# Economics of Fire: Exploring Fire Incident Data For A Design Tool Methodology

**PhD Thesis**

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# Abstract


Fires within the built environment are a fact of life and through design and the application of the building regulations and design codes, the risk of fire to the building occupants can be minimised.

However, the building regulations within the UK do not deal with property protection and focus solely on the safety of the building occupants. This research details the statistical analysis of the UK Fire and Rescue Service and the Fire Protection Association's fire incident databases to create a loss model framework, allowing the designers of a buildings fire safety systems to conduct a cost benefit analysis on installing additional fire protection solely for property protection.

It finds that statistical analysis of the FDR 1 incident database highlights the data collection methods of the Fire and Rescue Service ideally need to be changed to allow further risk analysis on the UK building stock, that the statistics highlight that the incidents affecting the size of a fire are the time from ignition to discovery and the presence of dangerous materials, that sprinkler activations may not be as high as made out by sprinkler groups and that the the activation of an alarm system gives a smaller size fire.

The original contribution to knowledge that this PhD makes is to analyse the FDR 1 database to try and create a loss model, using data from both the Fire Protection Association and the Fire and Rescue Service.

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# Acronyms

**ADB** Approved Document B

**AEC** Architecture, Engineering & Construction

**AFD** Automatic Fire Detection

**ASET** Available Safe Evacuation Time

**BCIS** Building Cost Information Service

**BIM** Building Information Modelling

**BSI** British Standards Institution

**CLG** Department of Communities and Local Government

**FM** Facilities Management

**CFD** Computational Fluid Dynamics

**CSV** Comma Separated Value

**DOE** Department of the Environment

**DSS** Decision Support System

**EPSRC** Engineering and Physical Sciences Research Council

**FSEC** Fire Service Emergency Cover

**FPA** Fire Protection Association

**FRS** Fire and Rescue Service

**GUI** Graphical User Interface

**IFE** Institute of Fire Engineers

**IRS** Incident Reporting System

**IRMP** Integrated Risk Management Plan

**ISD** Inherently Safer Design

**NFPA** National Fire Protection Association

**NIST** National Institute of Standards and Technology

**QDR** Qualitative Design Review

**RIBA** Royal Institute of British Architects

**RICS** Royal Institution of Chartered Surveyors

**RRO** Regulatory Reform (Fire Safety) Order

**RSET** Required Safe Evacuation Time

**SFPE** SFPE Handbook of Fire Protection Engineering

**SIP** Structural Insulated Panel

**VOA** Valuation Office Agency

# Publications

Publications published as part of this PhD are detailed below and are referenced in the text as required.

## 0.1 Journal Papers

1. C Salter, G Ramachandran, S Emmitt, N Bouchlaghem **(In Review)** Economic Cost of Fire: Exploring UK Fire Incident Data To Develop A Design Tool, *Fire Safety Journal*.

## 0.2 Conference Papers

1. C Salter, N Bouchlaghem (2011), **Fire Engineering in the UK : A UK Practitioners View**, *International Conference on Building Resilience*.
2. C Salter, G Ramachandran, N Bouchlaghem (2011), **A Cost Benefit Tool for Fire Protection Engineers : An Analysis**, *2nd IRMP Conference*, Glasgow University.

## 0.3 Seminars and Presentations

This work has also been presented at the following Institute of Fire Engineers seminars and lectures. No papers were published for these events.

1. C Salter, S Emmitt, N Bouchlaghem, G Ramachandran (2012) **Economics of Fire: A Design Tool Methodology** In: IFE Heritage Special Interest Group Seminar, 13 March 2012
2. C Salter, S Emmitt, N Bouchlaghem, G Ramachandran (2012) **Cost of Fire: Exploring Fire Incident Data For A Design Tool Methodology** In: IFE Kent Group Continuing Professional Development Training Seminar, 29 May 2012
3. C Salter, S Emmitt, N Bouchlaghem, G Ramachandran (2012) **Cost of Fire: Exploring Fire Incident Data For A Design Tool Methodology** In: British Sprinkler Association Meeting, 11 June 2012

# Acknowledgements


> *"To all who stood with me, when we stood as one*
> *Thank you for guiding me, for bringing me home*
> *And if it seems that I'm obliged to say these words*
> *I write this in gratitude, the least that you deserve"*
> Ronan Harris

This section is far to small to acknowledge all of those whose support has proved invaluable thoughout this work, however, I have attempted to list them in no speific order and if I've missed you from below, it's only due to lack of space that you don't appear.

I'd like to thank the hard work, support, dedication and encouragement from my supervisors, Prof. Stephen Emmitt and Prof. Dino Bouchlaghem. Your guidance helped me achieve this work. The advice and phone calls with Prof. G Ramachandran proved enlightening and helpful. I would like to thank my family, whose support and sometimes, nagging, has helped me reach this final stage! None of this would have been possibly without your support throughout this and all my previous endevaours.
This PhD would not have been possible without the economic support provided by EPSRC, for which I'm enternally grateful. The guidance and wisdom of the partners of the IRMP project also helped guide both this and the IRMP project and I'd like to thank you all for the advice you provided. I'd like to thank Hoare Lea for employing me during the writing up period and kindly allowing me to continue writing alongside working full time.

Those students within the hub who helped make my time at Loughborough incredibly enjoyable. The tea and biscuit sessions are now sorely missed in the new job! To those within the Airsoft Society and the Computer Society that provided distractions from the PhD work. I would like to espcially thank Dr Mark Rodgers - whilst your work isn't engineering related, the general PhD advice was of great help to know that what I was suffering was a common element to all PhD's and that it would pass in time.

# Chapter 1

# Introduction

## 1.1 Introduction

This chapter details the research scope of the following thesis, investigating the economics of fire protection. The background of the project is considered and the aims and objectives of the PhD are laid out with the original contribution to knowledge highlighted. Lastly, the structure of the thesis is set out.

## 1.2 Research Motivation

Ever since it's discovery, fire has been a benefit to mankind but can also be problem, especially in the built environment. Yet, though careful management and building design, the risk of fire to people and property can be decreased. For this reason, society has deemed that minimising the risk from fire is a worthwhile investment in man hours and money. Due to this, buildings built today have to prove sufficient means of escape and preventative measures are installed to prevent fire spread hampering escape and to minimise the risks should a fire occur. This is achieved through the use of Building Regulations, standards and building codes of practise. This approach leads to inflexible requirements and potentially costly over design. The main aim of the fire regulations are the life safety of building occupants, however stakeholders in the construction and maintenance of buildings are now questioning whether it is also possible to consider protecting the property as well as keeping the design safe for occupants (Association of British Insurers, 2009). Over the last ten years in the UK, fire deaths have gradually declined in the number of occupants that are killed, yet the cost of fire has steadily been increasing (Department for Communities and Local Government, 2010). The concern raised by the insurance industry, fire industry (Watkinson, 2011) and the sustainability agenda, mean that reductions in the damage to property and buildings can reduce costs to the insurance industry, the UK economy and the effect and costs of fire on the environment.

In the UK, the Building Regulations govern the minimum standards of fire safety that a building should meet to be deemed "compliant" or safe. This is usually achieved through the application of Approved Document B (ADB) (Communities and Local Government, 2006). However, more advanced or architecturally flamboyant designs may require a different approach to meet the Building Regulations. Fire engineers are specialist engineers, whose sole focus is on achieving Building Regulation compliance for a potential building design, especially in instances where the application of ADB would either make the building uneconomical or provide a hinderance to the design. The Institute of Fire Engineers (IFE) define fire engineering as:

*"Fire Engineering is the application of scientific and engineering principles,*

> *rules [Codes], and expert judgement, based on an understanding of the phenomena and effects of fire and of the reaction and behaviour of people to fire, to protect people, property and the environment from the destructive effects of fire."* (Institute of Fire Engineers, 2013)

Their role is to ensure that the design meets the Building Regulations by the application of ADB, British Standard 9999 (BSI, 2008) or through a deterministic approach. By analysing the design of the building, the fire engineer can ensure that compliance is achieved and if not, highlight areas to the design team that will require changing. If the brief allows, the fire engineer can also advise the design team on a number of changes that might benefit the final design in terms of cost savings or architectural features (i.e. the removal of additional stair cores that may not be required).

Research on fire costs has been carried out over the past 40 years. Previous work completed by Ramachandran on the economics of fire protection (Ramachandran, 1998) has investigated the costs of fires. Whilst Ramachandrans book (1998) details the economic theory of the cost benefits of fire protection, it only provides the theoretical base and no easy to use tool for use during the design stage of a building by those responsible for its design. A gap in the knowledge was identified in that no work had been attempted to help fire protection engineers construct a cost effective fire solution, over and above that required by the Building Regulations. Building on the work done previously by Ramachandran and others, a decision support tool methodology is put forward in this thesis.

Cost benefit tools that currently exist in the UK Architecture, Engineering & Construction (AEC) industry are only focussed on a small subsection of the fire safety costs. For example, National Institute of Standards and Technology (NIST) have published a free to use tool on its website to see if the installation of a fire sprinkler system within a property in the US is cost beneficial (NIST, 2011) - this tool does not consider the additional factors that might affect a fire size and therefore fire damage. Additionally, this tool does not prove beneficial to those in the UK as the results are very US focussed. Other such tools focus on specific building types, such as schools (Fraser-Mitchell, 2010). A fire loss model based on questionnaires has been constructed by Lin *et al* (Lin *et al.*, 2009) which indicates the factors affecting the losses from a fire. Whilst this provides an estimation of losses, it does not achieve this using statistical data collected by organisations, such as the Fire and Rescue Service (FRS) which would allow the data to be based on qualitative data, rather than quantitative. With the addition of a fire cost calculation, a tool would allow fire engineers to estimate the losses from a fire and calculate the associated cost of that fire - running the same analysis with a different amount of fire protection would allow a cost comparison between the two solutions to be presented to the client. None of the current tools available to the fire engineers can achieve this due to the specific nature of them.

My original contribution to knowledge is the analysis of the FDR 1, Fire Protection Association (FPA) and Building Cost Information Service (BCIS) datasets to create a cost benefit decision support tool methodology, based on empirical evidence, to aid fire engineers in the design phase of a building to consider the cost benefits of the fire safety measures that they are implementing within the building and what effect this is likely to have on the size of the damage in a fire scenario.

## 1.3 Background

This PhD is part of a larger Engineering and Physical Sciences Research Council (EPSRC) funded project being undertaken at Loughborough University. The project, called the Integrated Risk Management Plan (IRMP) project, is undertaking research in the "Evaluation of Prevention and Protection Activities for Commercial, Public and Heritage Buildings" and its main aim is:

> *"how to identify, measure and mitigate the social and economic impact that fire and other emergencies can be expected to have on individuals, communities, commerce, industry, the environment and heritage"* (O'Connell, 2008)

The project focusses on the evaluation of prevention and protection activities for commercial, public and heritage buildings and is one of the first projects ever in the UK to feature collaborative efforts from fire related stakeholders such as Department of Communities and Local Government (CLG), the FRS, English Heritage, FPA, British Standards Institution (BSI), fire engineers in the AEC industry and the insurance companies.
The research consists of seven different work packages, which can be seen in greater detail in 1.1.

The workflow for the IRMP project can be seen in Table 1.1. This shows that work packages that each project researcher worked on and how this fitted into the larger overall research project. The diagram shows that this PhD ties into the IRMP project by fulfilling the fifth work package of the IRMP project with the aim of developing a methodology for the evaluation of the cost effectiveness of prevention and protection measures used in the built environment. By fulfilling this objective, the design of buildings in the UK can potentially be improved so that fires in the future may not be as damaging, both to the building owners in terms of costs and to the environment in terms of damage.

The work conducted within this PhD also fulfills part of the work package one as the literature review for this PhD was fed back into the literature review for the IRMP project.

**Table 1.1:** IRMP Project Work Packages

| Work Package | Notes |
|---|---|
| 1 | Literature review and review of current practise within the FRS's. |
| 2 | Identify existing evidence bases to assess the effectiveness of protection measures. |
| 3 | Investigate the effects of FRS resource allocation. |
| 4 | Develop a methodology for decision making regarding the allocation of resources for fire safety interventions. |
| 5 | Develop a methodology for the evaluation of cost effectiveness of prevention and protection measures. |
| 6 | Disseminate the project work in formats that are accessible for the FRS, the academic community and stakeholders. |
| 7 | Stakeholder liaison and project management, including quarterly meetings, financial management and information exchange setup. |

In addition, the work conducted on the statistical evidence bases was also fed back into the IRMP project.

More information can be found on the project website (O'Connell, 2008).

## 1.4 Aims

The aims of this research are:

Firstly, understand the UK AEC industries views on when fire engineers should be involved in a project and how involving fire engineers affects the costs of a project.

Secondly, analyse and interpret fire incident data collected by CLG and the FPA.

Lastly, using the collected data, construct a decision support tool methodology for use by fire engineers to easily propose different design proposals to a client and make it clear on the cost benefits of one design over the other.

