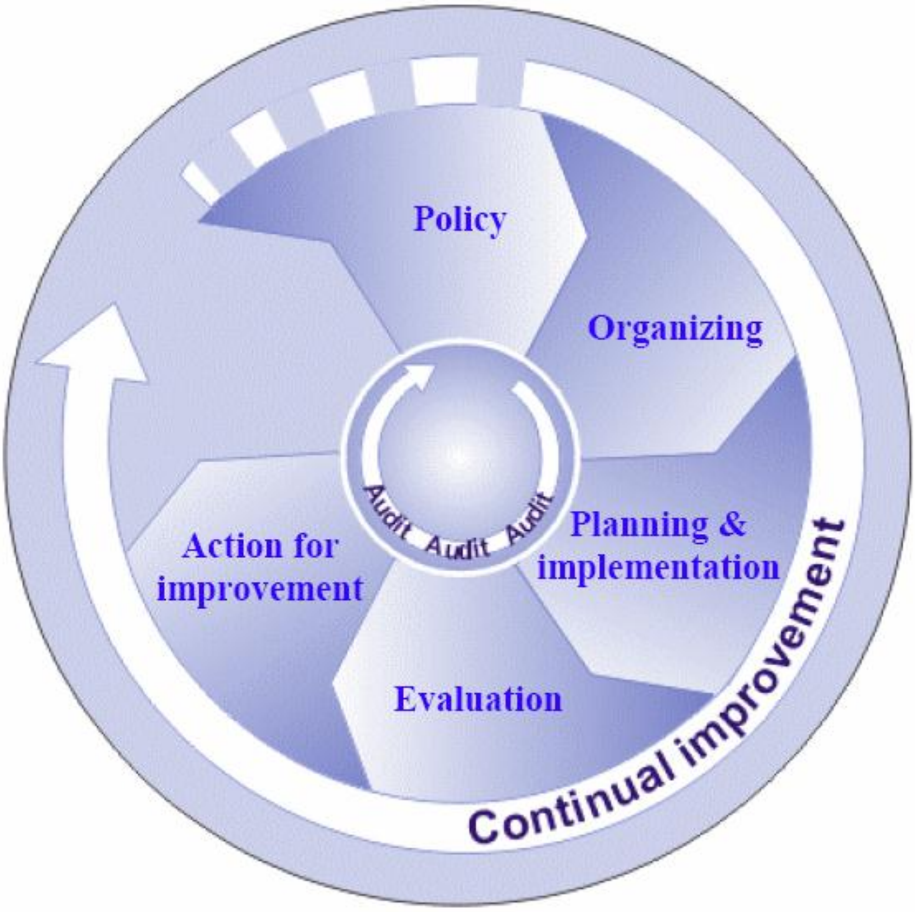


Figure 7.2 Main elements of the OHS management system (ILO, 2001)

7.4.2 UK Safety Management Model

In the case of UK, the BS EN OHSAS 18001 sets out the requirements of a SMS with elements of OH&S Policy, Planning for Hazard Identification, Risk Assessment and Control, Implementation and Operation, Checking and Corrective Action and Management Review (BSI, 2007a). System audits are based on the organisation's ability to conform to its own safety policy. Management of change is explicitly specified in the standard to contain the risks arisen as a result of changes in the organization, the OH&S management system, or its activities. Each of the elements is further elaborated as follows.

- OH&S Policy - Top management shall define and anthorise the oragnisation's OH&S Policy and ensure that it is within the scope of its OH&S management system. The policy signifies the commitment of the top management on the OH&S performance and the aspiration for continual improvement.
- Planning - the organization shall establish, implement and maintain a procedure for:
    - ongoing hazard identification, risk assessment, and determination of necessary controls.
    - Identifying and accessing the legal requirements that are applicable to it, and to communicate the information to the interested parties.
    - Defining the objectives which are measurable, and a programme for achieving the objectives.
- Implementation and Operation
    - The top management should allocate sufficient resources to implement and maintain the OH&S system.
    - The organization shall ensure that all persons are competent on the basis of appropriate education, training or experience, and shall retain the training records.
    - The organization shall set up a communication channel on OH&S matters to all internal and external stakeholders, and to involve and consult the workforce before the implementation of the systems.

- The organization shall develop a system for the approval, review and control of documentation.
- The organization shall determine those operations and activities that are associated with the identified hazards where the implementation of controls is necessary.
- The organization shall develop procedures to identify potential emergency situations and preparedness of response.

- Checking and Corrective Action
  - The organization shall establish, implement and maintain procedures to monitor and measure OH&S performance on a regular basis.
  - The organization shall establish, implement and maintain procedures to periodically evaluate compliance with applicable legal and other requirements that it subscribes.
  - The organization shall establish, implement and maintain procedures to record, investigate and analyse incidents; and to take corrective and preventive actions accordingly.
  - The organization shall establish and maintain records to demonstrate conformity to the requirements of its OH&S management system and the result achieved.
  - The organization shall ensure that internal audits of the OH&S management system are conducted at planned intervals to determine whether the system is effective in meeting the organisation’s policy and objectives; and to feedback the results to top management.

- Management Review - the top management shall review the organisation's OH&S management system at planed intervals to ensure its continuing suitability, adequacy and effectiveness. Reviews shall include assessing opportunities for improvement and the need to change the system, policy and objectives. The review shall be communicated to the organization and consultation shall be elicited from the workforce.

The British model can be depicted by Figure 7.3.

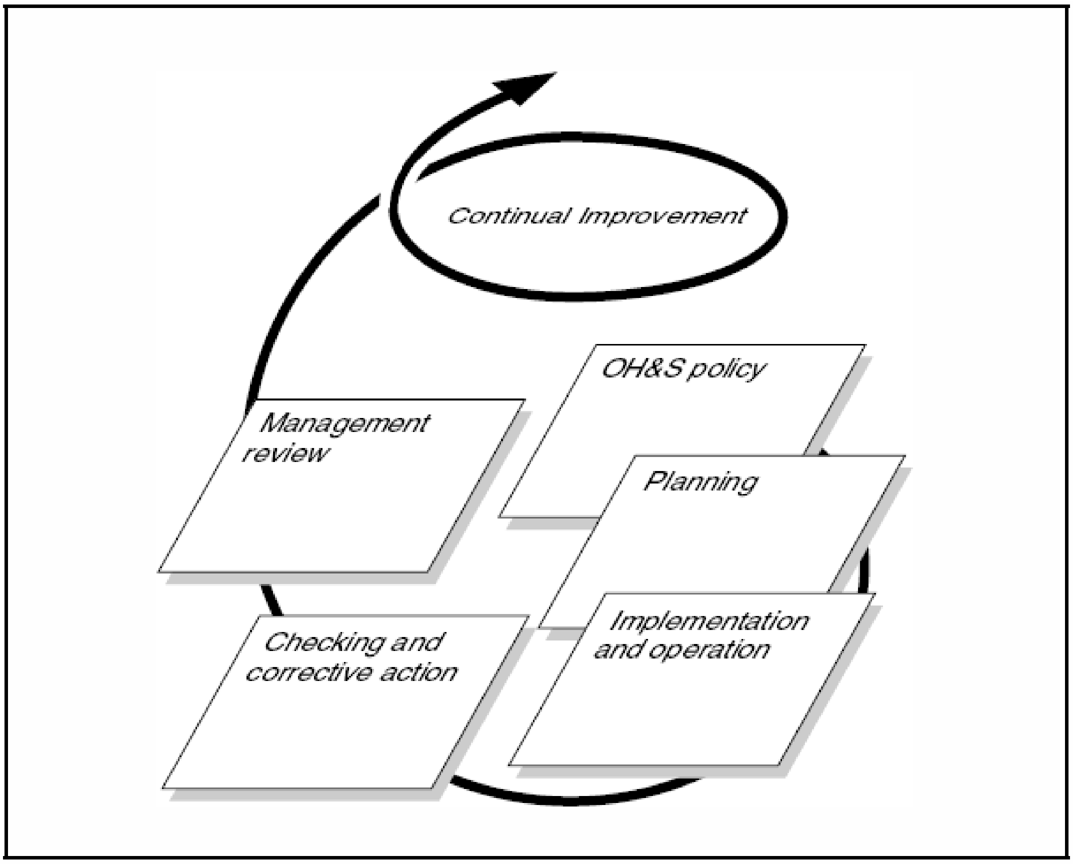


Figure 7.3 UK OH&S management system model (BSI, 2007a)

7.4.3 The Hong Kong Safety Management Model

In the scene of Hong Kong, the local government has conducted a review on industrial safety in 1995 and concluded that the idea of compliance through law enforcement should be replaced by self-regulation in line with the worldwide trend. Enterprises must embrace self-regulation and a safe management regime so as to achieve a high standard of health and safety at work. This system is now enshrined in the Factories and Industrial Undertaking (Safety Management) Regulation which was enacted in 1999 (Laws of Hong Kong, 2002). In devising the regulation, the BS 8800 Guide to Occupational Health and Safety Management Systems is taken as the reference. Under the Safety Management Regulation, proprietors or contractors of designated undertakings[9] and certain industrial undertakings are required to develop, implement and maintain in respect of the undertakings a safety management system which contains a number of process elements. For instance, a building contractor having an aggregate of 100 or more workers in a day working in a single site shall have to include a total of 14 key elements of:

- Safety policy
- Safety organization
- Safety training
- In-house safety rules and regulations
- Safety committee
- Programme for inspection of hazardous conditions

[9] A designated undertaking is defined as an industrial undertaking involving the generation, transformation and transmission of electricity, town gas, liquefied petroleum gas; or container handling. An industrial undertaking includes contractor relating to construction work, shipyard business, or factory.