## 1.5 Objectives

Specific objectives to meet the aims of this research are as follows:-

1. To investigate the current practise within the fire engineering industry through questionnaires and interviews;

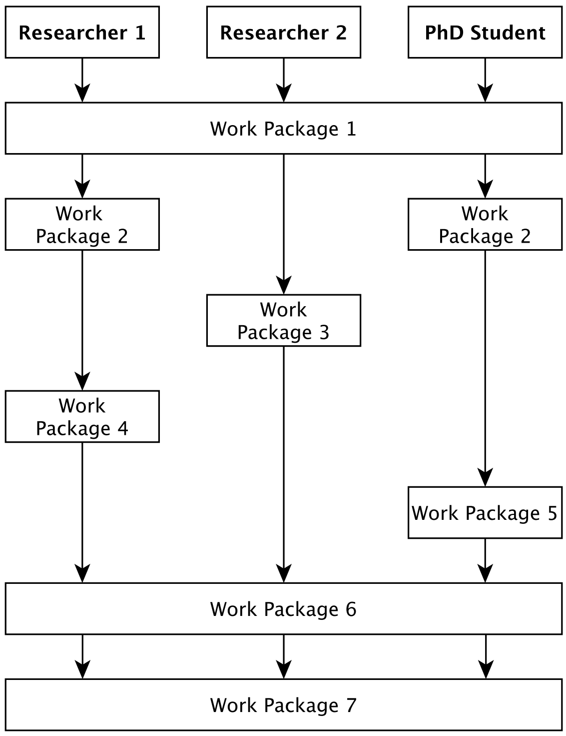



**Figure 1.1:** IRMP Project Workflow

2. Analyse questionnaires and interviews to consider if a cost benefit tool is needed;
3. Review of fire protection measures and their applications;
4. Identify the different aspects that will affect the costs of a final design;
5. Statistically analyse data collected by CLG and FPA;
6. Identify data within the FPA and FDR 1 datasets that can identify building protection systems and measure and how effective they are;
7. Identify costs of building materials and estimated costs should a building fire occur;
8. Use the FPA and CLG data as an evidence base, develop a cost benefit tool framework.

## 1.6 Summary of Methodology

A brief summary of the methodology is covered here - the full methodology is detailed within Chapter 3.

The PhD analysed the UK Fire Incident data, data collected from the attendance of the UK FRS's to fire incidents across the country. Other data used was data collected by UK insurance industries and collated by the FPA. This data was compared and analysed. Regression analysis was performed on the data to attempt to investigate what recorded data within the incident databases could be seen to affect the area damaged within a fire. In addition, the BCIS database was investigated to see how, taking the area damaged from a fire, the cost of the damage that occurred, could be estimated. Using the data from the analysis of the fire incident data and the cost data within the BCIS and FPA tools, a cost Decision Support System (DSS) tool methodology is proposed, allowing fire engineers to consider the additional cost savings of installing additional fire protection, over and above that required by the UK Building Regulations for life safety within new builds.

## 1.7 Structure of Thesis

Chapter 1 - Introduction
This chapter contains the introduction to the project, which includes the scope of the research, background on the PhD and research project this PhD is part of, the aims and objectives of this PhD, a list of publications that are the outcome of the this research and finally an overview of the structure of the thesis.

Chapter 2 - Literature Review
The literature review covers a background of fire protection, the research previously done in the area of fire risk management, fire risk assessment and cost benefit analysis in regards to fire to identify a research gap. It then goes on to include literature searches on the construction of design tools, methods of software design and methods of data analysis to explain how and why a design tool methodology will be constructed.

Chapter 3 - Methodology
The methodology chapter details the steps taken by similar DSS tools and what methodologies they followed. It will analyse these methods and evaluated and how they differ from the methodology that this research will follow.

Chapter 4 - Method
The method chapter sets out how the research proceeded and what steps were taken to meet the aims and objectives of the research. This chapter details the questionnaire and interviewing methods that took place within the research and what the results of this will be used for.

Chapter 5 - Questionnaire and Interview Analysis
A questionnaire and interview, conducted to meet the objectives of the research are analysed within this chapter.

Chapter 6 - Analysis of Fire Incident Data
This chapter covers the analysis of the data provided by CLG and the FPA. This analysis is to form the evidence base for the cost methodology and the DSS tool.

Chapter 7 - Decision Support System Model
The DSS methodology was to be the main outcome of the research, considering the statistical analysis of the fire incident databases. This chapter deals with the method behind the construction of a possible DSS tool and the framework methodology behind the data being used for the tool.

Chapter 8 - Discussion and Conclusion
The final chapter provides a summary of the research. It discusses the statistical analysis of the data, recommendations for future collection of fire incident data within the UK as well as the implications the data has for a DSS tool. A conclusion states how the research met the aims and objectives that it set out to do.

References, Appendices and Bibliography
Finally, the thesis will have supporting documentation for chapters available in the appendices and references will be included.

# Chapter 2

# Literature Review

## 2.1 Introduction

This chapter details previous work done in and around the area of fire engineering by other academics and researchers. Through the literature review, a research gap will be identified that this research is intended to fill. This research gap will be highlighted at the end of this chapter.

Fire engineering covers a broad aspect of research, from investigation into costs, materials and construction methods to the psychology of building occupants during fires. This chapter covers the research done in these areas, mainly in regards to construction and costs of fires. It also includes a brief literature review on the construction of a software tool as this was the predicted outcome of this research.

## 2.2 Fire Protection

Society dictates that people should be able to enjoy a reasonable level of safety during day to day activities; part of this is protection from natural and man made phenomena such as fire. Such demands for safety led to the initial development of the Building Regulations in the UK (Stollard and Johnston, 1994). These Building Regulations (Crown Copyright, 2010) developed over time, especially after large incidents where a considerable loss of life or property occurred, into the current form which are met though the recommendations, published in the Approved Documents. These documents set out the easiest way of meeting the Building Regulations; the one in relation to fire safety is Approved Document B (ADB) (Communities and Local Government, 2006). These Building Regulations are in place so that the building can be designed to allow occupants to safely escape should a fire occur and to prevent excessively quick fire spread; allowing for time to escape. This focus on life safety is the main concern behind the current regulations and appears to have been reasonably successful, as fire deaths have declined steadily over the past decade (Department for Communities and Local Government, 2010), shown in Figure 2.1.

However, there has been a steady increase in the cost of fires over the same period as seen in Figure 2.2. These figures seem to show that whilst the Building Regulations seem to be working for reducing and keeping the number of fire deaths low, there does not seem to be any reduction to the cost of fires by constructing to meet the functional requirements of the Building Regulations. This is potentially a result of the past policy decisions which focussed on life safety as Brannigan points out in his paper (Brannigan, 2000) as fire safety was previously argued as only life safety, possibly due to the fact that saving lives is conceptually easier (and cheaper) than trying to save property.

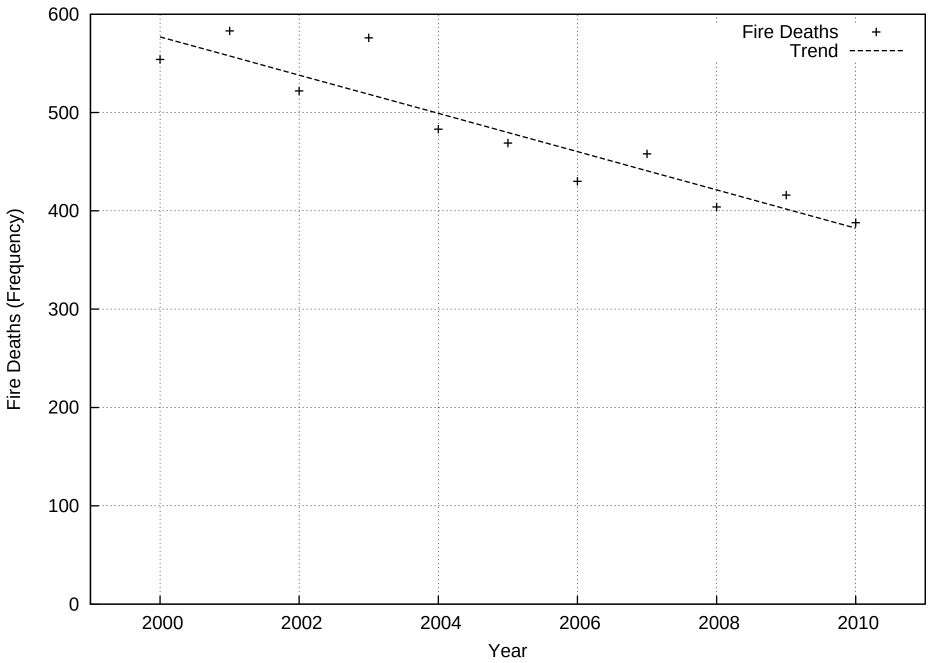



**Figure 2.1:** Fire Deaths in Decline
*Taken from (Department for Communities and Local Government, 2011a)*

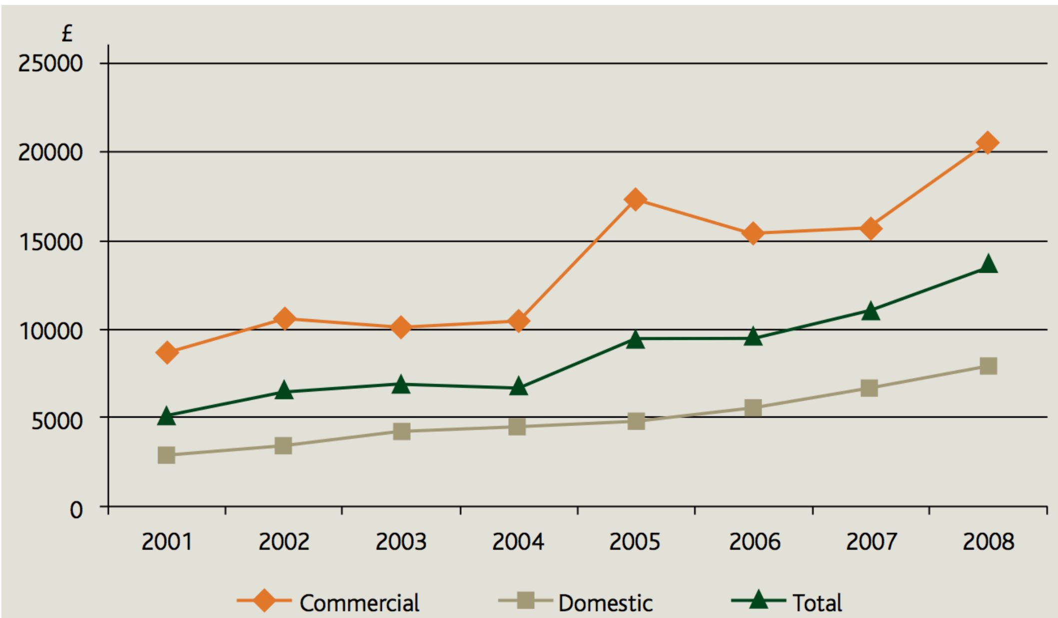



**Figure 2.2:** Average Cost of A Fire Claim 2001 - 2008
*Taken from (Association of British Insurers, 2009)*

ADB (Communities and Local Government, 2006) is the document printed by Department of Communities and Local Government (CLG), detailing the easiest method of meeting the Building Regulations in England and Wales (Scotland have their own system) in regards to fire safety. Yet, whilst a building following the recommendations in ADB will comply to the requirements of the Building Regulations, the recommendations are quite strict and architects and designers may want more design freedom than ADB offers. ADB states on page 5

> *"There is no obligation to adopt any particular solution contained in an Approved Document if you prefer to meet the relevant requirement in some other way"* (Communities and Local Government, 2006)

This quote implies that the requirements of the Building Regulations can be met through alternative means, usually through the use of fire engineering or an alternative building standard such as BS 9999 (BSI, 2008) or BS 7974 (BSI, 2003a). "*BS 9999: Code of Practice for Fire Safety in the Design Management and Use of Buildings*" is a relatively new code that attempts to make it easier for designers to incorporate fire safety into more complex structures without having to use "*PD 7974: Application of Fire Safety Engineering Principles to the Design of Buildings*", which is used in the most complex of buildings because it reduces fire safety to the first principles of fire science and requires an understanding of flame spread, fire dynamics and combustion science to use effectively. These two standards allow for more flexibility than the recommendations laid down in ADB. This allows the designers to customise the fire safety systems to suit the building and prevents costly over design of buildings and allow architects and engineers more design freedom.

### 2.2.1 Fire Process

Before starting the analysis of the data, it is beneficial to discuss the fire process in more detail. A fire can occur within a building and is either started accidentally, be it human error or a failure of some sort or deliberate action (arson). Regardless of how it starts, a fire poses a threat to both the occupants and the property itself and measures are taken during the design and building process to minimise the risks to life safety. This is the primary purpose of the Building Regulations, which provide a set of guidelines that architects and designers are required to meet in the construction of a building. These systems are assumed to activate or provide protection during a fire incident, though the UK also maintains a Fire and Rescue Service (FRS) to provide assistance and fire-fighting capabilities for cases where these designed systems do not extinguish or contain the fire.

Most fires will follow the same process from start to finish. Figure 2.3 shows a diagram of how a fire progresses.