- Job hazard analysis
- Accident and incident investigation
- Safety promotion
- Process control programme
- Personal protection programme
- Health assurance programme
- Evaluation, selection and control of sub-contractor
- Emergency preparedness

They are also required to have the system regularly audited or reviewed. In order to provide a practical guidance for the employers, the Labour Department has published a Code of Practice on Safety Management to address the legal requirements (LD, 2002).

The entire safety management system comprises the following processes:

- Planning - It is the process of determining in advance what is to be achieved. The industrial undertaking will have to conduct an initial status review to the existing system in managing health and safety. Risk assessment will also be required to decide on the priorities and objectives for hazard elimination and risk control. Thereafter, periodic status analyses should be conducted to facilitate continual improvement.
- Developing - It is the process of determining how the health and safety objectives should be materialized. The employer is required to endorse a safety policy to expressly spell out and commit on the health and safety

objectives. The top management will need to allocate resources for executing the policy, and to get the involvement of the workforce such as consultation and provision of training. To carry out the policy, the employer should prepare a safety plan which gives specific directions and guidance for the employees to follow so as to achieve the objectives. The regulation further requires that the policy statement be reviewed not less than once in every 2 years, or as prompted by changes to the particulars of the business operations.

- Organizing - It is the process of prescribing formal relationships between people and resources in the organization to achieve objectives. Organizing represents the integration of human resources and the structure of the organization into the activities such that the management system can be implemented. A safety committee comprising members of the top management and the workforce is called for to provide a communication channel and consultation.
- Implementing - It is the process of executing the plans to achieve the objectives. Adequate control and supervision is built up to ensure proper performance in accordance with the plans.
- Measuring - It is the process of checking performance against standards and to sort out where improvement is required, and a means of monitoring the extent to which the objectives are met. Measuring will form a feedback loop for the entire safety management system and help to reinforce and maintain the effectiveness and reliability of the management system.

- Auditing/Reviewing - It is the action phase of the feedback loop to assess the safety performance in addition to routine monitoring. Usually, a third party auditor is deployed to conduct the audit periodically to ensure impartiality. The audit report will draw up a plan for improvement of the safety management system.

The safety management model can be depicted by Figure 7.4.

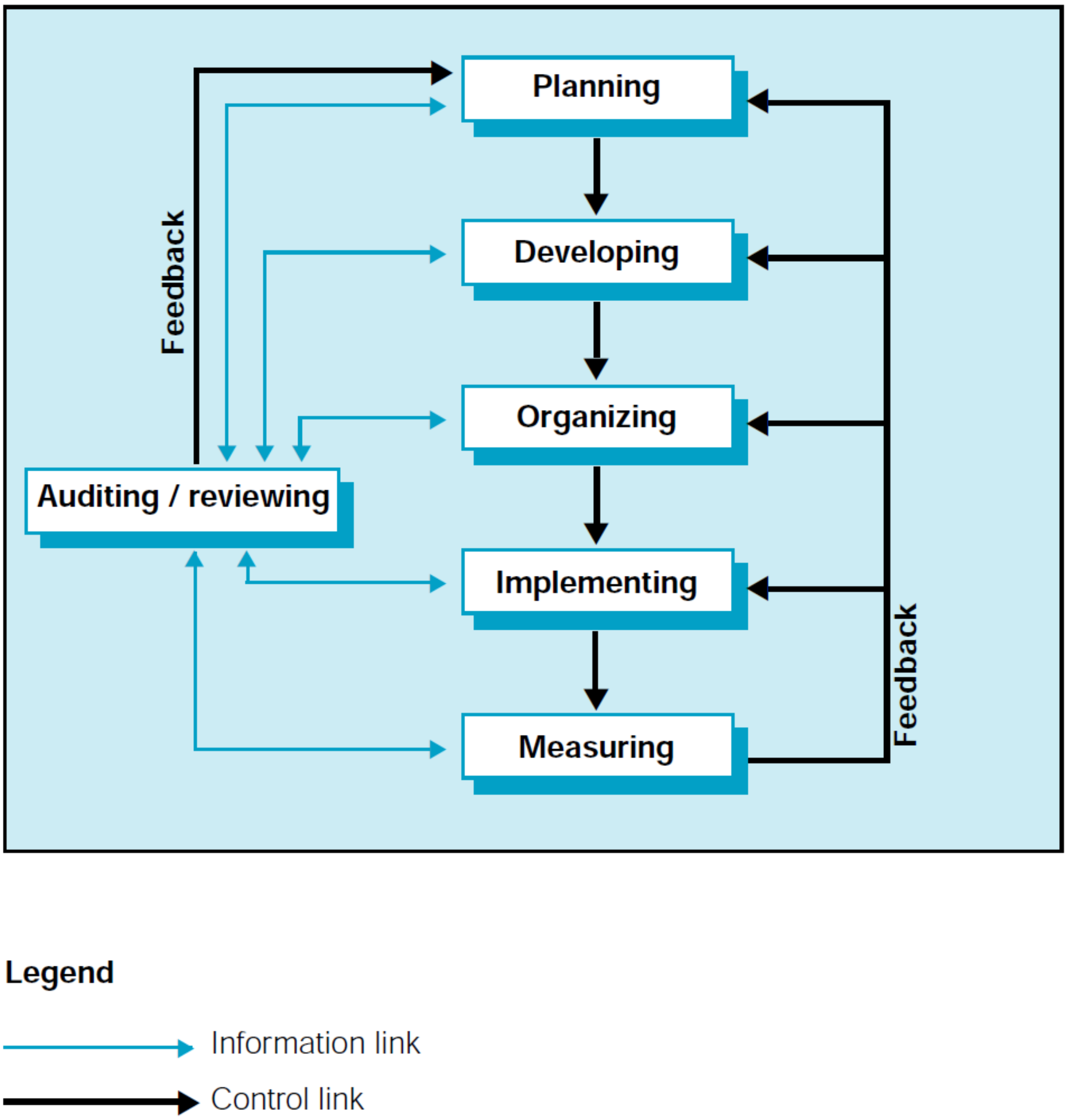


Figure 7.4 Management Model to develop, implement and maintain a safety management system (Labour Department, 2002)

All in all, there is no significant difference between the safety management models from the ILO, BSI and the local Labour Department. They intend to integrate the SMS into the daily business management system. The conventional management model of Planning, Organising, Commanding, Coordinating and Controlling still apply to the SMS. Nonetheless, safety management builds upon the quality management concept which emphasizes on continual improvement. Audit becomes an important ingredient in the entire SMS in order to maintain the effectiveness and reliability of the system.

7.5 FSM as part of Safety Management

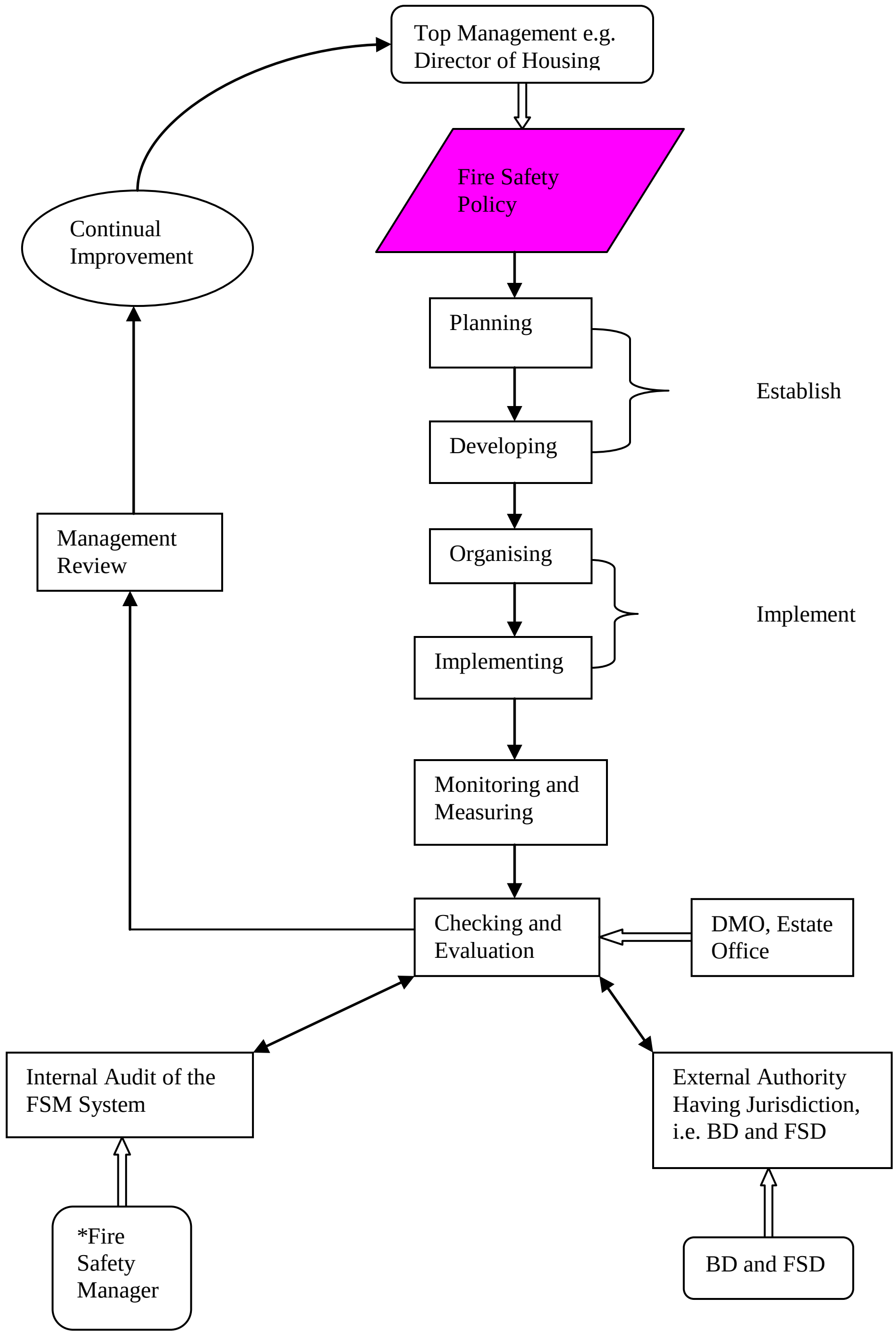
It has been pointed out that FSM is crucial to fire safety in buildings (e.g. Chow, 2007). However, there is currently in lack of a formal FSM system with respect to fire safety in Hong Kong. The function is normally embedded within part of the daily activities of the property or estate manager. This is considered to be unsatisfactory because it is not part of the core competence of a property manager by training in handling fire safety issues. For instance, it is unlikely that a property manager is knowledgeable to prepare a fire safety manual. The situation is even more obvious for large and complex building portfolios; or where a building is designed on a performance-based approach. A dedicated fire safety manager can better serve such function.