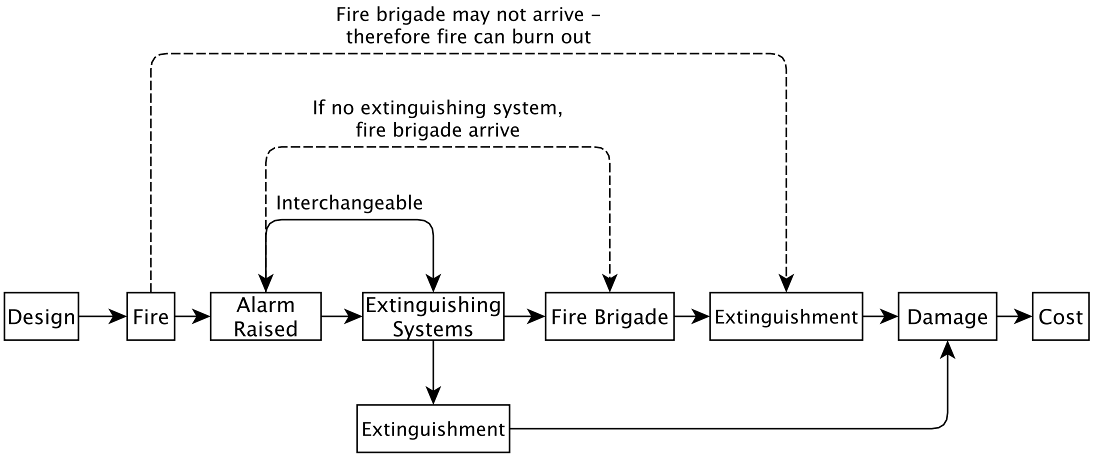



**Figure 2.3:** Diagrammatic View of the Fire Process

A building is initially designed with protection measures installed to meet the Building Regulations. These protection measures are specified in the design stage and this is the first step of the fire process. All buildings went through an initial design phase and an alarm system considered even if it was relying on one person raising the alarm as discussed in ADB (Communities and Local Government, 2006).

The next stage is the fire itself. In this instance, we are assuming that that a fire occurs in the building - some buildings may last for the entire buildings life cycle without a fire incident. However, during the design phase, fire engineers assume that a fire will occur and design the building to deal with this most probable fire, known as the design fire (The Chartered Institution of Building Services Engineers, 2003) and therefore it is assumed here that the building will have a fire as well.

At this point, if the fire is not discovered, either by an alarm system or in person, the fire may continue to burn until it burns all available combustible material and then the fire will die out without a fuel source present. This could be when the item first ignited is consumed (if the fire does not spread to surrounding materials/items), the fire consumes all within the compartment of origin without breaking the compartmentation or when the entire building has been consumed by the fire.

However, if the alarm is raised, either by an installed alarm system or a building occupant, then it is likely that an extinguishing step may take place. This is likely to either be from a fixed fire fighting system such as a sprinkler, a first aid fire fighting system such as a fire extinguisher or from FRS intervention. It should be noted that if a fixed fire fighting system is present, this may set the alarm off after activating (in the case of a sprinkler system with flow rate alarm) and therefore these two steps (alarm raised and extinguishing system) can be viewed as interchangeable with one potentially initiating the other. If there is no extinguishing system or first aid fire fighting attempts are not made, then the FRS will be called and attend the scene.

The FRS will attempt to extinguish the fire and the fire will either be extinguished through fire fighting activity or when the fire has consumed all available fuel and burns itself out.

Once the fire has occurred and been extinguished through whatever means, there will be damage, even if it's only a small amount. There will be some damage from direct burning; this will be the damage caused by the pyrolysis process of the fire as the fires fuel source. In addition to this, there will likely be smoke damage to the surrounding areas from the waste products of the fire (unless the fire was a smouldering fire), heat damage to surrounding areas and there is likely to be water and other damage from fire fighting attempts. All of this damage can be totalled together to give the total damage caused by the fire. This all then has a cost to be replaced, repaired or removed. The final step in the fire process is the cost of the fire itself, how much money the fire costs the company/building owners for having a fire and potential interruption in business and a loss of confidence in the company by the public and clients.

A similar image is shown in Figure 2.4. This is based on a diagram in the "Insured Large Loss Fires Project" report, published by the Fire Protection Association (FPA) (Fire Protection Association, 2009).

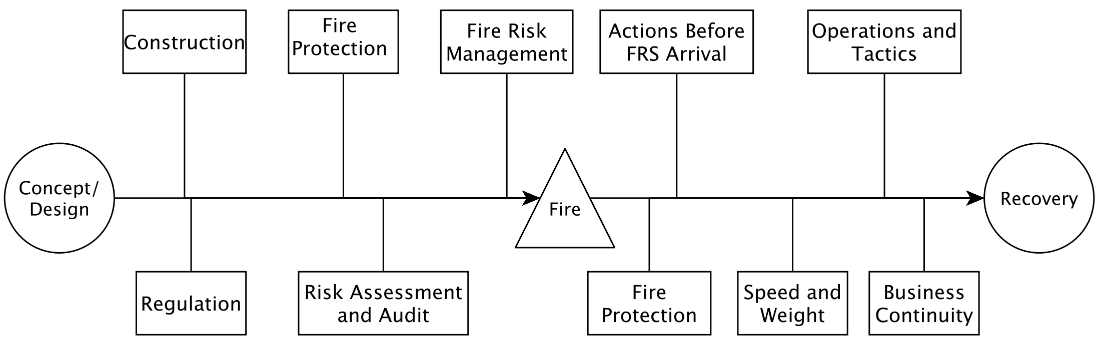



**Figure 2.4:** Fire Life Cycle Timeline
*Taken from (Fire Protection Association, 2009), Pg 12*

This process is very similar to Figure 2.3 but differs in that it shows the fire fighting effects on the fire by describing the speed and weight of the fire fighters response and considering the business continuity. This figure shows more of the factors that are assumed to affect the size of the fire damage but not all of the variables in this figure can be considered using the statistics being used by this project.

With the process of a fire laid out, it helps to identify aspects of the process that affect the fire size and damage - for example, a longer time between ignition and discovery (or at any point before any fire fighting activity occurs) will mean that a fire has a longer time to develop and grow; if a $t^2$ fire model (Heskestad, 1984) is used to express the fire growth, then it can be seen that the growth of the fire will increase exponentially as time increases. Reducing these time scales can mean that the fire is far smaller when fire fighting attempts are made.

Figure 2.3 does not take into account other factors that might affect the fire size and damage such as what occupancy type the fire occurs in and how the construction of this building affects the fire size. These factors are considered to affect the fire size - for example, the insurance and fire industry is concerned about timber framed buildings being more flammable than other UK construction techniques (Association of British Insurers, 2009, Fire Protection Association, 2009, Fire Risk Management, 2012) and want to see if these pose a bigger risk; therefore have meaning that higher premiums should be associated with these methods of construction.

### 2.2.2 Fire Protection Methods

To meet the fire regulations, buildings have to be protected by different fire protection methods, which form the fire protection system. These installed systems delay or prevent the spread of fire, thus extending the time occupants have to escape the building. A summary of the different fire protection methods are described below.

#### 2.2.2.1 Fire Engineering Basics

When designing fire protection systems, engineers consider the Required Safe Evacuation Time (RSET) and Available Safe Evacuation Time (ASET) for allowing people to escape the building. RSET is the required time it takes a person to reach a place of relative safety (such as an exit from the fire floor) and ASET is the time they have available to do so (based on the fire growing to untenable conditions). Figure 2.5 shows the constituent parts of ASET and RSET. Designers want to maximise the ASET whilst minimising the RSET. Doing so allows the occupants more chance to escape the fire safely. This ASET/RSET principle is used in both BS 9999 and ADB and is considered in BS 7974 for fire safety design in the UK. Yet, not everyone agrees that this is the best method for calculating occupants escape time from a building (Babrauskas *et al.*, 2010). Babrauskas *et al* write in their paper (2010), that the ASET/RSET is a flawed concept, based on how it treats people acting when an alarm is sounding in a building. The concept relies on people making for the exits as soon as the alarm system is sounded, which is not the case, as shown in another study (He and Nelson, 2008) and in real world fires, such as the Manchester Debhanhams fire in 1987 (Redpath, 2006). It was found that occupants often complete what they are doing before moving towards the exits, called pre-movement time, which has been shown in case studies (Redpath, 2006). They also raise the question of who should the ASET be aimed at in terms of social group - the elderly, the infirm or the average building occupant? The concept of ASET is a subjective decision taken by the designer and whilst provisions are placed on escape for disabled occupants, both in ADB and Approved Document M (Communities and Local Government, 2004), the main focus is on escape for able bodied adults (based on a risk assessment of the buildings end use).

However, designers are aware of this fact and try and overcome it. In a paper by Charters *et al*, the probability distribution of the pre-movement time in shops/commercial premises is considered. Though only a small sample was considered (16 individuals), it was found that 80+ percent of the pre-movement is completed in two minutes or less (the *de facto* escape time in the UK is two and half minutes - the only reference in the Building Regulations is in ADB where it is used in the formula for calculating stair widths) , however some cases exceeding seven minutes were found. This was mainly seen where the occupants were found in a separate compartment to the fire ignition and therefore they didn't perceive a threat, something that ADB attempts to prevent by minimising inner room situations. In the BS 9999 handbook (Green and Joinson, 2010), Green and Joinson make reference to this pre-movement time before occupants move to the exit and add it to the RSET to allow occupants to complete this time before escaping the building.

#### 2.2.2.2 Passive Fire Protection

The design of the building itself and the restriction in the use of combustible materials used in the construction prevents fire spread, which is the main aspect of the Building Regulations. This method of preventing fire spread is referred to as passive fire protection, as the protection does not need to change state to complete its function in preventing fire or smoke spread. However, additional systems, such as fire alarms and extinction systems are installed alongside these passive protection measures. The combination of both active and passive measures provide the complete fire protection system for a building. Previous research has suggested that the inclusion of active measures such as sprinklers can reduce the passive protection measures included in a building (Baldwin and Thomas, 1974) though it is still believed that both systems should be used to complement each other as active systems may not always activate (Haack, 2004).

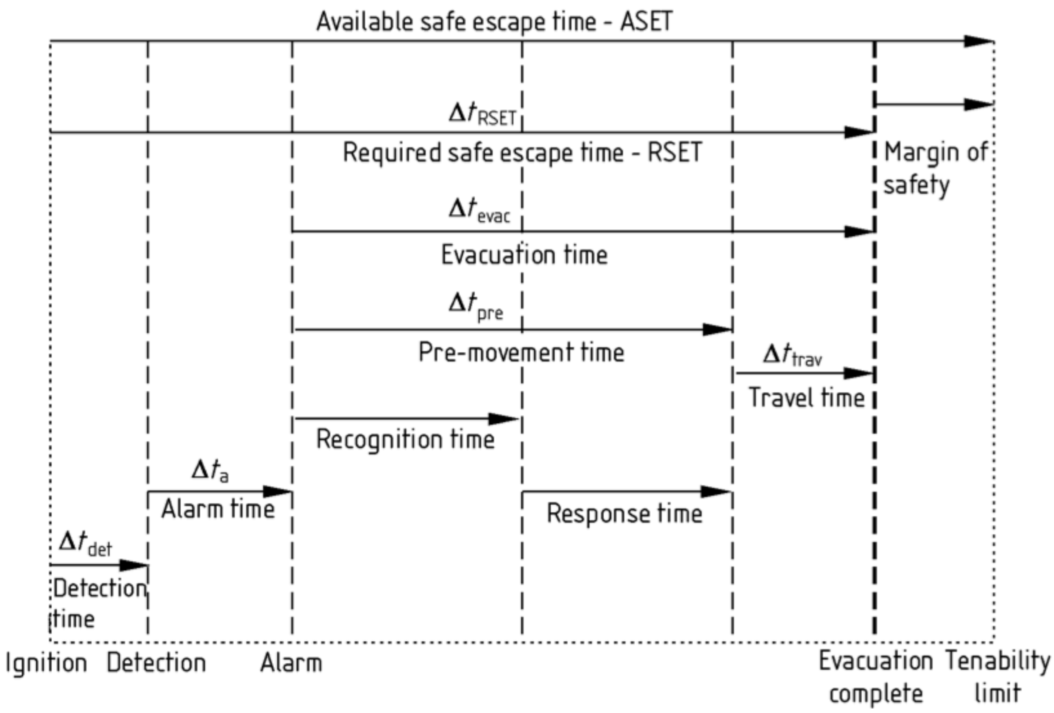



**Figure 2.5:** Figure Showing The Fundamentals Of ASET and RSET
*Taken from (BSI, 2003b), Pg 6*

Passive systems, such as fire resisting construction are a protective system. Pekalski *et al* describe the differences of protective and preventative systems in their paper on explosion prevention measures:

> *"It is very important to be aware of the difference between preventive and protective systems. In general, preventive systems, depending on the design purpose, sometimes reduce the probability, but more commonly eliminate the possibility for occurrence of an unwanted event. In contrast, the protective system allows an explosion to occur, but reduces the adverse effects of the event."* (Pekalski *et al*., 2005)

Passive fire protection stops the spread of flame and fire products by providing a physical barrier between the room of fire origin and the rest of a building. It is normally specified according to the time it takes for a fire to penetrate the protection, in minutes. Therefore, it is often specified in multiples of 30 minutes fire resisting and this is how building standards such as ADB and BS 9999 refer to the protection (not by specifying the actual material itself, but by specifying that the material that should be put in place should have a fire resistance of $x$ minutes, dependant on the situation - this allows the contractor and architects to select the material that best suits the situation, according to the aesthetic requirements of the architect). Yet, as passive fire protection provides a barrier to stop the spread of fire and fire products, it is only effective if it is installed and maintained correctly. Faulty installation can render the protection incapable of providing the specified fire resistance;

therefore the fire would be able to spread more quickly than the building is designed to withstand; something already seen in actual fires, such as the Digital fire where flawed installation of passive fire protection led to the office fire spreading far quicker than if the passive fire protection had been intact (Bowen, 2006). Concerns are raised in the industry that passive protection is not being installed correctly and that this affecting the safety of building and occupants. Parlor states in his article in the Fire Safety Engineering journal that Building Control (the body responsible for checking that Building Regulations in the UK are being followed) are only checking that the building design complies with the Building Regulations, but are not checking that what is actually installed is correct or installed correctly (Parlor, 2009). This view is shared abroad as the fire engineer Schulz makes clear that fire engineers in New Zealand also complete checks on the installation of fire protection methods they have specified in the fire strategy and design (Schulz, 2009) to ensure that the specified design has been followed. Some believe that fire engineering solutions are stripping out the passive fire protection of buildings and are therefore removing the over engineering and the robustness that the Building Regulations provide but not replacing it with anything else (Rowan, 2010).

Research into passive fire protection has not been as widespread and research conducted into the economics of passive fire protection has only been done in specialised applications such as offshore structures (Shetty *et al.*, 1998) and chemical warehouses (Tyldesley *et al.*, 2004). The majority of most recent research into passive fire protection focusses on alternative methods of passive protection for buildings such as the work on passive fire protection production from biomass incineration (Vilches *et al.*, 2005, Khoury, 2008), the use of ablative fire protection methods (Staggs, 2008) or the different formulation of intumescent paints (Landucci *et al.*, 2009) that are more sustainable or eco-friendly.

Research has also been done on how structural components work together in a fire to provide protection. Initially, buildings were designed to rely on one item providing the fire safety protection - for example, in steel framed buildings, the steel is considered a weak point of the building in a fire - if a fire occurs, the structural strength of steel declines, losing about half of its strength as it reaches 600°C. However, it was not until the ‘Broadgate Phase 8’ office fire in 1990 where it was seen that there was an interaction between the structural components that enabled the building to maintain structural integrity and prevent collapse (Jenkins and Bressington, 2006). The building was expected to collapse due to the prolonged fire (over four hours), the high temperatures (the fire was estimated to have been over 1000°C) and the lack of fire protection on the structural steel. Yet, the concrete floors and steel acted as a membrane and prevented collapse (British Steel, 1999). This research has been continued as investigating how the whole structure is affected by a fire can lead to advancements in building design (Lamont *et al.*, 2006a,b) and because the fires in structures without fire protection are still occurring (Menéndez and Vega, 2009) without collapse. Lamont states in her paper:

> *"Increasing the passive fire protection to the structure is one way to improve a structures performance in a fire but it may not be the most robust"* (Lamont *et al.*, 2006b)

because passive fire protection isn't always installed correctly and fire spread may be unhindered by the compartmentation provided by the fire barriers.

There has been research in the Chemical Engineering industry that focuses on Inherently Safer Design (ISD) which includes passive protection systems, the principles of which can be transferred to the fire engineering sector. Kletz states in his paper (2003):

> *"Instead of keeping hazards under control by adding on protective equipment we should use inherently safer designs whenever they are 'reasonably practicable'. When that is not possible passive safety equipment is better than active equipment"* (Kletz, 2003)

This quote highlights that passive protection and inherently safer design should be the cornerstone of safety, and then extra systems should be used to achieve the required safety level. This principle should apply to fire safety as well, with buildings built to contain fire and save lives from a design point of view with passive fire protection installed to help this aim. If this is achieved, active systems shouldn't be needed as much as they currently are. Gupta and Edwards states:

> *"All chemical engineers have a stake in making our industry safer so that its public image as well as its profitability improves."* (Gupta and Edwards, 2002)

Replace the term chemical engineers with fire engineers and the same statement applies equally well to the fire industry.

#### 2.2.2.3 Sprinklers

Sprinklers are a fire protection method whose aim is to prevent fire escalating by controlling the speed of the fire spread. Sprinklers are an example of an active fire protection method - they have to change state to affect the fire. As the fire grows, the heat it generates increases (Drysdale, 1998). Once this heat reaches a certain level, the bulb in the sprinkler head shatters and water is released from the sprinkler head, either containing the fire, reducing the heat of the fire and slowing its spread or in the best case scenario, extinguishing the fire.

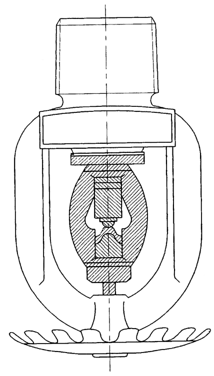


**Figure 2.6:** A Sprinkler Head Diagram
*Taken from (Kim, 2003)*

Sprinklers come in various different systems, which, depending on the application of the sprinkler system will affect its operation (BSI, 1990). The majority of sprinklers are a wet pipe type system where water remains in the pipes at all times, giving a faster response time should a sprinkler head activate. However, this might not always be a good system (for example, where the pipes run the risk of freezing) and therefore a dry pipe system can be used, where the water enters the piping system only when needed.

There has been a lot of research on the use of active protection measures in buildings, espcially sprinklers (Melinek, 1993b,a, Hall, 2010, Vaidogas and Šakenaite, 2011) and investigating the costs of sprinklers in various buildings, such as in car parks (Li and Spearpoint, 2004), residential properties (Butry, 2009) and schools (Fraser-Mitchell, 2010).

From the research of Melinek (1993), it is seen that sprinklers help reduce the fire severity and reduce the probability of a large fire (over $100m^2$) occurring in a property. This means that buildings with sprinklers should have a fire size; causing a lower damaged area and therefore incurring a lower cost due to the area damaged. This reasoning is often why insurance industries give discounts on insurance premiums for having a sprinkler system in place. Yet Gottuk and Dinaberg highlight in their paper (2012) that sprinkler installations in American warehouses may not be effective; acting as the main method of fire fighting tool that they currently are. This is based on concerns raised by fire engineering practitioners in National Fire Protection Association (NFPA) seminars. However, in the same paper, they also highlight the fact that installation of sprinklers in warehouses in the US is cost effective for buildings over $85{,}000m^2$ (Gottuk and Dinaburg, 2012). Kidd states that fires in sprinklered building can cost up to 80 percent less than a fire in a building without sprinklers (Kidd, 2001), however, he does not state from where this lower cost arises.

Sprinklers are most commonly installed for life safety measures in non warehouse and industrial occupancies - seen by the increased travel distances and compartment sizes that are allowed in ADB and BS 9999 in sprinklered properties. However, in terms of cost savings (in warehouses), work by Fraser-Mitchell (2006) *et al* has shown property protection is more important when calculating the cost effectiveness of sprinklers (Fraser-Mitchell *et al*., 2006). In an earlier study, Poh and Bennetts constructed a risk analysis tool to see if sprinklers could be installed in a building cost effectively (Poh and Bennetts, 2005) and a similar tool is proposed for this research.

Work by Hall describes the state of sprinklers in the US. He states:

> *"This simple comparison understates the potential value of sprinklers because it lumps together all sprinklers, regardless of type, coverage, or operational status, and is limited to fires reported to fire departments. If unreported fires could be included and if complete, well maintained, and properly installed and designed systems could be isolated, sprinkler effectiveness would be seen as even more impressive"* (Hall, 2010)

His work states that fires where sprinklers operate can see a sixty six percent reduction in costs from buildings where fire occurs (slightly less than the cost reductions shown by Kidd in 2001). His work also states that sprinklers only fail in seven percent of fires where the fire is large enough to activate them (seen in work by Hinkley as 5m$^2$ (Hinkley, 1986) and by Ramachandran as 3m$^2$ (Ramachandran, 1990)) and where they operate are ninety seven percent effective.

#### 2.2.2.4 Alarm Systems

Alarm systems are almost a cross between active systems and passive protection - they are inert and useless until they activate and then let building occupants know of a fire, yet they do nothing themselves to contain or fight a fire. As Burry presents in his paper (1972) on fire detection systems and loss:

> *"Fire detection can never prevent fires. Unaided, it can do nothing to reduce fire losses"* (Burry, 1972)

Therefore an Automatic Fire Detection (AFD) system should be be used alongside other fire protection systems, such as extinction systems and passive fire protection to minimise loss. Burry also states (in the same paper), that the primary objective of any AFD system is to help in reduction of fire losses, be that life or property. By recieving notification of a fire, occupants can elect to escape the building or find the fire and provide first aid fire fighting measures such as using fire extinguishers or fire hoses.

Alarms are considered a main part of the ASET and RSET calculations mentioned in Section 2.2.2.1 as the time it takes for the fire detectors to detect the fire is time that the occupants are unaware of the fire and are therefore not using this time to escape the property. The quicker an alarm activates, the quicker the building occupants are aware of the fire and therefore should have longer to escape the building. It also stands to reason that the earlier the occupants are aware of a fire, the earlier fire fighting intervention can be applied - a quicker call to the FRS should mean the FRS attend the scene earlier.

Whilst AFD systems are generally not considered today in terms of any cost reduction, a paper by Rasbash in 1972 found that installing an AFD system may yield a small cost reduction (Rasbash, 1972). This cost saving was found to be three pence per $m^2$ was calculated at 1972 prices, equivalent to about twenty seven pence per $m^2$ in 2012. These cost savings could be attributed to a lower loss of life in a building where alarms activated and from the quicker action of the FRS. He pointed out that fires that occurred during non office hours (usually during the hours around midnight) tended to be larger than those during the day, where the alarm could be raised sooner by the buildings occupants.

### 2.2.3 Costs of Fire Protection

Fires cost money, both on the national level through the provision of the FRS and to the companies where the fires occur. According to the UK Fire Statistics (Department for Communities and Local Government, 2011b), the cost of fire in the UK was £8.3 billion in 2008. This figure, whilst small in comparison to the UK's 2008 GDP of £1,446 billion (Dye and Sosimi, 2009) (less than 1 percent of the UK GDP), is still a considerable sum of money. As such, research has been undertaken to understanding the costs of fire and to investigate how it can be reduced.

In a conference to the Institute of Fire Engineers in March 2012, Torero urged fire engineers to consider cost reductions in fire engineering. He observed that other engineering professions made cost reductions in their specific roles, yet as fire engineers deal with safety, when cost reductions are mentioned, fire engineers are viewed as 'criminals'. He stated that fire engineering had solved the issues of life safety, many years ago, and that fire engineering solutions were to protect property, not for life safety. Life safety was solved with prescriptive Building Regulations and that statistics prove this.

> *"Fundamentally, cost reduction is the only value we have to make our engineering better. If we don't embrace the idea of cost reduction, then what are we doing? Let's just go back to prescription and over prescribe everything and ignore the whole thing."* (Torero, 2012)

He voiced that fire engineering and cost optimisation should be inherently in the same sentence, which, they currently aren't. Until they are, fire engineering cannot be considered sustainable; as over compensating due to the prescriptive standards, safety factors and levels of uncertainty mean that fire engineering often means designs are over protected and additional materials are used in the consturction than are required which is not economical, cost effective or sustainable.

When writing about costs of fire, Ray (Ray, 1997) identifies the costs of fires into five main components. These are:

1. The cost of physical damage to property and its loss
2. The cost to the Fire Service and thus the Exchequer
3. The cost of fatalities and injuries
4. The cost of expenditure on reducing the risk of fires
5. The indirect cost of fire in terms of disruption of chains of production and supply in the business sector

This list encompasses all aspects of the fire industry, from the construction of buildings, to the insurance sector and the FRS and therefore the Government. The cost analysis of fire breaks down into different sections of this as well, and the majority of research can be shown to focus on one of these areas or a combination of them.

#### 2.2.3.1 Physical Damage to Property and Loss

Any fire will cause damage to a property, be it from direct fire damage, smoke damage or damage from fire fighting operations. Fire protection measures, such as compartmentation, aim to reduce the fire spread, mainly to prevent fire damage to prolong the time occupants have to escape a building and get to safety. Such measures also work to help minimise the damage to a building, though this is not normally their primary role. Regardless, extra protection measures may increase the chances of containing a fire and therefore reducing the amount of damage a building suffers.

Sprinklers are installed in buildings to contain fire spread to allow occupants more time to escape as discussed in Section 2.2.2.3 . Research shows that fires where sprinklers activate are smaller than fires without sprinklers (Beck, 1987, Melinek, 1993a) and work by Ramachandran shows that where sprinklers are installed, the probability of fire damage is reduced Ramachandran (1988, 1990) and Wright (Wright, 1998) details the reduction in fire risk rates. This proven track record in sprinklers is reflected in building standards, such as ADB that allows you increase the size of compartments (Communities and Local Government, 2006) and in BS 9999 (BSI, 2008), where the risk profile for a building can be reduced. Yet, research by both Ramachandran (Ramachandran, 1990) and Hinkley (Hinkley, 1986) indicate that even with sprinklers installed, fires will reach either $3m^2$ (Ramachandran) or $5m^2$ (Hinkley) before a sprinkler head is activated. This demonstrates that even with sprinklers installed, there will be at least some damage to the building from both fire and smoke and most probably (if the sprinklers activate), water damage. However, unlike films in Hollywood, the activation of a sprinkler is usually consigned to a limited number of heads and not an entire floor. In fact, the more sprinkler heads that activate, the likelihood is that the sprinkler system has failed to contain the fire. As more sprinkler heads activate, the system declines in effectiveness due to the loss of pressure and water.

Insurance companies recognise the fact that sprinklers reduce property damage and some warehouses cannot be insured without a correctly fitted sprinkler system being present Gottuk and Dinaburg (2012). A reduction in costs should a fire occur means that the insurance companies don't have to pay out as much for claims and therefore premiums can be reduced for companies who have installed a sprinkler system.