Since fire safety bears some similarities to general occupational health and safety, it is pertinent that the model of safety management can be borrowed to develop a FSM system. Beard and Santos-Reyes (1999) have once proposed a theoretical fire safety management system for offshore oil facilities by adopting the Viable System Model. The essential feature of their model is that there are 5 sub-systems which are inter-connected through a complex of information and control loops and the entire system is able to maintain a separate existence. The 5 sub-systems are actually comparable to the 5 conventional management functions.

Sub-system 1 is concerned with the implementation of the fire safety policy and activities of the system to maintain an acceptable level of risk in operating the offshore facilities. Sub-system 2 is concerned with the coordination of the various parts of the activities of the system and serves as a damping among the operational units. Sub-system 3 has a control function and maintains the internal stability of sub-system 1 based on a fire safety plan. It also allocates resources to sub-system 1, and carries out auditing. Sub-system 4 is concerned with the fire safety development and is part of the corporate fire safety planning. It gathers all relevant information about a system's total environment including now and future and acts as a complement to sub-system 3. Finally, Sub-system 5 is responsible for fire safety policy and strategic directions. It would represent the FSM system as a whole to any wider system such as the overall corporate management system.

7.6 A proposed FSM model for HKHA

Riding on the principles of safety management as discussed above, it is feasible to devise a FSM model in the setting of HKHA so as to achieve FSM performance in a systemic manner. As an example, a proposed FSM model for HKHA is depicted in Figure 7.5.



Legend: ⬠ input from responsible parties

↔ auditing function

* Senior Building Services Engineer (with specialization in fire engineering) can be appointed as the Fire Safety Manager

Figure 7.5 Proposed FSM model for HKHA

In the proposed model, each of the FSM functions can be described as follows:

- Fire Safety Policy - A formal Fire Safety Policy shall be prepared and signed off by the highest management, i.e., the Director of Housing to signify the commitment of the whole organization towards fire safety of the PRH. The policy shall lay down performance requirements and strive for continual improvements. The policy shall be reviewed periodically (e.g. once every five years) and upon organizational change or amendment of legislative requirements.
- Planning - The HKHA shall establish, implement and maintain procedures for fire hazard identification, fire risk assessment, and the proposed mitigation measures. The legal requirements are to be taken as the reference minimum. Based on that, the HKHA can set the fire safety objectives, and plan for various improvement works or management regimes to mitigate the hazards.
- Developing - The HKHA shall determine how the fire safety objectives can be realized. The top management shall allocate adequate resources such as financial budgets for carrying out the upgradation works, and to set up the fire safety management unit (FSMU) to oversee the entire FSM functions. The FSMU shall foster the fire safety culture for the whole organization and the general tenants at large.
- Organising - The HKHA shall prescribe a formal organizational structure and relationship among the various functional units, and how the resources are spread and utilized to achieve the objectives. The authorities,

accountabilities and duties of the FSMU and other functional units are to be clearly defined. The framework of measuring and monitoring the performance against standards shall also be documented.

- Implementing - This is the process of executing the FSM functions by various functional units. A formal fire safety plan and fire safety manual should be prepared by the FSMU to this effect for the reference of staff. For example, the conduct of fire safety training and promotion, routine maintenance of FSI, routine patrolling by guards etc. are common course of fire safety actions. The conventional control function of management such as the supervision of frontline staff in carrying the FSM activities and the supervision of maintenance contactors is also part of the “Implementing” function of FSM.
- Monitoring and Measuring - The measuring process starts the feedback loop to the entire FSM system. The fire safety performance of PRH such as ignition frequency per year, the statistics on fire casualty, the causes of fires etc. will be recorded and input from the respective functional units to the FSMU. Thereafter the data will be processed by the FSMU as the basis of gauging the overall effectiveness of the FSM system.
- Checking and Evaluation/Fire Safety Audit - This is the action phase of the feedback loop. Apart from the surveillance on compliance with the fire safety plan and analyzing the measured performance data, audit will take a proactive step in probing the FSM system. The effectiveness, integrity, and reliability of the FSM system will be evaluated to seek for continual improvements. The in-house Senior Building Services Engineer (fire safety) should be the incumbent for this function as an internal auditor. Fire

safety audit conclusion is the culmination of the FSM system and is not usually included in traditional management elements. The improvement proposal of the FSM system shall be drawn up by the FSMU and presented to the top management for review and acceptance.

- Management Review - The audit evidence, finding, conclusion and recommendation will be deliberated by the top management with ranking from Director of Housing to Assistant Directors. The fire safety policy may need to be reviewed and enhanced as necessary to echo the audit conclusion and form the basis of continual improvements. The degree of improvements can be evaluated during the next periodic audit, or an interim audit as directed by the top management for critical issues such as the amendment in relevant legislations. The details of fire safety audit will be further discussed in ensuing sessions.

A summary of the proposed FSM system for HKHA and their functions is given in Table 7.1.

Table 7.1 Summary of the proposed FSM system for HKHA and their functions

Sub-system	**Function**	**Persons involved**
Fire Safety Policy	Deliberate and make decision on HKHA's fire safety policy, and sign off a formal Fire Safety Policy statement, promote the fire safety culture in PRH across the organization and tenants	Director of Housing, Deputy Director of Housing, Assistant Directors of Housing
Planning	Fire hazard identification, risk assessment, planning for fire safety improvement works, setting of management regimes and fire safety objectives	Assistant Directors of Housing, Fire Safety Manager, Chief Housing Manager
Developing	Allocation of financial resources and set-up of the FSMU to oversee the entire FSM functions, fostering a corporate wide fire safety culture	Assistant Directors of Housing, Fire Safety Manager, Chief Housing Manager
Organising	Establishment of an organizational structure across all units and delineate their accountabilities, responsibilities and duties; balancing of resources to achieve the target performance	Assistant Directors of Housing, Fire Safety Manager, Chief Housing Manager
Implementing	Preparation of Fire Safety Plan and Fire Safety Manual, arrangement of fire safety training, maintenance of passive and active fire safety provisions, general housekeeping, daily patrolling and reporting, supervision of operating staff	Fire Safety Manager, Housing Managers, Building Services Inspectors, Clerk of Works, Housing Officers, Security Guards
Monitoring and Measuring	Provide fire safety statistics and investigation of fire causes, comparison with key performance indicators and historical trends	Fire Safety Manager with input from various functional units
Checking and Evaluation/Fire Safety Audit	Analysis of fire performance statistics, conduct field audit to evaluate the entire FSM, and to provide audit conclusion and recommendation to top management, to liaise with the AHJ regarding fire safety issues such as amendment on legislative requirements and evaluate the impact on HKHA	Fire Safety Manager
Management Review	Deliberate on the audit findings and conclusion as prepared by the FSMU, to amend the Fire Safety Policy and promulgate the Policy accordingly	Director of Housing, Deputy Director of Housing, Assistant Directors of Housing

7.7 A three tiers framework to FSM

As discussed in Chapter 3, the BD and FSD currently only require the building owners to have the Ventilating System and FSI be checked and inspected by a RVC and RFSIC annually. There is in lack of a formal monitoring mechanism from the AHJ regarding the FSM arrangement of occupied buildings. With a wider application of performance-based fire safety design, auditing and surveillance of the FSM is of paramount importance in order to keep the occupied buildings as per the design conditions.

In this connection, Lau (2008) has proposed a three tiers framework for fire safety management of buildings as shown in Figure 7.6.

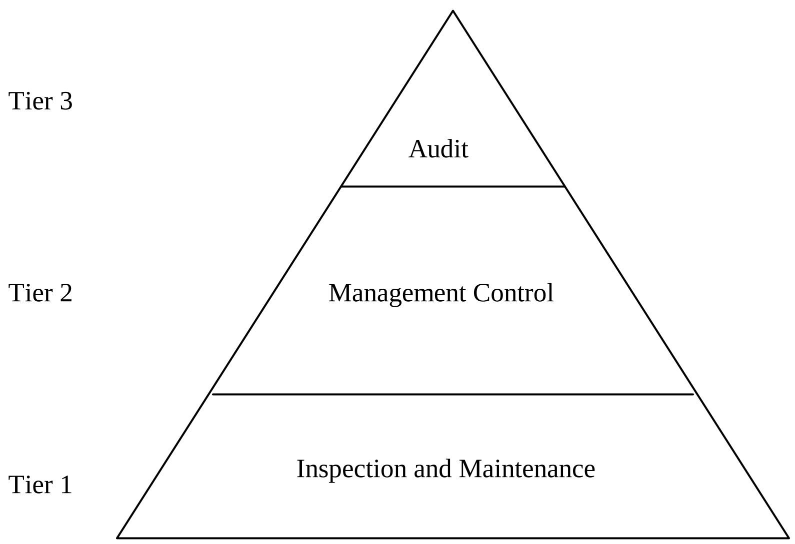


Figure 7.6 Proposed mandatory control framework on fire safety management (Lau, 2008)

Tier 1 is on inspection and maintenance. He argued that the current legislative requirement on annual certification of FSI is inadequate because the passive fire protection measures such as checking of fire doors are not addressed. The scope of annual certification should be enlarged to cover these building elements to plug the loopholes. Tier 2 is on management control. It is not uncommon for maintenance contractors to shut down the fire alarms during the course of various repair works. The malpractice can be averted through exercising proper control by the property management company. Tier 3 is on fire safety audit. He opined that fire safety audit is essential to ascertain the fire safety management system such as the standard of maintenance and shutdown of FSI; and the prevention of building management inadequacies.