As mentioned above, compartmentation, a form of passive fire protection, is installed into buildings to prevent fire spreading from one compartment to another. The UK Building Regulations require this (Communities and Local Government, 2006) though allow for larger compartment sizes if sprinklers are installed. However, research on compartmentation in the built environment tends to focus on specific applications, such as chemical warehouses (Tyldesley *et al.*, 2004) or offshore structures (Shetty *et al.*, 1998). Yet, passive protection and compartmentation are often considered in other studies that consider fire protection systems as a whole but these studies do not then break down the study down to investigate the effect passive fire protection has on the area damaged.

Passive protection systems are often mentioned when considering inherent safety as the passive protection measures are constructed with the design of new structures and therefore are integral to the building. Hendershot argues the case for inherent safety in chemical production (Hendershot, 1997) to prevent large losses. Whilst this paper deals with the chemical engineering industry and the design of chemical plants, it's underlying principles can also apply to a fire engineering context because by making the buildings inherently safe, you cut down on the active protection systems needed and don't need to rely on these systems activating to prevent a large loss. A similar point that is later raised in 2007 (Cozzani *et al.*, 2007) in that by making buildings inherently safe, you prevent accidents from undergoing the "domino" effect where one small accident can set off a chain reaction of events to culminate in a larger disaster.

To meet the Building Regulations in the UK, the best method is by following the prescriptive guidance in ADB. However, as mentioned previously, the regulations can be met by the application of alternative building standards, such as performance based standards like BS 9999. Performance based standards are assumed to be more cost effective than prescriptive standards as they allow more flexibility and prevent expensive over design. However, the cost of a performance based fire code has not been fully investigated (Page, 2005), yet it is still assumed within the fire engineering sector that performance based standards are more cost effective and more flexible. In New Zealand, the move to performance based standards occurred during the 90's and a side effect of the uptake of these performance based standards, has been found that the perceived life safety in buildings has been increased, yet the perception of property protection has declined (Buchanan, 1999).

The Building Regulations (Crown Copyright, 2010) main concern, within the UK, is that of life safety. The regulations are in place to allow the buildings within the UK to all meet a minimum level of life safety, ensuring that occupants that use the building in it's day to day capacity are protected in the event of a fire within the building. These regulations place restrictions on the building design, purely for the intent of protecting life. Some of the protection measures specified will have the additional benefit of providing some property protection to the building, but these are not the main aims. Installing additional fire protection is a method of ensuring that additional protection is given to property. The installation of additional fire protection will cost more in the building fit out, but is potentially likely to save money in the event of a fire, in terms of reduced damage. In his book (1998), Ramachandran describes the optimal cost of fire protection being at the point where the additional cost of fire protection meets the cost savings from the installation of the fire protection, as shown in Figure 2.7.

This value, in his book, should be the value that building designers should strive for in the design and building of new properties. Reaching this optimal point would ensure life safety *and* property protection, as long as the property protection measures are more onerous than the life safety measures - usually the case as demonstrated by the different risk classifications of sprinkler systems (BSI, 2004).

#### 2.2.3.2 Cost to the Fire and Rescue Service and Government

In 1995, the Government commissioned a report on the use of the FRS in the UK (Audit Commission, 1995). This report described how the Government were getting value

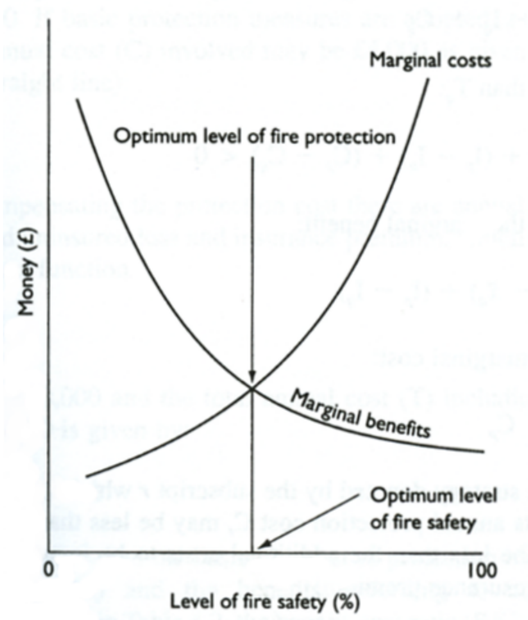



**Figure 2.7:** Optimal Costs of Fire Protection
*Taken from (Ramachandran, 1998)*

for money from the UK FRS and what could be done to improve this. It was found that insufficient emphasis was placed on prevention of fires and that the risk categories that the FRS used in planning didn't take into account the advances in fire protection methods. It concluded that the FRS needed to commission research so that a future framework for risk assessment and standards could be based on empirical evidence. This report is very closely mirrored by a later report in 2003 (Office of the Deputy Prime Minister, 2003) which indicated that the recommendations from 1995 were still not in place during the period that the 2003 report covered and therefore the FRS had not implemented the changes and were therefore not operating at their most effective state.

The Government method of implementing building fire safety is through the use of regulations and enforcement. In England and Wales, (Scotland and Northern Ireland have their own regulations) ADB (Communities and Local Government, 2006) covers the Building Regulations during the construction and design of a building but the enforcement of building management during the operational lifetime of the building is achieved through the Regulatory Reform (Fire Safety) Order (RRO) (UK Government, 2005) (which only applies to in England and Wales). The RRO sets out the requirements that building owners need to comply with. The RRO allows the UK FRS to inspect buildings and take the building owner(s) to court if the required fire safety standards are not met. Part of the requirements are that the buildings owner (or responsible person as the law states - which does not have to be the buildings owner or operator) must carry out continuous risk assessments of the property. This change in enforcement places more emphasis on the building owner to monitor the fire risk of their property, rather than relying on the FRS to issue fire safety certificates under previous legislation, though does place more focus on the prevention of fires. Since it's introduction in 2005, there has been research into how well the Order has been understood and taken effect (Wilkinson, 2008, Communities and Local Government, 2009). Both work by CLG and Wilkinson show that not all businesses were aware in the change of responsibilities that the RRO brought in. The Government produced report highlighted the link between the RRO and the Integrated Risk Management Plans (IRMP's). However, neither report investigated the costs of the RRO in terms of implementation or if the RRO had decreased the number of fires and therefore saved money through less fire damage which would potentially be an outcome of the increased focus on prevention of a fire occurring.

In the UK, the FRS is a public service and funded by the Government. In the US, the FRS is run differently and fire departments tend to be run by private companies. A report on the privatisation of the FRS was undertaken by Guardiano *et al* (Guardiano *et al.*, 1992). Privatising the FRS would mean substantially reduced costs to the UK Government. The report states that privatisation works as it relies on profit motive and competition and that the popularity of private FRS's has increased in America, especially in the South and West. It states that the main costs savings come from labour costs and that it is cost effective as subscribers (households) usually save more money than the cost of subscription (through reduced insurance). Whilst this may reduce costs to the Government, it would mean a massive change in policy for the UK to bring privatisation of the FRS into effect and potentially a move that would be blocked by the Fire Brigades Union.

Whilst Building Regulations aim to save lives, it has been considered that continued reliance on code compliance is a false objective (Slye, 2001) and that fire engineering solutions can help considerably in terms of costs. Slye also raises the point that insurance recommendations may not be appropriate for high tech or non standard applications.

A UK based project investigated lives and money saved through FRS operations in Merseyside (Merseyside Fire and Rescue Service, 2011). Previous research investigates the *cost* of fire damage, the TriData project and report calculated the costs using the overall *save* to the building, showing how much money was saved by the FRS intervening in a fire. It was assumed without fire fighting attendance, the properties in question would suffer a total loss and let the fire burn out after destroying the building it originated in. It used the Building Cost Information Service (BCIS) database (a database of costs, collected by the Royal Institute of Charted Surveyors and others, used for the estimation of building costs) and cost estimates from the fire officers in charge of the fire incident. The project estimated that the intervention of the FRS in Merseyside saved approximately £30 million during 2010. It also states that cost differences between the values predicted by the BCIS tool and the fire officers only differed by 0.6 percent overall (however, some values in estimates differed by over 1500 percent). No attempt is made to see if this result shows that Merseyside FRS is cost effective, the result is just stated that the FRS saved a total of £30 million by intervening in fire incidents. The view from this research is that the intervention of the FRS saves money and therefore the quicker the FRS can attend a fire, the quicker it can start saving property. However in an earlier report, conducted for the development of the Fire Service Emergency Cover (FSEC) toolkit, it was found that an earlier response time does not mean that fire fighting response will be more successful (Wright, 1998) and therefore the results the TriData project came up with do not necessarily mean that the earlier attendance of the FRS saved as much as originally stated.

Research at the University of Edinburgh has focused on helping fire fighters fight fires through the use of information gathered at the scene. The FIREGRID project (Upadhyay *et al.*, 2008) relies on a large number of sensors being installed within a building during construction and allowing fire fighters to see how the fire is developing by the use of real time computer modelling of the fire. By allowing the first responders to better understand how the fire has grown (since it started) and what the fire is likely to do, the fire fighters should be able to plan the fire fighting response more effectively, reducing the amount of time required to fight the fire and minimising the risk to the fire fighters themselves. However, the FIREGRID is currently conceptual and is hindered by a number of issues - such as the location of the sensors within the building (sensors cannot be placed in the middle of the room between floor and ceiling, without affecting the occupiers use of the building), the reliance on high performance computing power to allow on the spot modelling capability as well as bandwidth issues for getting all the sensor data to the computers. If the model cannot run without getting all the data from the building, the model is likely to diverge from the actual fire and the results will not reflect the fire (Wickler *et al.*, 2009). The installation of such a system within buildings at the design phase could have some fairly large benefits for firefighting in the future if the issues regarding the model could be overcome.

#### 2.2.3.3 Fatalities and Injuries

Placing a value on the cost of a human life is a controversial area (Baker *et al.*, 2009) as people don't often want to consider that human lives have a monetary value. To do so is to potentially value one human life as less than another human life and whilst that may be the case or may be the reasoning for calculating the cost of a human life, people who are potentially being compared may take offence to the results.

However, in the research and calculations of various safety projects, sometimes it is beneficial to calculate the cost of a human life to ensure that the cost of saving a life is not outweighed by the loss of life. This is of particular concerns to Governments where budgets are limited and public perception can affect party politics. Various research has been conducted into valuing a human life so a value can be used for cost benefit analysis calculation in various different aspects (not just fire safety). This allows a researcher to select a pre-made methodology for using human life valuation in a cost tool, but allows a selection of tools so the researcher can select a tool that they find ethically acceptable.

The FSEC toolkit only focusses on the loss of life and does not deal with the costs of a life loss (Greenstreet Berman Ltd, 2010) but calculates the potential loss of life depending on how long it takes the FRS to arrive at an incident. This model is based on the fact that more people will suffer fatal injuries the longer the FRS takes to arrive on the scene. It is then left to the FRS running the scenario in FSEC to consider the potential life losses and place a value on those figures themselves. However, the UK Government does provide guidance on the value of a human life to help in the decision (HM Treasury, 2003) and cites a specific value. This value is used in Government decisions and allows the designers to use this value without having to consider the method of calculating the cost in each project. It also provides a benchmark value for the Government to use across all safety measures (and measurements where a cost of human life will be required).

The SFPE Handbook of Fire Protection Engineering (SFPE) Handbook states that the best method of calculating the cost of human life is to use the 'willingness to pay' method (Ramachandran, 2002). This method of calculating costs revolves around asking people how much they are willing to pay to prevent injury or death for the risk involved. As people are willing to pay differing amounts for different risks, the average cost should then be taken and that value used in cost effectiveness decisions. However, this requires questioning members of the public and may prove to be time consuming and costly. Another study has shown that the value people are willing to pay drops off with age as well (Baker *et al.*, 2009) so careful consideration would need to be used in the selection of the people questioned to calculate the cost value, as a specific gender or age group selected could potentially bias the collected data and therefore the willingness to pay figure.

Various cost effectiveness papers avoid calculating the cost of human life. In a paper describing the cost effectiveness of Canadian apartment buildings, Beck and Yung quantified life safety as 'risk to life' and therefore avoided having to calculate the cost of human life (Beck and Yung, 1990). Other studies use the same method as the UK Government and choose a set value of life (Juås and Mattsson, 1994). The value chosen in this paper was $1.5 million and was taken from guidance from the Swedish National Road Administration. Choosing a value to represent the cost of human life avoids having to change the values depending on the occupants of the building because society is willing to pay more to avert risk to the young, the elderly and the infirm (Wright, 1998). By having a set value, this will have been taken into account.

Financial risk is easy to understand, but Bukowski states that in standards dealing with safety, it is inappropriate to be used (Bukowski, 1996). He goes on to state that risk to life is difficult to understand and communicate to the public. As all the performance based standards in draft (and now in practise) are risk based, it demonstrates that life risk is the metric for performance based standards. Considering that insurance companies mainly use the financial risk and the Building Regulations use life risk, there needs to be a method to take both options into account.

#### 2.2.3.4 Cost of Expenditure on Reducing Risk

In 2003, the Office of the Deputy Prime Minister issued a report on the state of the UK FRS (Office of the Deputy Prime Minister, 2003). This report detailed changes to the FRS and areas that the FRS could improve. One of these was the introduction of IRMP's and the recommendation that the FRS should place greater emphasis on fire prevention and for more efficient fire resource allocation. Direct research on the cost of the IRMP's is currently lacking, other than that produced at Loughborough University alongside this PhD (Konukcu and Bouchlaghem, 2010a,b, Baker and Bouchlaghem, 2011), potentially due to the fact the IRMP's are a recent introduction to the UK FRS. However, other research has been conducted into the costs of fire prevention measures.