Although periodic in-house fire safety audit can be arranged (e.g. Daws, 1988), it is recommended to have an external fire safety auditor to verify and authenticate the FSM system of an organization in the longer run. This may be part of the third party fire safety certification regime as discussed later.

7.8 Fire Safety Audit principles

Audit is the essential tool for striving continual improvement to any management system; and hence it is necessary to have a more thorough consideration on Fire Safety Audit as a specific type of auditing application. Shields (1996) has pointed out that emergency planning should be transparent and capable of being assessed. This is particularly true in the total quality management era. Fire Safety Audit therefore offers such assessment opportunity.

According to BS EN ISO 19011: 2011 Guidelines for auditing management systems, "audit is defined as a systematic, independent and documented process for obtaining

audit evidence and evaluating it objectively to determine the extent to which the audit criteria are fulfilled" (BSI, 2011). In order to conduct an audit effectively and to produce meaningful audit conclusion, there are six principles to be adhered (BSI, 2011).

- Integrity - the auditor should be a competent professional and perform the audit with due diligence and impartial in his judgement.
- Fair presentation - the auditor should report his audit findings and conclusion truthfully and accurately. Any unresolved difference in opinions between the auditee and audit team should also be recorded.
- Due professional care - the auditor should exercise his due care and make reasoned judgement during the audit process.
- Confidentiality - the auditor should handle the information that is collected during the audit in confidence. The information should not be used or disclosed inappropriately that may jeopardize the interest of the client.
- Independence - the auditor should not be involved in the activity to be audited to avoid conflict of interest. In the case of internal audit, the appointed auditor should not be under the line management of the functional units being audited.
- Evidence-based approach - the audit conclusion should be based on audit evidences which are verifiable. An appropriate sampling in collecting the

evidence is recommended to increase the confidence of the audit conclusion.

Though the auditing process has a great value to an organization, there are also some challenges that have to be considered as highlighted by Dunlap (2011, pp. 175-179).

- Commitment and ongoing support from the top management is critical to the success of the audit.
- Sufficient budget is necessary to run the audit programme and the hiring of auditors and the associated expenditures.
- The audit programme should be well-planned and scheduled such that each audit will produce fruitful results without wasting of time and resources. An ill-prepared and informed audit will lead to cancellation of the audit and a disruption of the other audits. At times, some units may lose confidence on the audit programme.
- Technical support such as information technology facilities should be provided to enhance effectiveness of the programme. For instance, the various audit requirements and protocols can be shared via the intranet system to facilitate the work of the auditor.
- Since fire safety covers a wide spectrum of knowledge and standards which are constantly changing, it is crucial for the auditor to keep abreast of the current state of knowledge in order to make an educated judgement. In case of uncertainty, the auditor can make use of the time that is dedicated to prepare the report to research the issue before informing the auditee of the outcome.

7.9 Competence of the Auditor

While auditing is considered as the indispensable tool in evaluating a management system; the success of the audit will in turn, hinge on the competence of the Auditor. As a whole, the Auditor should possess general and discipline-specific knowledge and skills. For instance, the British Standard BS EN ISO 19011 (BSI, 2011) has provided guidance on the knowledge requirements for an Auditor on OHS. The criteria can be equally applied to an Auditor on FSM system which is proposed as follows:

General knowledge:

- general management concepts, process and terminology such as planning, budgeting and personnel management
- the auditor should be familiar with the common auditing principles and methods such as conducting document review, data analysis and sampling techniques, site inspection and the compilation of a check list, communication skill with the audited parties etc.
- the principles and practices for identifying potential emergency situations and planning, prevention, response and recovery
- understanding on the culture and habits of human factors in devising fire safety strategies
- fire safety training and methods to encourage staff and tenant participation

Discipline-specific knowledge:

- understanding of the legal requirements on fire safety
- hazard identification
- fire risk assessment
- engineering knowledge on active and passive fire protection systems
- fire incident investigation and evaluation
- methods for monitoring and reporting on fire incident statistics

A Senior Building Services Engineer with specialized training in fire safety engineering would be a suitable person to take up the duty as a Fire Safety Auditor. Since the appointee has been working within the HKHA for a long period of time, he would have the prime advantage of acquaintance of the organizational culture besides possessing the expert knowledge on fire engineering. In addition, he will be given specialised training on auditing skills so as to enable him to discharge his duties effectively.

7.10 Fire safety engineering professionals in Hong Kong

The Hong Kong Institution of Engineers (HKIE) is a professional body incorporated under the Hong Kong Institution of Engineers Ordinance, Chapter 1105 of the Laws of Hong Kong in 1975. The Institution sets standards for the training and admission of local engineers. It has strict rules governing the conduct of its members and, as a learned society; it enables its members to keep abreast of the latest developments in engineering. Within the HKIE, there are 20 practising disciplines. The Fire Division of the HKIE was initially established in 2008 from local professionals and academics to share their expertise and knowledge on the evolving discipline of fire safety engineering. Subsequently in 2009, the Fire Discipline was formed with formal admission of professional fire engineers.

The admission requirements for Corporate Membership to the Fire Discipline (HKIE, 2011) are generally in par with other disciplines. A candidate is normally assessed in three stages. Firstly, the candidate should have an academic qualification equivalent to a bachelor engineering degree (with honours) relevant to fire engineering which is accredited by the institution. Thereafter, he should receive a 2-year recognized "Scheme A"[10] training followed by 2 years of responsible experience; or 5-year general experience training together with 1-year of responsible experience. Finally, the applicant for Corporate Membership of the HKIE will need to attend a Professional Assessment comprising the submission of reports on his training and experience, engineering project documentations, professional interview and the writing of an essay.

For the Fire Discipline in particular, the core competence of the applicant includes:

- application of combustion and fire science which relates to the fundamental theories of fire physics and chemistry

[10] "Scheme A" training is a formal and structured training scheme developed by the HKIE for University graduates who aspire to become a Corporate Member of the institution. The graduates should join an organization registered with the HKIE in operating the Scheme and the training content and experience of the graduates will be supervised by an Engineering Supervisor and monitored through a log book.

- enclosure fire dynamics which deals with the principles of initiation, development and spread of fires in buildings, and the application of computer modelling
- design of active fire protection engineering systems such as fire detection, sprinkler etc.
- design of passive fire protection in buildings including compartmentation, various structural elements to resist the action of fires
- smoke control design such as smoke ventilation and control of smoke spread
- the evacuation design and interaction between fire and people
- integrated fire engineering design through developing a myriad of fire safety strategies on a performance basis
- fire risk analysis and fire safety management of buildings
- fire safety legislation control and public fire safety administration

In parallel with the HKIE, there is an Engineers Registration Board (ERB) which was established under the Engineers Registration Ordinance enacted in 1990. The ERB is responsible for administering the registration of professional engineers in various disciplines in a way that would confer the applicant a title of Registered Professional Engineer (RPE). Such protected title would indicate that the RPE is competent to practise in a particular discipline. To qualify for registration, the applicant must be a Corporate Member of the HKIE, or membership of an equivalent engineering body which is acceptable to the ERB. Moreover, the applicant must be ordinarily resident in Hong Kong and have at least one year relevant post-qualification experience. The two tier arrangement in the registration of engineers will safeguard the consumer public who wish to appoint the RPE for executing engineering services.

7.11 Proposal for a Registered Fire Engineer (RFE) scheme

It has been an international trend to change the regulating regime of fire safety in buildings from a prescriptive control by the AHJ to self-regulation. For example, Singapore has already launched the self-regulation and third party fire safety certification scheme in 2004. The scheme requires that all building construction works are to be designed and supervised by a Qualified Person (either a professional architect or engineer); and the completed fire safety installations are to be inspected and checked by a Registered Inspector before the Qualified Person can apply for a Fire Safety Certificate for the purpose of occupying the building. To qualify as a Registered Inspector, the applicant must be a Qualified Person with at least 10 years of experiences in designing and inspecting fire safety works. As remarked by Boo (2009), the scheme manifested to be successful and sustainable.

In 2004, the Hong Kong Government has commissioned the Efficiency Unit to conduct a departmental business study for FSD. The study concluded that FSD should concentrate her role as a regulator, and gradually leave the fire safety certification to the industry in line with other international practice.

Building upon the experience of Singapore, FSD has issued consultation letters to the relevant stakeholders in 2004 and then a consultation paper on “The implementation of third party fire safety certification by introducing a Registered Fire Engineer Scheme in Hong Kong” to various government departments and trade institutions in

2007 (FSD, 2011b). According to the paper, FSD proposes to establish a registration mechanism for fire safety certifiers, i.e. the Registered Fire Engineer (RFE) similar to the registration of Authorised Person under the Building Ordinance. To apply for registration, the candidate shall be a Corporate Member of the HKIE and also a RPE in the Fire discipline which is designated as RPE(FRE). The main duties of a RFE (as a third party certifier) include the certification for compliance of fire safety requirements for FSI and ventilating systems in licensed premises[11]; and the certification for compliance of required standards for FSI alteration and addition works for all types of buildings.

After collecting the comments from the industry, the FSD then revisited the proposal and issued another consultation paper entitled the "Revised Scheme for the implementation of Third Party Fire Safety Certification by Introducing a Registered Fire Engineer Scheme in Hong Kong" as the second round of consultation (FSD, 2011a). In a gist, the revised scheme seeks to simplify the qualification requirements for registering as RFE. Incidentally, the scheme introduces an option of categorizing the RFE into 3 classes termed as option B in comparison with the original single class which is described as option A.

As outlined in the consultation document, there are 3 distinct classes in the so-called option B; viz. RFE (Risk Assessment), RFE (Fire Services Installation) and RFE

[11] Licensed premises refer to any premises where a licence is required to operate with the business conducted thereon. They include General Restaurant, Light Refreshment Restaurant, Factory Canteen, Funeral Parlour, Dance Hall, Cinema, Theatre, Karaoke Establishment, Bakery, Food Factory, Billiard Establishment, Public Bowling Alley, Public Skating Rink, Places of Public Entertainment, Hotel, Guesthouse, Club, Child Care Center, Residential Care Home, Amusement Game Center, Designed School, Non-designed School, School for Non-local Higher Education and Professional Courses, and Massage Establishment.

(Ventilating System) to be registered according to their own expertise. On the other hand, the original so-called option A will only have a single class of RFE, i.e. RFE (Fire) who are registered to carry out all the above three types of fire safety engineering duties. Obviously, it would be more efficient for the operator of the licensed premises to have fire safety certification under option A because he only needs to engage a RFE (Fire) to carry out all the fire safety works and the cost and time is likely to be less under a “one-stop-service” engagement. Alternatively, the categorization of the RFE into three classes would allow more supply of RFE to meet market demand since the applicants from a wide spectrum of disciplines can apply to be registered as RFE based on their own expertise.

Notwithstanding the options proposed, the basic requirements of being a RFE are generally the same. FSD would require that the prospective applicant for RFE to be a RPE as the basic professional qualification. In addition, the applicant shall within the 3 years preceding the date of application have had a continuous period of one year of relevant local fire engineering experience. However, the requirement of “being a member of HKIE” is dispensed with. This arrangement simplifies the registration procedures without compromising the qualities and standards of the RFE.

The details of the options, classes of RFE, and the scope of works for each class are shown in Table 7.2.

Table 7.2 Class and Scope of works for RFE

Option	Class of RFE	Suitable candidate	Scope of works
Option A	RFE (Fire)	RPE (FRE)	To perform all the fire safety certification works for licensed premises including conducting fire risk assessment, formulating fire safety requirements and certification of compliance for both FSI and Ventilating Systems
Option B	RFE (Risk Assessment) [RFE (RA)]	RPE (FRE)	To conduct fire risk assessment and formulate fire safety requirements for licensed premises
	RFE (Fire Services Installation) [RFE (FSI)]	RPE (FRE), or RPE of other disciplines such as Building Services with proof of experience in FSI works	To conduct compliance inspection for fire safety requirements in licensed premises (except ventilating system) and to issue fire safety certificates
	RFE (Ventilating System) [RFE (VentS)]	RPE (FRE), or RPE of other disciplines such as Building Services with proof of experience in fire safety aspects of Ventilating Systems	To conduct compliance inspection for fire safety aspects of ventilating system in licensed premises and to issue fire safety certificates

In order to ensure the standard and consistency of fire safety standards, the fire safety requirements formulated by the RFE are subject to endorsement by FSD. In addition, for installation works certified by RFE, FSD would take random audit inspections after the issuance of the Fire Certificate by the RFE. Should any discrepancies be unveiled during the audit inspection, FSD will require the licensee to make good the discrepancies within a reasonable time through the issuing of a Fire Hazard Abatement Notice. At the same time, the licensing authority and the RFE will be informed of the discrepancies identified and the action taken by FSD. Depending on the situation, the licensing authority may take other legal action as appropriate. Furthermore, the RFE may be subject to disciplinary action against failing to exercise reasonable care to discharge his duties by a RFE Disciplinary Panel.

Initially, the above scheme is intended to be rolled out for licensed premises. After 24 months of implementation, FSD will conduct a review and consider the revamp and expansion of the scheme to certification of building FSI alteration and addition works, and the FSI compliance check for new building projects.

It can be expected that a RPE in the Fire Discipline or a RFE (upon the implementation of the third party certification scheme) with additional training on auditing is the right person in conducting fire safety audit because they possessed the expertise knowledge and training on fire safety engineering. In the case of HKHA, a Senior Building Services Engineer (with specialization in fire engineering) can be appointed to lead the FSMU both in the formulation of fire safety strategies and the conduct of fire safety audit. He should be directly responsible to the top management, i.e. the Director of Housing, in discharging all duties relating to Corporate and PRH fire safety.

7.12 Development of a Fire Safety Management Index (FSMI) for buildings in Hong Kong

In the interim when there is no formal legislation on FSM, the fire safety culture can be boosted up through instilling the concept of organized FSM to the property management company. In this connection, a voluntary “Fire Safety Management Index” (FSMI) scheme is proposed in order to promote and to gauge the fire safety management level of residential buildings.

For example, Howarth and Kara-Zaitri (1999) had developed a FSMI for passenger terminal using ten elements namely:

1. organizational arrangements
2. risk assessment methodology
3. compliance of fire safety law
4. emergency plans and procedures
5. communication and information
6. reporting and investigating fires
7. training
8. maintenance and standards
9. budget
10. audit

Each of the elements will be given a score out of a maximum of 5 and the total score will reflect the standard of fire safety management. Such index, together with a fire risk index and a passenger density factor will rank the overall fire safety standard of the terminal. Although developed for passenger terminals, the above 10 elements are equally applicable for residential buildings and can be taken as a reference.

In the situation of Hong Kong, a similar FSMI is proposed below for residential buildings under 10 major elements with 20 components as shown in Table 7.3.

Table 7.3 Proposed components of a Fire Safety Management Index for residential buildings

1.	**Organizational arrangement**	
	1.1	A fire safety policy commitment from senior management of the organisation
	1.2	Appointment of a Fire Safety Manager
	1.3	Staffing level of property management
2.	**Budget on fire safety**	
	2.1	To have sufficient annual budget for expenditures on maintenance of fire services installation, training and education etc.
3.	**Compliance of fire safety legislation**	
	3.1	Regular maintenance of fire services installation
	3.2	Regular patrol to ensure no blockage to the exit route
	3.3	General housing-keeping
4.	**Fire risk assessment (FRA)**	
	4.1	To conduct periodic FRA to the premises and when there is change in use or alteration works
5.	**Emergency procedures**	
	5.1	To prepare a documented fire safety manual
	5.2	To post fire escape plans on each lift lobby
	5.3	Staff should be familiar with the evacuation procedures
	5.4	A clear instruction to duty guards on calling the fire service in case of fire
6.	**Fire reporting**	
	6.1	Record keeping on fire incidents and investigations
7.	**Staff training**	
	7.1	A clear staff training plan including refresh training on fire safety and emergency procedures
8.	**Works control**	
	8.1	Control on tenant’s fit-out works
	8.2	Control on landlord’s alteration and fit-out works
9.	**Liaison with the FSD**	
	9.1	Arrangement of fire safety talks with FSD
	9.2	Arrangement of fire drill with FSD
10.	**Fire safety audit**	
	10.1	Periodic fire safety audit by the Fire Safety Manager to ensure the integrity of the FSM system
	10.2	To seek for continual improvement of FSM after audit

A score ranging from 1 to 5 can be accorded with an aggregate total of 100 by BD in conjunction with FSD. The FSMI of a residential building can serve as a hallmark to indicate the commitment of the owner and manager in the management and maintenance of the building to achieve a high level fire safety performance. A certificate can be awarded by the authorities in recognition of such achievement. The award would bring enhancement to the asset value of the buildings and is a driver to the property owners in devoting efforts to fire safety. This voluntary certification approach can be quite similar to the Hong Kong Building Environmental Assessment Method (HK BEAM) as described in the next paragraph.

Actually, a similar "Certified Fire Safety Building Indication System" is in operation in Japan (Tokyo Fire Department, 2012a). Owners of certain types of large public buildings with persistent good performance in fire safety can apply to the fire station chief under the scheme. An "Excellence Mark" certificate will be granted by the fire station chief after verifying against the fulfilling criteria. The owner can display the certificate at the building entrance to signify that the building is "well prepared" for fire incidents.

7.13 Success example of the HK BEAM

The HK BEAM is operated by the Hong Kong BEAM Society and was launched in 1996 under the funding of the Real Estate Developers Association of Hong Kong (e.g., HK BEAM Society, 2010). It is a voluntary assessment scheme which provides building users a hallmark label that signifies the environmental performance of a building. Originally, the scheme was developed on the concept of the UK Building Research Establishment Environmental Assessment Method for new and existing office buildings. In 1999, an additional version for new residential buildings was also issued. The assessment is comprehensive and spans the whole building life cycle including planning, design, construction, management, operation and maintenance. In 2005, Lam Tin Estate phase 7 & 8 (with 4 residential blocks) developed by the HKHA was assessed as the 100th green building project under the scheme. By then, the HK BEAM is the most widely used scheme of its kind in the world (on a per capita basis) covering 52,000 residential units (HK BEAM Society, 2005).

In order to evaluate whether the buildings certified under HK BEAM are equivalently rated if assessed by similar schemes in other countries, Lee and Burnett (2008) had conducted benchmarking study against those schemes in UK and US. By statistical analysis of the energy assessment results of 60 new office buildings based on the earliest versions of the schemes released in the 1990s, they concluded that the local scheme is generally comparable to the international counterparts despite there are some differences in the energy use assessment methods and simulation tools.