Work by Juås and Mattsson (Juås and Mattsson, 1994) investigated the effect of various aspects on the costs of fire, prevention measures being one of the areas investigated, amongst other aspects. However, they found the data available to calculate the effects of prevention measures was insignificant to allow them to draw any conclusions.

Prevention of fire is achieved through education of the risks and through good management practises. Donahue investigated effects of management on the costs of a buildings fire protection (Donahue, 2004). Her work focuses on the state of New York in the US, however, the results can be applicable to any developed country that has a FRS. She found that management was only involved in an organisational way and that costs fell when the FRS had more say in the in the management of buildings and events. It was also found that fire departments that analysed the costs of the department and made decisions based on previous performances were more cost effective than those that did not. Finally, it was concluded that having more highly trained and experienced fire fighters led to better performance and cost effectiveness. This work shows that having fire management in place affects the cost of reducing risk but the report does not go further and attempt to quantify these cost savings. Based on this consideration, it is possible that the IRMP's in the UK will enable the UK FRS to act more cost effectively by analysing the previous performances and costs of the department, something that will be under even more scrutiny with pressing local budgets as the UK Government attempts to offset the nation's deficit.

Automatic fire detection systems, such as smoke alarms, are cited as being a potential life saving device and thus great emphasis is placed on installing them in homes, both in the UK and the US. In the UK and the US, FRS's are known to be able to fit and install a smoke alarm in residential occupancies. Research has been undertaken to value the cost effectiveness of these preventative measures (Parmer *et al.*, 2006). The research by Parmer *et al* investigated the costs of a smoke alarm and public education campaign across four states in the US. Initially, it was found the costs of a sprinkler installation program were not fully understood, yet they identified the main cost areas as the cost of man hours, installation costs, equipment and education. The study proved to only be a cost outcome analysis rather than a fully fledged cost benefit analysis, yet it was concluded that the programs could potentially be seen as cost effective, however more research would be required before it could be concluded with certainty that this was the case.

As discussed previously in Section 2.2.2.3, sprinklers can reduce the risk of damage within properties where they are installed and reduce fire losses. Research in America has shown that sprinklers installed within US homes are a cost effective method of reducing fire damage (Butry *et al.*, 2007, Butry, 2009). Yet, earlier research in New Zealand (Duncan *et al.*, 2000) showed that systems built to the New Zealand standard at the time were not cost effective, though it was concluded that the costs of the domestic sprinkler system could be reduced though legislation, competition and design requirements and therefore a reduction in costs could mean at a later date, the installation of sprinklers are cost effective. A study in the UK (Communities and Local Government, 2010) investigated (as one of the options within the research), if the installation of residential sprinklers was cost effective. They concluded that sprinklers may be cost effective in *some* cases and advised that building contractors and designers might want to consider the installation of sprinklers on a case by case basis. It did not recommend the mandatory installation for sprinklers throughout the study area (the Thames Gateway) or in all social housing. It was pointed out that this cost benefit was conducted assuming the position as 'society' as a whole, rather than as the Government or building contractor - therefore if the work was done from these points of view, the cost effectiveness may be different - it depended on who bore the costs of the sprinkler policy.Whilst these different cost effectiveness studies focuses on residential, this study does not consider the residential occupancy type though it does provide an insight as to the economies of scale and sprinklers (more cost effective in larger buildings).

It is within insurers interests to try and reduce the risk of fire within the properties covered in its portfolio. By reducing the risk of a fire occurring, the insurer will reduce their liability and the chances of having to pay out for a fire occurring. Research by (Wilkinson, 2010) explores the role of the insurer within the fire engineering industry and how they can influence the costs of fire safety and property protection within the UK. He concludes that:

> *"It is clear the insurer does not play a suitably active role in the building design process, nor do they command sufficient influence"* (Wilkinson, 2010)

He notes that this may be due to a number of reasons such as:

1. The commercial insurer is not determined at the design stage of the building.
2. The contract works insurer has a different set of priorities than commercial insurers.
3. Insurance brokers can mean initial contact between clients and insurers does not occur during the design phase, when changes could more easily be implemented.
4. In a soft market, insurers are less likely to insist on expensive fire protection measures as client can take their to a competing insurance company.
5. Fire engineers are reluctant to involve insurers, for fear of needing to install costly fire protection measures for property protection.

Whilst insurance companies are responsible for insuring the finished building, they often do not get a say on the fire protection measures being installed and therefore, the building can actually have fire protection measures stripped out (fire engineers often make cases for the reduction of passive protection and the removal of sprinklers), measures that the insurer would prefer to see remaining within the building to prevent the spread of fire. If the fire engineer is making use of PD 7974 (BSI, 2003a) and following the Qualitative Design Review (QDR) procedure within, then the release of PD 7974: Part 8 (BSI, 2012) provides a guideline for the property protection and protection of the building for purposes other than life safety. Such guidance can help protect the safety of the occupants and provide a level of safety that means the insurers also face a reduction risk.

#### 2.2.3.5 Indirect Costs of Fire

Research conducted into the indirect costs of fire has found the indirect costs to be difficult to quantify. Research by Peaker (Peaker *et al.*, 1977) investigated the consequential losses to the national economy, though found that the majority of fires did not affect the economy. The point is raised that in the chemical industry however, fire could affect the national economy through the loss, due to the nature of the business being undercut by cheap foreign competition. Marchant (Marchant and Henesy, 1980) took this research further and investigated it with case studies of fire hit businesses in the UK.

Later research by Moller (Moller and Danish Emergency Management Agency, 2001) indicates a lack of research in this area, stating that this is due to a lack of usable data.

In the SFPE Handbook (Society of Fire Protection Engineers, 2002), Ramachandran details a National Institute of Standards and Technology (NIST) study of indirect costs in the US (Ramachandran, 2002) and the estimates on how to calculate indirect costs given the direct costs. He describes the estimates for indirect losses are (added to the direct losses):

- *65 percent for manufacturing and industrial properties*
- *25 percent for public assembly, educational, institutional, retail, and office properties*
- *10 percent for residential, storage, and special structure properties*
- *0 percent for vehicle and outdoor fires*

(Ramachandran, 2002)

This shows for a industrial premises, sixty five percent of the direct loss is added to the overall cost as the indirect loss. In the UK, the cost of fires recorded by insurance companies and collated by the FPA does not include the indirect costs and is only the result of the direct burning, which, if the values in the list above are correct, are seriously underestimating the costs of fire to the UK economy.

A 2006 study of the cost of fire in Australia found that the cost of fire was slightly higher to that of the UK (1.15 percent of GDP in Australia in 2006) (Ashe *et al.*, 2006). However, the study found that majority of the costs of fire were due to indirect costs. It highlighted that ninety three percent of fire loss in Australia was not associated with a direct loss. This figure is significantly higher than even the cost estimates that Ramachandran highlights and therefore the majority of the fire costs in Australia are a result of the indirect costs.

### 2.2.4 Fire Economic Models and Statistical Models

Cost decision support systems in fire protection aren't commonplace. This research intended to see if costs were considered within the UK Architecture, Engineering & Construction (AEC) industry and found that cost tools are not used within the fire engineering departments. Research into costs, as described above is broken down into differing areas and only Ramachandran attempts to bring them together in his book, “The Economics of Fire Protection” (Ramachandran, 1998). However, a few cost Decision Support System (DSS) tools are available; although these tools only focus on a single area of the fire design process, rather than encompass the entire fire design process.

Schools in the UK are built to meet the requirements of the Building Regulations but additional requirements and recommendations are considered in the design, through the use of Building Bulletin (BB) 100 (Department for Children, Schools and Families, 2005), due to the potential for loss to the community and the risk to minors should a fire occur. BB 100 helps detail the extra protection measures a school should have in place , such as the addition of sprinklers or additional fire protection. This is considered as the loss of a school is a large loss to the local community and therefore more than just the cost of the building is being considered at the design stage. BB 100 recommends sprinkler installations where cost effective and work by Fraser-Mitchell has led to the construction of a cost benefit tool aimed at designers of schools (Fraser-Mitchell, 2010). This tool is used by the fire engineers to consider if the fitting of a sprinkler system is a cost effective method of providing additional fire safety measures for the school, and is used alongside the insurance companies and the building designers clients to consider if the the cost is sufficient. It focusses only on the sprinkler installations in schools and not in any other occupancy type.

A similar tool has been developed by NIST in the US (NIST, 2011). This tool focuses on sprinklers in residential occupancies and is based on the work done by NIST in a report produced by NIST in 2007 as indication of economic performance of different sprinkler types in residential occupancies (Butry *et al.*, 2007). This web tool allows users to input their own values of cost, damage and receive data on if it’s worthwhile installing sprinklers in an individual home or community wide. Again, this tool is focussed entirely on residential buildings and does not consider other occupancies.

The work done by Fraser-Mitchell on the sprinkler systems in schools used some figures from the UK fire statistics to provide background to his cost benefit tool. He describes how the use of the area burnt statistic was used to calculate the probability of a fire starting and reaching a certain severity in the building. The use of fire statistics to inform the design of a new build assumes that past performance is an indicator of future performance, though this seems to be a reasonable assumption in regards to fire statistics. Yet, significant developments in fire safety systems or changes to the building code could mean that future performance differs significantly from past performance and make any assumptions based on statistical analysis invalid. However, it does provide a vast database of data to allow informed decisions to be made.

Ramachandran describes the use of fire statistics in fire engineering.

> *"The analysis of statistics provided by real fires is the basis of most probabilistic fire risk assessment, from the frequency of ignition to the conditional probability of failure of a fire protection system. Statistical analysis takes data that has been collected on building fires and transforms it into information that can be used to predict the likelihood of occurrence of future events and their consequences"* (Ramachandran and Charters, 2011)

This analysis of the fire incident data provides the evidence base for the proposed DSS tool.

On the subject of using fire statistics, Tillander describes the factors that should be considered when using statistics as the evidence base for a model. She states:

> *"All factors must be quantified, such as fire ignition and fire development, performance of building occupants, level and reliability of fire safety systems (incorporating both the active and passive measures), intervention of the fire department, and damages caused by fire in addition to their interactions"* (Tillander, 2004)

From this work, it can be seen that all aspects of the fire should be considered and quantified - work on which was started by Ramachandran and investigated in detail in his books "The Economics of Fire Protection" (Ramachandran, 1998) and "Quantitative Risk Assessment in Fire Safety" (Ramachandran and Charters, 2011). Ramachandran's work used fire statistics from the fire incident records prior to the formation and collection of the UK FRS FDR 1 incident database used in this thesis and it's possible that changes in fire incident recording and advances in fire protection technology means that results from current data analysis will provide differing results. In his 2011 book, Ramacahandran highlights that there are 4 different methods of probabilistic models that can be used to quantitatively model fires. These are:

1. Statistical methods
2. Logic tree analysis
3. Stochastic models
4. Sensitivity analysis

From the dataset of previous incidents and with statistical analysis it should be possible to infer probabilities of fire and other statistics, detailed later in this thesis. Mentioned above is that past performance is not an indicator of future performance - the fire safety management rules in England and Wales changed in 2005 with the introduction of the RRO (again, Scotland and Northern Ireland have their own rules). This change in policy may affect the future statistics (if fire safety management is seen to affect the outcome of a fire). Likewise, newer buildings are built with the newer fire standards and fire engineered solutions - fires in these buildings may perform differently to those just built to standards set down in ADB. Whilst these values changed, they are not assumed to affect the statistical analysis in this research. This is due to the fact that the data collected is for the years between 1998 to 2008 and for various reasons detailed in 3.5.1.1, only the year 2005 data is used. It is assumed that as the change of law only came into effect partway through the year, the number of fires where the RRO could have affected the fire is low. For this work, it is assumed that the statistics collected will provide results that are indicative of the future of fires in England and Wales, at least for the foreseeable future. However, the statistical analysis carried out within this thesis could be checked annually to check that the application of the statistical analysis is still valid.

Ramachandran's work, whilst detailed, did not combine the different aspects of the economics of fire protection into an easy to use tool, which this work intends to do, to allow the fire engineering industry to make use of the economics data and utilise the work.

A cost model similar to the proposed design tool was investigated in 2009, looking at fires in Taiwanese residential buildings (Lin *et al*., 2009). This model focuses on the factors that affect the fire losses and models these factors to get an explanatory model that attempts to model the estimated outcome of a fire. This model uses 918 fire incident records for Taiwanese residential fires and uses questionnaires and interviews to determine the factors influencing the fire. It goes on to use multi step regression analysis to analyse how the outcome of a fire is influenced by each factor. However, the paper makes clear that the data it uses is based on a social science approach, rather than an engineering approach, as the majority of the data collected and used was qualitative data, based on interviews and questionnaires rather than statistical analysis of the fire records.

## 2.3 Existing Methodologies

Chapter 2 details the previous research done in and around the aspects of fire engineering and costs. Some of these studies investigate the costs of fire or the costs of fire protection in various different buildings.

These studies make clear the methodology they followed and the limitations of the methods they used. This section is to evaluate the methods that were used in the different studies and if the methods used in previous studies can be used in this study. However, if not, it will be made clear why the method used will not be used in the following work.