As of March 2010, HK BEAM even provided recognition to landmark properties in Beijing, Shanghai and Shenzhen, totaling over 10.5 million m^2 of spaces and 56,000 residential units.

The success story of the HK BEAM does manifest that a voluntary assessment and certification scheme for recognition of building performance is an attraction to building owners and well received by the industry. The scheme award will provide a quality hallmark for the property owners; who could attempt to obtain the certification on a pace to meet their own needs and constraints such as budget for improvement works.

7.14 Constraints on implementing the FSM system in HKHA

The existing FSM arrangement in HKHA is already structured and orderly. In order to upgrade the entire system into a formal one and integrate it into the whole management system as proposed above, due considerations should be paid to the constraints.

Firstly, similar to SMS, FSM system requires the commitment from the top most management. There is no doubt on this aspect because it is one of the missions of HKHA to deliver a quality, safe and healthy living environment to our public tenants. The next step is to rationally allocate the resources for establishing a systemic FSM system such as the setting up of a dedicated FSMU. This unit should be working at headquarters level which would report directly to the Director of Housing on fire safety issues.

Secondly, for a FSM system to be effective, a fire safety culture should be further developed and reinforced across all staff of the organization and the tenants at large. This can be done by fortifying the current estate fire safety campaign and fire drill on a more frequent basis such as annually in lieu of once every 2 to 3 years. More talks or promotional inculcation must be arranged to the tenants to deepen their knowledge and understanding in fire safety such as the proper use of electricity and disposal of waste. It is critical to win their support and co-operation in order to achieve the fire prevention goal. In addition, more fire safety training to frontline estate management staff should be arranged by the FSMU in conjunction with the training unit.

Thirdly, it is necessary to balance the resources allocated to fire safety improvements either on active or passive provisions or other management aspects. A fire risk assessment (FRA) exercise should be conducted for prioritizing the works among the estate portfolios as well. The FRA should be conducted by the FSMU to each estate as an initial status review process to identify the major hazards present and how “risky” the estate is. In view of the large portfolio of estates, a Qualitative methodology with the use of a check list would suffice for the purpose.

Fourthly, the FSMU should be responsible for developing technical standards on fire engineering issues such as maintenance of FSI, fire cause investigation etc. The unit will need to collaborate with the estate management staff in devising management procedures such as hot work permit system, suspension of FSI, isolation of fire alarm system, fire safety educational promotion, general housing keeping and fire prevention practices.

Fifthly, the Fire Safety Manager would need to participate as a member to the new project team for the design of new buildings to provide opinions and feedback on fire safety management considerations. This is particularly important where a performance-based design is deployed and FSM is called for as one of the tactics or bounding conditions of fire safety design. Under such circumstances, the Fire Safety Manager has to draw up the Fire Safety Manual very carefully after compromising with the design engineers and architects. This serves as the guidance documents for the subsequent operation, maintenance and management of the occupied building. All future alteration and addition works shall be passed to the Fire Safety Manager for prior review and comment to verify whether the bounding conditions are still maintained. A fire engineering consultant may need to be engaged to offer design input and submission to AHJ on fire safety package when complicated alteration and addition works are proposed to such buildings.

Finally, the FSMU should be responsible for arranging periodic Fire Safety Audit to verify whether the fire safety practices of various units conform to the in-house rules and requirements. Most importantly, the robustness of the entire FSM system should be assessed and recommendation on improvement put forward to the top management for review. This is the most difficult task because it relies on the support, rapport and trust from every staff across the organization.

7.15 Summary

In this Chapter, the fundamental principles of management; and the application of such principles to quality management, environmental management, and safety management have been briefly reviewed. It is observed that the traditional functions of management namely, Planning, Organizing, Commanding, Coordinating and Controlling in achieving business objectives can be equally applied to these specialized management contexts. The safety management models from the ILO, UK and Hong Kong are further revisited. Actually, there is no significant difference in these models because they apply and integrate the traditional management practices together with the quality management concepts of Plan-Do-Check-Act into a safety management model. Therefore SMS will emphasize on continual improvements on the system through an audit mechanism.

Based upon the SMS principles, it is suggested that similar FSM system can be constructed despite there is no formal legislations on building FSM. In the case of HKHA, it is considered that good FSM is a contributing factor in having a good fire safety performance across the building stocks despite that some buildings were constructed many years ago and may not comply with current fire safety codes.

While the FSM system in HKHA is structured and systematic, it is not totally "systemic". A FSM system to suit HKHA is therefore proposed in this Chapter.

As suggested in this system, a full time Fire Safety Manager in the rank of Senior Building Services Engineer with specialization in fire safety engineering is recommended to lead a FSMU to handle all issues relating to Corporate and PRH fire safety. Similar to OHS practice, he should report directly to the Director of Housing in order to signify the commitment of the top most management.

As an indispensable tool to probe into any management system, fire safety audit and hence the competence of the Fire Safety Auditor is further discussed. The Fire Safety Manager with training on auditing is a suitable person to take up the role as the internal auditor because he is readily knowledgeable on fire safety engineering and corporate culture.

On the other hand, it is also found that FSD has just launched the consultation on third party fire safety certification scheme regarding the Ventilating Systems and FSI for licensed premises. Nevertheless, the prime purpose is on the certification of active fire protection systems only. Pending on the roll out of the system in the coming years, it is highly recommended that the FSD would also review the application of the RFE as an external auditor in verifying and certifying the integrity of the building FSM system and passive fire protection as well.

Actually, the maintenance of fire safety provisions to the requirements of the AHJ and fire safety management is complimentary to each other. The upkeeping of fire safety provisions as per the legislative code is generally prescriptive in nature and is considered as the bare minimum. On the contrary, FSM will rely on a goal setting approach of the organization with respect to fire safety performance. It is recommended to have a mandatory systemic FSM system in place particularly for buildings with performance-based design or large residential property portfolios. In the interim, a voluntary FSMI scheme for instilling the fire safety culture and recognizing the achievements of the property owners and managers on fire safety performance is proposed. The scheme would encourage the property owners to devote more commitments to fire safety.

The Chapter concludes by outlining the considerations for implementing a systemic FSM system in HKHA.

CHAPTER 8 Conclusions and Recommendations

8.1 Introduction

In Chapter 1, the overall fire safety performance of buildings in Hong Kong is reviewed through past fire statistics from local FSD and comparison is also made with other international statistics. It is found that the overall fire safety standard in Hong Kong in terms of fire death per 100,000 persons is good. It is ranked second to Singapore and better than most developed countries including UK and USA. The background and the aim of the research are outlined; and the research methodology is presented.

In Chapter 2, the concepts of risk and available fire risk assessment methodologies ranging from Qualitative, Semi-quantitative and Quantitative are reviewed. The choice of the methodologies is discussed. Quantitative Risk Assessment technique will be used to conduct risk analysis to existing HKHA buildings with a view to realizing the contribution of organized FSM towards the reduction of fire risk.

In Chapter 3, the fire safety legislation in Hong Kong is reviewed. It is noted that there is no clear cut legislation on FSM in place although its importance is increasing revisited. Only fundamental requirements on preventing the blockage of escape route and regular maintenance of active and passive fire services provisions are mandated under the BMM code. The major deviations from the four current code books regarding the fire safety provisions of existing HKHA buildings have been highlighted. While every effort has been endeavoured by the HKHA to upgrade the fire safety provisions to these older buildings, there may still be limitations as to the extent of the improvement works. Moreover, the implementation of upgradation works may even be prohibitive either on grounds of technical constraints, or excessive nuisance to the daily lives of residing tenants.

In Chapter 4, the concept of FSM as a fire safety strategy is introduced and the FSM practices in HKHA are reviewed. As HKHA is a quasi-government organization, the FSM is well organized and there is close liaison between HKHA and FSD. Furthermore HKHA has been investing heavily on fire safety education. The effectiveness is manifested by the independent consultancy reports on “Survey on Fire Safety Awareness of Tenants in Public Rental Housing”.

In Chapter 5, the fire incident records of HKHA buildings from 2006 to 2010 are retrieved and analysed. The ignition frequencies of the existing buildings with different block design have been studied. In addition, diurnal variation patterns of the ignition frequencies are also plotted in polar diagrams. It is generally observed that more fires will tend to happen in the day time when there will be more human activities such as cooking. On the other hand, more fires tend to happen in winter time possibly due to more festive activities and heating requirements. Broadly speaking, the annual ignition frequencies per block do not exhibit significant difference amongst the different block design. This finding suggests that those older buildings having more deviations from the present day fire safety codes are not likely to have higher chance of fire occurrence. Good FSM appears to play a role because of the high level of preventive and precautionary measures taken.

In Chapter 6, the causes of fires from different countries have been reviewed and compared. It is found that the leading causes of fires are invariably cooking, electrical and cigarette disposal; which are generally similar to the case in Hong Kong. At the same time, the fire risk level of an existing example building of HKHA has been further assessed by the FTA technique on a conceptual basis with the aid of the "Fault Tree+" software. The Fault Tree Diagram of "A flat on fire" is constructed and its probability is calculated from the estimated probabilities of the basic events. The improved probability with structured FSM in place is further evaluated and compared. In addition, a Consequence Event Tree Diagram is also constructed to assess the consequence which is described in terms of the "Effectiveness of evacuation". Since there is no reference information on the values of probability or likely consequence due to FSM, it is estimated based on questionnaires return from experts in fire engineering such as Building Surveyors, Building Services Engineers and Estate Managers as a start. The overall fire risk level of the example building is found to reduce by **74%** due to structured FSM. It demonstrates that good FSM is very crucial to building fire safety.

In Chapter 7, the fundamental principles of management and their application to safety management is revisited. Unlike traditional management basics, SMS builds upon the quality management concepts and hence continual improvement is persistently pursued. As pointed out in the literature, a FSM system should be "systemic" and the current SMS models can be borrowed to develop a FSM model. To this end, a FSM system for HKHA is further proposed and the considerations before implementation discussed. Since there is no formal legislation calling for systemic FSM in the interim, a Fire Safety Management Index scheme is further proposed as a voluntary scheme for instilling a fire safety culture and fostering a structured FSM practice in the property management industry.

8.2 Fire safety concern of existing HKHA buildings

HKHA is the owner of 1,420 rental buildings which accommodate some 30% of the local population. To maintain the buildings in a habitable and safe state is a major challenge to the HKHA. Among others, fire safety to these buildings is a great concern. Since some "older" buildings are constructed many years ago, they may not comply with present day fire safety descriptive codes. However, the fire safety level of such buildings may not be inferior to that of newer buildings because of structured FSM. There is no significant variation in the ignition frequencies per block among older and newer block design within HKHA.

It is the aim of this research project to study the contribution of structured FSM with particular reference to the case of PRH. As estimated in Chapter 6, the overall probability of having "A flat on fire" has reduced from **0.1619** to **0.03974** due to structured FSM and the overall risk in terms of "Effectiveness of evacuation" has reduced from **0.1619** to **0.04217 units** (i.e. a reduction of 74%) through a conceptual analysis by FTA. This has demonstrated the effectiveness of FSM on the reduction of fire risk in buildings.

8.3 Discussion and recommendation on legislation on FSM

The finding of the research gives an insight to the contribution of FSM. Taking into consideration the positive effect of structured FSM in preventing fires and to respond orderly in fire emergencies, legislation on FSM is highly recommended. This is especially important for buildings which are designed based on the fire engineering approach (FEA). For existing buildings where the upgradation works to current prescriptive standards may not be feasible, enhanced FSM to complement FEA is a viable strategy (Chow, 2007).

As Walters and Hastings (1998b) have once commented, the role of the property manager on fire safety is largely ignored. This situation can only be improved through legislation which mandates that a qualified Fire Safety Manager be appointed to take care of the fire safety issues of the property portfolios under his management. This will embrace the fire risk management functions comprising setting up a holistic fire safety management unit, fire safety promotion and education, preparation of the fire safety manual, organizing of fire drills, continual monitoring of the building in use, checking of fire safety aspects of alteration and addition works, controlling hot works, procurement of fire insurance covers, fire investigation and fire audits etc. According to Santos-Reyes and Beard (2001), the FSM system should be systemic in order to be effective.

The Singapore example

In Singapore, there is a legislation which requires the appointment of a Fire Safety Manager to look after the fire safety issues (Tan, 2009). Under the Fire Safety Act enforced by the Singapore Civil Defence Force (SCDF); all commercial buildings and industrial complexes with a total gross floor area larger than 5,000 m^2 or having more than 1,000 occupants; are required to employ a Fire Safety Manager. A trained

Fire Safety Manager shall be officially appointed by the building owner and registered with the SCDF. The Fire Safety Manager shall be responsible for:

- Supervising the maintenance of all fire safety works in the premises
- Ensuring that there is no overcrowding
- Conducting daily checks and removing any fire hazard
- Preparing the fire emergency plan
- Training the occupants in the use of first aid fire fighting tools and evacuation procedures
- Preparing annual report on all fire safety awareness activities carried out in the premises

As part of the fire safety assurance system, the building is expected to maintain an in-house emergency response team to tackle fire incidents. Furthermore, all buildings operating under the Fire Safety Manager scheme are subject to annual check by the fire inspectors to ensure that the active and passive fire safety provisions are properly maintained; and there is no unauthorized alteration in the building structure. Upon satisfactory inspection, an annual Fire Certificate will be issued by the SCDF to the building owner. It is likely that this stringent control regime is one of the success factors in keeping almost the best fire safety record of the country in terms of fire fatality per 100,000 persons throughout the past years.

The Japan example

In parallel, Japan requires the "Entitled Persons" (i.e. the building owners or occupiers) of large public assembly places[12] to engage a Fire Protection Manager and practise fire protection management under the Fire Service Law (Tokyo Fire Department, 2012b). The duties of the Fire Protection Manager include:

- Preparation of fire protection plans for fire protection management
- Training of firefighting, emergency reporting to the fire department, and evacuation
- Inspection and maintenance of fire protection equipment
- Guidance in the proper handling of open flames, heaters, etc.
- Management and maintenance of evacuation/fire prevention systems and equipment
- Control of the number of people in buildings

In addition, the Fire Protection Manager needs to:

- Prepare a Fire Protection Plan according to the actual situation of the workplace. The Plan should be filed with the local fire station chief.

[12] The public places include:
(i) social welfare facilities with 10 or more people admitted who may have difficulties in evacuating themselves in fire emergency; (ii) public assembly facilities with 30 or more people admitted like theatres, restaurants, stores, hotels, hospitals etc.; (iii) apartment houses, schools, factories, warehouse, offices with 50 or more people admitted.

- Prepare a Fire Prevention Guidance the contents of which are to give guidance to the building members the safety regulations and the importance of fire protection.
- Give firefighting, emergency reporting and evacuation training to the private fire brigade in preparing for a fire according to the fire protection plan.
- Revise the Fire Protection Plan if necessary.

Although the appointment of a Fire Safety Manager in both Singapore and Japan are only mandated for special types of premises but not for ordinary residential buildings, it can serve as good reference for such practice. In the local environment where clusters of high rise residential structures are built, it is recommended that similar regulations requiring the appointment of a qualified Fire Safety Manager should be considered. Choi (2000) has also concluded that "Legislation is the main driver for the implementation of fire safety management".

8.4 Conclusions

In this research project, the legislation on fire safety in Hong Kong has been reviewed and the deviations from the current fire safety codes of those existing buildings within HKHA have been discussed.

The contribution of good management practices towards a lower and stable fire safety performance across the stock of newer and older buildings in HKHA has been demonstrated through analysing the annual ignition frequencies of the building blocks of different types from the year 2006 to 2010. There is no observed significant variations in the ignition frequencies per block across different building types do suggest that structured FSM has a positive effect on fire safety performance.

A conceptual fire risk assessment of an example building using Fault Tree Analysis is conducted. The relative risk level as a result of a structured fire safety management system is estimated to be reduced by **74%** in terms of "Effectiveness of evacuation". The improvement in fire safety is quite substantial.

However, to have an effective FSM system, it has to be systemic. Therefore a FSM system in the setting of HKHA is proposed and discussed based on some SMS models. The FSM model can be further tested out on its robustness and effectiveness later on through analysing the fire safety indicators such as ignition frequencies and casualty statistics should the system be implemented.

8.5 Recommendations for further research

While risk-based approach to fire safety design is not too popular in Hong Kong due to the lack of sufficient statistical figures for input to the fault trees, some missing data can be provided through engineering judgement by the fire safety engineer in consultation with the Authority Having Jurisdiction. Bearing in mind that fire safety engineering is an evolving discipline, the adoption of engineering judgement to a greater extent than traditional engineering field such as mechanical or electrical is reasonable provided that the judgement is based on sound arguments and justifications.

A good sensitivity analysis can give us more confidence to the results of the risk assessment as the order of magnitude of the risk is defined within bound and the risk-informed decision can be made with more comfort. The risk assessment process is particularly useful on a comparative basis with respect to buildings which are considered to comply with the prescriptive codes. The overall risk level provides a benchmark for comparison amongst the combination of fire safety design features.

In order to realize the contribution of structured FSM on the reduction of fire risk quantitatively, more statistical evidences are required in the longer run. This requires that the database from the FSD be strengthened. For instance, the FSD officers may need to record the information on “Room of fire origin”, “Item first ignited”, and “Spread of fire beyond room of fire origin” similar to other advanced countries. With such information, it is possible to investigate the effects of various fire safety factors including FSM on life risk. Therefore it is recommended that research on setting up a local database on such information be built up for future use of fire safety professionals.

On the other hand, it has been pointed out by researchers that the fire safety culture and response of local citizens may be quite different from that of foreign people (e.g., Hu et al., 2005) and some of the reference data from oversea design guides may not be directly applicable to Hong Kong. Moreover, it has been emphasized that successful escape is the decisive factor in reducing fire fatalities (Lin, 2004). Thus, extensive research on the human behaviour of local citizens in case of fire should also be conducted in order to better understand the evacuation aspects of building design (Kobes et al., 2010). Management and emergency procedures can then be devised to meet the response of the evacuees accordingly.

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Appendix A - Fire Safety Plan of Hong Kong Housing Authority (Yeung, 2007a)

1 Fire Prevention Plan

1.1 Emergency Vehicular Access (EVA)

1.1.1 To maintain an updated EVA layout plan of each estate and put up on the estate notice board. Prior approval must be sought from the FSD for any subsequent alteration works that may affect the EVA.

1.1.2 To erect signage at entrance to EVA warning the public that it should be kept clear and free from obstructions at all times.

1.1.3 To tow away vehicles that parked illegally along the EVA.

1.1.4 Estate Assistant (EA) to patrol the EVA daily to ensure that the EVA is clear from obstruction and the road surface is level.

1.2 Fire escape route in each building

1.2.1 EA to patrol the building daily and to make sure the smoke lobby doors are closed at all times. Defective smoke door to be repaired once discovered.

1.2.2 To arrange for removal of all obstruction items such as furniture, bicycles, decoration materials from fire exits in accordance with the authority vested by the Housing Ordinance.