### 2.3.1 Construction Of Explanatory Fire-loss Model For Buildings

In 2009, the work by Lin *et al* investigated the costs of fires in the Taiwanese residential building sector (Lin *et al*., 2009). The aim of this work was to construct a fire loss model that would take the factors affecting the fire damage to a residential building and give an estimate of the fire loss that the building would suffer in event of a fire.

The authors considered only direct losses to the building premises and did not consider indirect losses as this would increase the complexity of the model.

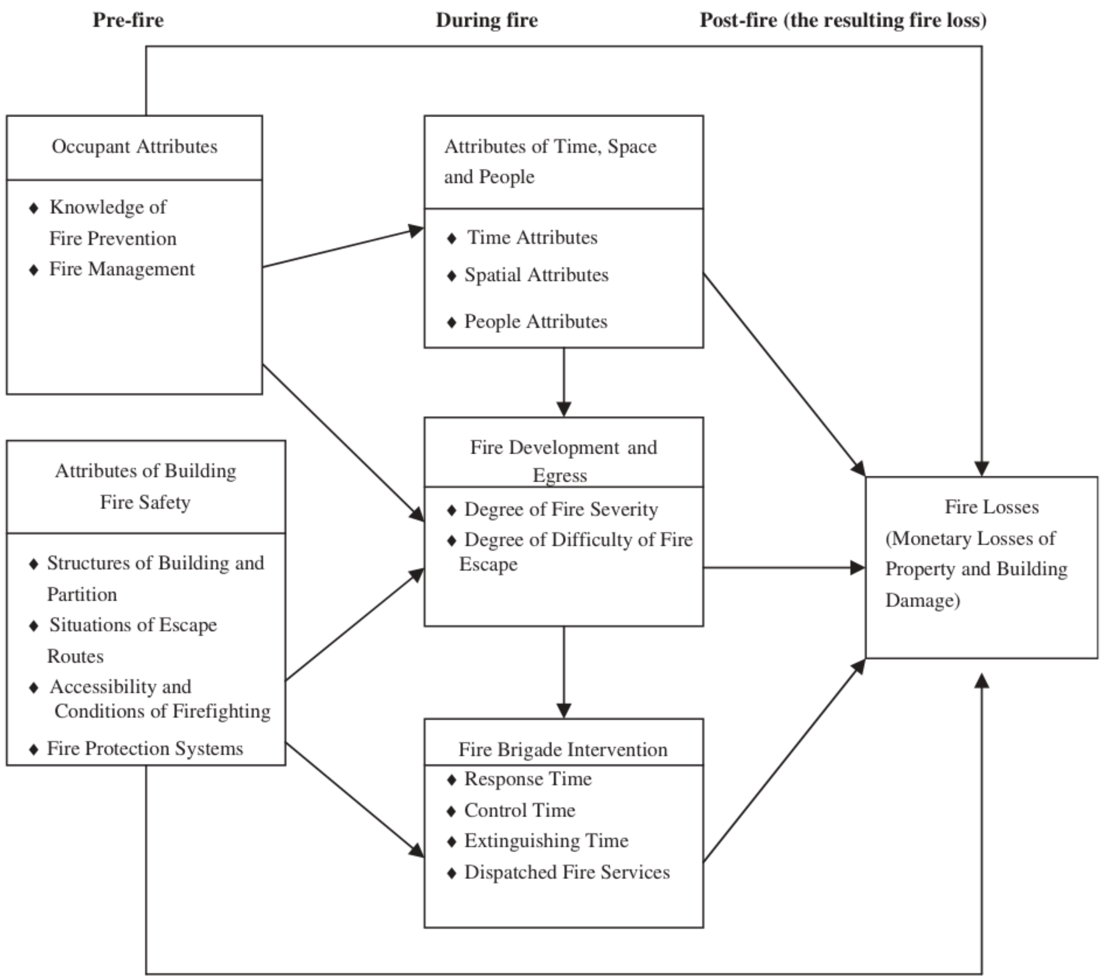



**Figure 2.8:** Hypothetical Framework of Fire-loss Model
*Taken from (Lin* et al.*, 2009), Pg 1047*

As mentioned above, this work only focussed on residential buildings and did not consider alternative occupancies. This work by Lin *et al* assumes that all fires within the buildings are approached using the same fire fighting techniques and that the construction of the buildings where the fires occurred are similar (reinforced concrete). To identify the aspects of what affected the size of a fire, two questionnaires were conducted, one to investigate the fire safety management of properties before a fire and the other was for fire fighters to use to speak to occupants that had suffered a fire incident and to consider how the fire brigade dealt with the fire.

The results from these fires were then converted into factors and probabilities and then used in a stepwise regression models to try and model the outcome of the fire. Figure 2.8 details the the conceptual framework for the proposed model. The extinguishing time variable was removed because it was found that control time was more critical to the size of the fire and building structure was also removed as it was found partition structure played a bigger role in the statistical analysis.

This framework shows the outcome as a monetary loss but the study does not mention how the calculation to the costs of fire to a building are determined and no consideration was given to the cost of loss of life. The final model, discussed in the paper only outputs the value of as a size and does not consider the size of the initial property.

The paper makes clear that the limitations of its qualitative approach in that all the probabilities and factors are taken from a questionnaire and are not from an engineering or statistical evidential base. Therefore this research aims to meet this shortcoming in Lin *et al's* research by using UK fire incident records as a quantitative evidential base for statistical analysis, backed up by an initial questionnaire and interview session to ensure that the proposed DSS tool and methodology would cover the areas required by the end users.

The proposed questionnaire and interview section of this research will achieve objectives 1 and 2 of the research, set out in Section 1.5. These are to investigate the current practise within the UK AEC industry and to see if a cost benefit DSS tool would be of interest and of use to the AEC industry.

The study makes clear that it considers all residential structures involved in the study to be of similar fire loading and construction. This would not be the case across different occupancies. Therefore whilst this was not considered in the Lin *et al* study, this thesis will include analysis of different occupancies and therefore these aspects will have to be considered, especially in the case of warehousing and industrial occupancies where fire loading can differ greatly. Consider the industrial processing of oil and petroleum to the manufacturing of wooden furniture - both are industrial processes involving flammable materials but both have very different potential for fire spread due to the physical properties of the materials involved, including the different heats of combustion and burning rates of the materials.

### 2.3.2 BRE Quantifying the Cost of Meeting Building Regulations Fire Safety Requirements in New Buildings

In 1996, BRE, in association with Arup, investigated the costs of meeting the Building Regulations in a number of different occupancy types (Davis Langdon and Arup Fire, 1996). The study was undertaken to try and estimate the effect that meeting the Building Regulations through the application of ADB had on the total cost of a building project. The aim was to help inform the Department of the Environment (DOE), in assigning priorities to the future development of the Approved Documents and related research.

The research investigated the costs and compared the marginal costs of meeting the fire safety requirements, rather than a comparison to no fire safety at all. A reduction in building costs was considered possible through the early application of ADB, such as the requirements for external fire spread being considered at the earliest stage and fire fighting staircases could be reduced amongst other items. All values within the research are quoted in terms of cost in 1993 and inflation would need to be considered for comparison to different years. Like this research, the study only considered new buildings and did not consider renovations. It was considered the design of suitable fire safety measures was more cost effective when it was considered at the appropriate stage of the design process.

The study concluded with the following points (the reasons for cost savings are emphasised in the points below):

- Greater recognition in the benefit of sprinklers (*reduction in damages*);
- Increased travel distances to protected stairs can be achieved with little to no reduction in safety (*less stairs required*);
- Shopping mall populations, estimated at $2m^2$ per person are unrealistic (*therefore the number of occupants is greater than expected and exits widths and stair widths will be greater than needed*);
- The need for fire fighting shafts (increased fire protection) in buildings over 7.5m high and area of $600m^2$ is questioned (*less protection and therefore less expensive materials required*);
- No mention of staircase ventilation within ADB (*ventilation would remove smoke from the stairs and prevent additional stair protection being required*); and

- Ductwork for mechanical ventilation in basements with sprinklers is still required to be fire rated to 400°C (*a sprinklered fire is likely to have smoke below 400°C and therefore the smoke ductwork could be reduced in regards to it's fire rating, saving money*)

The cost savings were considered by the group of consultants, based on archetypes of the building being studied (all building occupancy types were considered, including residential buildings such as flats). These archetypes were discussed amongst the consultants carrying out the work and the DOE. These buildings were considered to be typical of the time that they were built and therefore the results apply to these archetypes and may be different to the same building occupancies but different layouts and sizes - the results should therefore be considered only as a guide for the cost savings.

The methodology of the research meant that the costs of the buildings considered were only those considered to be average by the engineering consultants carrying out the work - if the consultancy was specialised in a specific area or building type, then the results for the other results could potentially be skewed. The methodology for this PhD is to evaluate the losses within buildings and then construct the loss tool off of that information, rather than potentially creating buildings that might not represent the actual built environment. Costs to the building were calculated by the consultants and were not calculated using a construction tool. The methodology for this PhD will make use of the BCIS and FPA database to construct a construction cost estimate of a building, based on a buildings footprint that will provide a more quantitative model, than the a method using qualitative data.

### 2.3.3 The Costs and Benefits of Sprinklers in Schools

Work done by Fraser-Mitchell at BRE Global investigated the cost of sprinklers within school buildings in the UK and derived a cost benefit analysis tool (Fraser-Mitchell, 2010). This tool, aimed at fire engineers and those that have an interest in seeing the costs of fitting sprinklers into school buildings, uses a quantified risk assessment method to calculate frequencies and probabilities and forms the core of the tool.

The probabilities of fire starting are taken from the Government fire statistics (Fraser-Mitchell references private communications with the Fire Statistics Unit - it is assumed that this data is taken from the FDR 1 dataset, discussed in more detail in Section 3.5.1.1) and from data from the Department for Children, Schools and Families. This data is the number of fires in schools and the number of schools respectively. From this, the likelihood of fire was calculated.

As the outcome of this tool is a cost benefit analysis, the paper in which Fraser-Mitchell describes the tool discusses the costs of installing fire sprinklers. To calculate the costs of installing sprinklers, he uses a quantity surveying firm to appraise the costs of installing sprinklers into a school. From this, an average value of £38.96 per $m^2$ is calculated. The same quantity surveyors estimated the costs to the school buildings as well and calculated these at £1,700 ± £400 for primary schools and £1,330 ± £260. These values were taken from a small collection of schools. Cost of human life and cost of injuries are discussed and the issued guidance on the value of human life is used, taken from the Treasury Green Book - Appraisal and Evaluation in Central Government (HM Treasury, 2003).

The tool therefore uses data from statistics to provide the background to the DSS tool that is the outcome of the research. However, the tool is narrowly focussed and only applies to schools and sprinklers in the UK. The tools uncertainties are not calculated, meaning that value of the net benefit must be 1.65 times the value of uncertainty to give a confidence level of 95 percent.

This research intends to use the fire incident records for the analysis of the fire statistics as an evidential base, similar to that of the Fraser-Mitchell work. However, it isn't clear from his paper if the FDR 1 incident records were used - this work aims to make it more transparent regarding what data is used from the FDR 1 records and how that data was collected, collated and used.

By using the FDR 1 data and data collected by the FPA, objectives 5 and 6 of this research are met.

### 2.3.4 Fire Statistics Use

Previous work by Ramachandran has investigated the costs of fire in the UK and is summed up in his 1998 book (Ramachandran, 1998). As discussed in Chapter 2, his work focussed on statistical analysis of fire incident records, using the data prior to the formation and collection of the FDR 1 records. Through statistical analysis, he is able to find the probabilities of fires starting and the probability of the fire spread.

Ramachadran states in (Ramachandran, 1980) that statistical analysis of fires should be undertaken to investigate how each factor affecting the fire damage can be evaluated and their individual contribution to the fire damage can be calculated and compared. It is proposed that this can be achieved using multiple regression analysis. Work since this date has not shown any indication that multiple regression models were used in calculating fire size and area damaged, until the work by Lin *et al* discussed above in section 2.3.1 where stepwise multiple regression was used. The use of a regression model allows the different factors that affect the dependent variable (in this case, area damaged and therefore costs) to show to what degree they affect the dependent variable and depending on the method of regression used, the model itself can exclude the items that have little to no effect.

The data made available for analysis in this project is the UK FRS FDR 1 incident data records. More details on how the data is collected is discussed later in Section 3.5.1.1. However, these forms are completed on attendance to a fire incident. There has been little previous research using the data collected in this dataset. The FDR 1 data was assumed to be used in the fire sprinkler cost tool completed by Fraser-Mitchell (Fraser-Mitchell, 2010) though his work only used the data to inform the probabilities of fire starting in schools and from his 2010 paper, it appears that only the data he requested (that was specific to schools) was sent to him by CLG. Work completed by Bureau Veritas (Bureau Veritas, 2011) used the data to "provide technical insight into the environment and community impacts of fire with sprinklers and no sprinklers in single story commercial and industrial premises" in the UK. Like the Fraser-Mitchell work, only a small subset of FDR 1 data was sent by CLG for analysis (the Veritas report shows the data used on Page 124 in Appendix 4). The data sent only covered the commercial and industrial buildings and the areas damaged by direct burning.