1.3 Disposal of domestic refuse

1.3.1 The cleansing contractor is to arrange disposal of domestic refuse daily.

1.4 Fire drills

1.4.1 Housing Manager (HM) is required to arrange with the local fire station on fire drill every year. After the drill, the fire officer will conduct a briefing to the tenants on the proper operation and use of the fire hose reel and fire extinguishers.

1.4.2 In order to make the drill more effective, HM should extend invitation to “Estate Management Advisory Committee” members to participate as they are the core representative of the tenants.

1.4.3 Households requiring special assistance (such as disabled) should be encouraged to participate in the drill.

1.4.4 After the drill, a review will be conducted to identify any inadequacy such that future drill could be held better.

1.5 Fire Safety Manual

1.5.1 A Fire Safety Manual will be prepared for each building to establish the management procedures, with one copy kept in security guard console in each building and the estate control room respectively.

1.5.2 HM will co-ordinate the updating of the Manual.

1.5.3 A list of households requiring special assistance during emergencies of individual estate should be kept in sealed envelope and attached to the Fire Safety Manual kept at the tower guard counters for FSD's reference during rescue operations.

1.6 Education and publicity

1.6.1 Message on fire safety should be widely publicized through estate newsletter.

1.6.2 Message of prosecution against offenders on misuse of fire hoses should be publicized through estate newsletter.

1.6.3 Message to remind tenants to keep the kitchen doors closed should be publicized through estate newsletter.

1.6.4 HM to arrange annual "Estate Fire Safety Campaign" to promote fire safety and fire prevention. Tenants are encouraged to join the "Fire Safety Ambassadors" scheme as organized by the FSD.

1.6.5 To set up "Fire Safety Education Path" in various estates to promote and inculcate the tenants on awareness and knowledge on fire safety.

2 <u>Maintenance Plan</u>

2.1 EA to inspect the FSI everyday for any obvious damage.

2.2 EA to inspect the hose reels every week for any damage to the nozzle, instruction plate, gate valve etc. Moreover, white mark will be provided on the tubing to indicate the length of 30m as required by the FSD. EA should inform the Building Services Inspector (BSIn) to arrange replacement of the hose in case of absence of such mark (e.g., due to vandalism).

2.3 EA to inspect the fire alarm bells and the manual alarm call points every week for any damage or obstruction.

2.4 EA to check for any missing fire extinguishers every week.

2.5 EA to inspect the heat/smoke detectors every week for any damage.

2.6 EA to inspect the sprinkler heads every week for any damage.

2.7 EA to inspect the fire hydrants every week for any damage to the hand wheel.

2.8 EA to inspect the fire pump room every week to make sure that the indicating lamp for the pump control panel is functionally properly, and there is no low level alarm of the associated water tank.

2.9 BSIn to arrange the lift maintenance contractor to conduct weekly servicing and inspection; and the annual examination and certification to the Fireman's lift alongside with other passenger lifts.

2.10 BSIn to arrange testing of the direct telephone link to the FSD at bi-weekly interval.

2.11 BSIn to arrange running the emergency generator by the electrical contractor every month under load condition for not less than 30 minutes. Annual maintenance and certification will also be conducted by the RFSIC. Diesel oil to be refilled after each test.

2.12 BSIn to arrange testing of emergency lighting and exit sign by the electrical contractor at half-yearly interval. The emergency lighting and exit sign will be operated under battery power supply for 1 hour. Annual maintenance and certification will also be conducted by the RFSIC.

2.13 BSIn to arrange the RFSIC to conduct maintenance and certification of the FSI at half-yearly interval.

2.14 BSIn to arrange the electrical contractor to conduct "Periodic Inspection, Testing and Certification" for the main switchboard and communal electrical installation at three-yearly interval.

2.15 Shutting down of FSI must be strictly on a need basis and the installation should be resumed as soon as possible. FSD will be notified for any shutdown overnight or exceeding 24 hours.

2.16 BSIn should monitor the shutdown of FSI and its progress, and to report any shutdown exceeding two weeks to the Building Services Engineer and Senior Building Services Engineer.

2.17 Four 4.5kg dry powder type extinguishers should be provided during the shutdown period, with two extinguishers placed at the ground floor and top floor respectively.

3 Staff Training Plan

3.1 Training to HKHA staff

HKHA will provide regular training to the patrol and estate management staff on the use of FSI in estates. BSIn are to arrange the demonstration to them annually. Web-based training modules and video compact disc (VCD) on fire safety for easy access and learning of staff has been launched.

3.2 Training to security guard

The security contractor is required to provide the training to their guards to get familiar with the fire safety knowledge and Fire Safety Manual. The VCD as prepared by HKHA is also provided to the security contractors to facilitate their training.

4 Fire Action Plan

4.1 In case of fire alarm, the Tower Guard (TG) in the building concerned should immediately find out from the fire alarm control panel the zone and location of suspected fire.

4.2 The TG shall inform the FSD immediately.

4.3 The TG shall keep communication with and seek assistance from the Estate Control Room supervisor who will mobilise other staff to assist in evacuation etc.

4.4 In case of false alarm, TG should try to mute/silent the building fire alarm as soon as possible to minimize noise nuisance. However the fire alarm system should not be reset until the false alarm is verified and the cause of the false alarm investigated by the BSIn.

4.5 The guard should try to put out the fire by hose reels or fire extinguishers if safe to do so.

4.6 A tailor-made evacuation plan for blocks having a high concentration of elderly residents should be prepared by the HM of those particular blocks.

Appendix B Structured Interview Questionnaire

Structured Interview Questionnaire **EngD (BC)**

Fire Risk Assessment for Public Rental Housing

The completed questionnaire can be returned via
If there is any question, please feel free to contact Mr. C.H.YEUNG at the above email.
Thanks for your support and kind assistance!

Note: Please ☑ as appropriate

Part 1. General Background

1. **Your profession**
   ☐ Building Services Engineer
   ☐ Building Surveyor
   ☐ Estate/Facility Manager
   ☐ Others, please specify
   ____

2. **Years of experience in your profession**

   ☐ Below 5 years ☐ 5 to 10 years ☐ 10 to 15 years

   ☐ 15 to 20 years ☐ Over 20 years

3. **Your company/organisation nature**

   ☐ Private ☐ Government

   ☐ Public Organization ☐ Others ____

4. **Core business sector**
   ☐ Property/Facility Management
   ☐ Property Developer
   ☐ Contractor
   ☐ Consultant
   ☐ Transport & Logistics
   ☐ Medical & Clinical Services
   ☐ Hotel
   ☐ Finance & Banking
   ☐ Education
   ☐ Civil Service & Public Administration

   ☐ Others ______________________

5. **Property managed or maintained by your organisation**

Type	Occupancy mode: Owned	Occupancy mode: Managed for clients
Domestic/residential	☐	☐
Office	☐	☐
Commercial	☐	☐
Hotel	☐	☐
Health Care/Hospital	☐	☐
Others	☐	☐

Part 2. Views on causes of fire

6. How much do you aware about the causes of fire inside a domestic flat?

		Fully Aware	Very Aware	Aware	Slightly Aware	Not Aware
6.1	Careless disposal of cigarette ends	☐	☐	☐	☐	☐
6.2	Cooking	☐	☐	☐	☐	☐
6.3	Electrical fault	☐	☐	☐	☐	☐
6.4	Careless disposal of joss sticks and candles	☐	☐	☐	☐	☐
6.5	Children playing with matches	☐	☐	☐	☐	☐
6.6	Overheating of machinery	☐	☐	☐	☐	☐
6.7	Other causes (please specify) ________________	☐	☐	☐	☐	☐

Additional opinions:

7. Given each of the above causes, what do you think will be the underlying sub-causes and the possible events leading to the sub-cause?

		Sub-cause 1	Sub-cause 2	Sub-cause 3	Sub-cause 4	Sub-cause 5
7.1	Careless disposal of cigarette ends					
7.1.1	Possible events leading to the sub-cause					

7.2 Cooking					
7.2.1 Possible events leading to the sub-cause					
7.3 Electrical fault					
7.3.1 Possible events leading to the sub-cause					
7.4 Careless disposal of joss sticks and candles					
7.4.1 Possible events leading to the sub-cause					
7.5 Children playing with matches					
7.5.1 Possible events leading to the sub-cause					
7.6 Overheating of machinery					
7.6.1 Possible events leading to the sub-cause					
7.7 Other causes (please specify) ________________					
7.7.1 Possible events leading to the sub-cause					

Additional opinions:

Part 3. Views on reduction of likelihood of fire incidents due to structured fire safety management (FSM)

8. If a structured and organized FSM system is in place, what do you expect the percentage (%) of reduction in the likelihood of a fire from occurring inside a flat?

		0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
8.1	Fire safety education on fire prevention	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8.2	Control on tenant's fit-out works	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8.3	Increased frequency of mandatory checking for communal electrical installations (from once every 5 years to 3 years)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8.4	Planned rewiring of domestic flats over 20 years old	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Additional opinions:

Part 4. Views on reduction of consequence of fire incidents due to structured fire safety management (FSM)

9. If a structured and organized FSM system is in place, what do you expect the percentage (%) of reduction in the consequence of a fire from occurring inside a flat?

		0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
9.1	Regular fire drill every year	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9.2	Speedy removal of obstruction items in means of escape	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

9.3	Regular patrol to ensure no smoke door is wedged open	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9.4	To prepare a list of vulnerable tenants in the Fire Safety Manual for quick reference of firemen in rescue	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9.5	Increased frequency of checking for fire alarm and hose reel from once a year to half year	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9.6	Increased frequency of checking for exit sign from once a year to half year	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Additional opinions:

10. Other comments you wish to make on the role of FSM on fire safety

Remark: All your information and opinions provided will only be used for academic purposes and the information will not be disclosed in other occasions.

Thank you very much for your support and kind assistance!