The biggest use of the FDR 1 data was in the construction of the FSEC toolkit, a toolkit for the UK FRS to help plan operational locations and organisation of fire resources. The FSEC toolkit uses FDR 1 statistics to form an evidence base, work which was conducted by Greenstreet Berman (Greenstreet Berman Ltd, 2010) and Wright for Entec (Wright, 1998, Wright and Archer, 1999). The work completed by Wright formed the initial model for the FSEC toolkit. The later work by Wright and Archer detailed the cost model built into FSEC. This model uses the FDR 1 database, along with publicly produced figures by the FPA to produce a linear cost model for use within the FSEC toolkit to allow FRS's to investigate the cost of their actions (through delays in attendance times). The work by Greenstreet Berman updated the FSEC toolkit using more recent up to date data - the initial calculations were done using data from the 1990's. This work used the whole FDR 1 dataset and used various statistical tests to calculate costs and effects for use in the FSEC toolkit. However, the FSEC toolkit is only available for use by the UK FRS and not by other businesses and does not consider the building design.

Using the statistics software, SPSS, a regression model can be constructed by using the statistical data gathered and contained in the FDR 1 and FPA datasets. SPSS settings allow the model to either include all independent variables to start with and then exclude the factors that have little to no effect on the model (Remove Method) in various steps. The regression model can also include none of the independent variables and can add different variables over the course of repeated steps (Fill Method). This allows the values that accurately affect the dependent variable to be considered and not include the variables that do not effect the final regression model to be be included and therefore keeping the model simple and only using the values that are required.

Use of SPSS on the fire datasets collected by the FPA and FRS, it will be possible to achieve objectives 5, 6 and 8 of this research. By using a multiple regression model, it will be possible to find the factors within the databases that affect the final costs and then use this to calculate the expected damage and the value of that damage.

### 2.3.5 Costs of Fire

The previous methods detailed above have discussed how to calculate the fire damage to the building but the aim of this research is to construct a design tool methodology that would allow building designers and those responsible for the fire safety systems in the AEC industry to calculate the cost benefits of installing additional fire protection measures into buildings at the design stage.

Once the amount of damage has been estimated, the cost of this damage then needs to be determined so that a cost figure can be output to the user of the proposed DSS tool. This cost figure would allow direct comparison between different cases being run through the cost tool and enables a cost benefit analysis to be carried out by the user. For this to occur, an estimate of the costs need to be considered and built into the methodology.

In the Fraser-Mitchell work discussed in Section 2.3.3, the cost calculations were gathered through the employment of a quantity surveyor. This method means that a very precise figure could be gathered through the tools the surveyor has at their disposal. However, the costs of hiring would be impracticable for this project. Yet, some of the tools that are available to the quantity surveyor are available to all. Such data is the Spons Cost books (Davis Langdon, 2012) which has costs of different materials and labour costs set out as cost per $m^2$. Another resource is the BCIS tool which collects data from quantity surveyors and others in the AEC industry to provide a database of cost of building various different occupancies.

By using these tools, it is possible to use the previous experience from quantity surveyors and the AEC industry to inform the cost estimates of the fire protection used in the building and the potential cost of losses. It should be made clear that the FPA dataset also contains cost estimates of the cost of the fire - these cost estimates include the cost of damage to the property and estimates of the cost of the fire to the business (business interruption). These costs are estimated by the loss adjustor's filling in the forms.

Objective 7 of this PhD is to "Identify costs of building materials and estimated costs should a building fire occur". By using the various datasets already built up by the combined experience of all in the AEC industry, these datasets will allow the cost of building materials to be identified which can then inform an estimate on the combined building losses from a fire.

## 2.4 Decision Support Systems

A DSS can be defined as a

> *"computer based systems that help decision makers confront ill-structured problems through direct interaction with data and analysis models."*(Sprague and Watson, 1993)

These systems allow designers and managers to access help in the decision making process.

The majority of DSS tool have similar features in common. These are:-

- They are non routine and involve frequent *ad hoc* analysis, fast access to data and generation of non standard reports
- They often address "What if?" questions
- They have no obvious correct answer; a manager has to make qualitative trade off's and take into account situational factors

These features are discussed in a paper by Keen (1981) entitled "Value Analysis: Justifying Decision Support Systems" (Keen, 1981). This paper discusses the fact that DSS tools are helpful in the role they play but are difficult to quantify in regards to cost savings that the individual tool provides to the decision making process. However, Keen also states that tools should be:-

1. Flexible
2. Easy to use
3. Responsive
4. Communicative

He explains that it should be flexible to handle different situations, easy to use so it can be put into different users work flow, responsive as it must not impose a structure on the user and be rapid in its calculations and communicative so that the end user can get the knowledge they need from the tool quickly and easily. By following these four "rules", the tool should be of the most use to the end users.

In his earlier book (Keen, 1980) , Keen describes the perceived benefits of a DSS system. These are:

1. Increase in the number of alternatives examined
2. Better understanding of the business
3. Fast response to unexpected situations
4. Ability to carry out *ad hoc* analysis
5. New insights and learning
6. Improved communication
7. Control
8. Cost savings
9. Better decisions
10. More effective teamwork
11. Time savings
12. Making better use of data resources

Not all of these 12 benefits can be applied to the design tool in this research, however the proposed tool does achieve a number of these points, specifically points one (alternative approaches), eight (cost savings), nine (better decisions), eleven (time savings) and twelve (making better use of data resources). By allowing the end user to run more alternatives to the fire design, it is hoped that a better, more cost effective solution can be put forward as an alternative to the other plans a designer might submit.

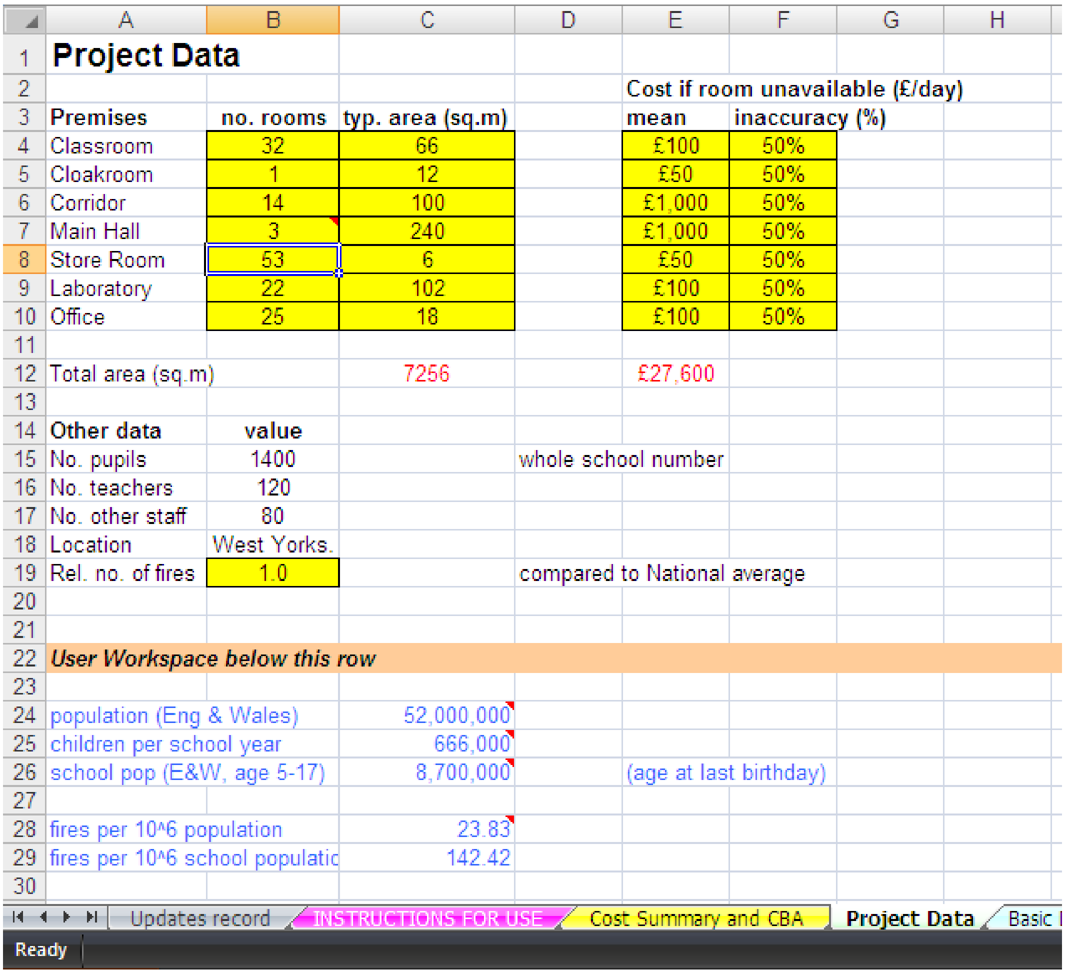
### 2.4.1 Previous Tools

As mentioned in Section 2.2.4, there are a few different tools available to fire engineering professionals that focus on aspects that the proposed decision support system will cover. These have been programmed in a variety of different ways. The merits and drawbacks of these tools are discussed below. These design tools are aimed to reduce the costs of fire engineering within the total design brief of a building. Previous research by Rezgui *et al* indicate that cost savings can potentially be made in the project brief by using IT based tools (Rezgui *et al.*, 2001). Whilst this isn't something considered at this point of the research (the appointment of fire engineers ranges from ad-hoc to planned and budgeted as part of the design brief), it is something to consider for future research.

#### 2.4.1.1 BRE Sprinklers in Schools Tool

The tool developed and made by BRE (Fraser-Mitchell, 2010) is developed in Excel. It's main drawback of this tool is the tools user interface. Figure 2.9 shows the main data input worksheet for the tool.

The colour of the font and highlighting of cells has been used to indicate to the user



| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Project Data | | | | | | | |
| 2 | | | | | Cost if room unavailable (£/day) | | | |
| 3 | Premises | no. rooms | typ. area (sq.m) | | mean | inaccuracy (%) | | |
| 4 | Classroom | 32 | 66 | | £100 | 50% | | |
| 5 | Cloakroom | 1 | 12 | | £50 | 50% | | |
| 6 | Corridor | 14 | 100 | | £1,000 | 50% | | |
| 7 | Main Hall | 3 | 240 | | £1,000 | 50% | | |
| 8 | Store Room | 53 | 6 | | £50 | 50% | | |
| 9 | Laboratory | 22 | 102 | | £100 | 50% | | |
| 10 | Office | 25 | 18 | | £100 | 50% | | |
| 11 | | | | | | | | |
| 12 | Total area (sq.m) | | 7256 | | £27,600 | | | |
| 13 | | | | | | | | |
| 14 | Other data | value | | | | | | |
| 15 | No. pupils | 1400 | | whole school number | | | | |
| 16 | No. teachers | 120 | | | | | | |
| 17 | No. other staff | 80 | | | | | | |
| 18 | Location | West Yorks. | | | | | | |
| 19 | Rel. no. of fires | 1.0 | | compared to National average | | | | |
| 20 | | | | | | | | |
| 21 | | | | | | | | |
| 22 | User Workspace below this row | | | | | | | |
| 23 | | | | | | | | |
| 24 | population (Eng & Wales) | | 52,000,000 | | | | | |
| 25 | children per school year | | 666,000 | | | | | |
| 26 | school pop (E&W, age 5-17) | | 8,700,000 | | (age at last birthday) | | | |
| 27 | | | | | | | | |
| 28 | fires per 10^6 population | | 23.83 | | | | | |
| 29 | fires per 10^6 school populatic | | 142.42 | | | | | |
| 30 | | | | | | | | |

Updates record | INSTRUCTIONS FOR USE | Cost Summary and CBA | Project Data | Basic I

Ready

**Figure 2.9:** BRE Tool Data Input

where changes should be made, however, no help is provided on the current worksheet to tell the user what each colour or highlighting corresponds to though the tool does contain instructions on this at the beginning of the document. Therefore, if you wish to consult the documentation during use of the tool, you are required to switch between the current worksheet and the instructions worksheet to view them. Putting the help on the same worksheet as the user is using prevents this switching action. This breaks rule 8 of Shneiderman and Plaisant golden rules on reducing short term memory load which are discuss in later in the paper.

Data within the worksheets is not protected - a warning on the instructions worksheet states that values in red should not be changed - however no validation or write protection is built into the sheet and therefore a user can deliberately or accidentally change these values and give a completely different result than might be expected. Excel supports the locking of cell contents except those defined by the programmer to allow changing. In this manner, the sheet can be locked and the end user can only write in the cells that are unlocked - this would prevent errors due to accidental formula or base calculation figures being edited and is something that should be considered for a tool. However, the flexibility to add or change details should remain within the tool so that if required, an advanced user can change these values to suit.

An Excel document is very easy to save. When doing so, it will save everything within the file, such as inputs and the outputs. However, it is very easy to save over a document. Whilst the user and/or the business the user works for should keep backups of files, the program should make it easy for users to save the document and not overwrite any default data or if it occurs, make it easy to reset the sheet to the defaults. This worksheet does not accomplish that and only prompts the user to save a copy in the initial document page. If the user was to ignore this section, or at a later date, forget what was on this page, they may find themselves overwriting and deleting previous files that they wished to keep. Therefore the proposed design tool shall have a functionality to remind users either on save or make it impossible to save without creating a blank template copy.

However, whilst the sheet does have a list of problems, it does do the job of calculating the cost benefits - it's main let downs are the user interface which can be improved upon.

#### 2.4.1.2 NIST Sprinkler Tool

The NIST sprinkler tool is different to the BRE one in the fact that the tool is a web based tool - this means that no other software other than a web connection and internet browser are required to use it. This is a different aspect than the options considered in this paper, which require software to be installed on the PC the user is using.

The ability to have instant access to the tool, regardless of the computer the consultant

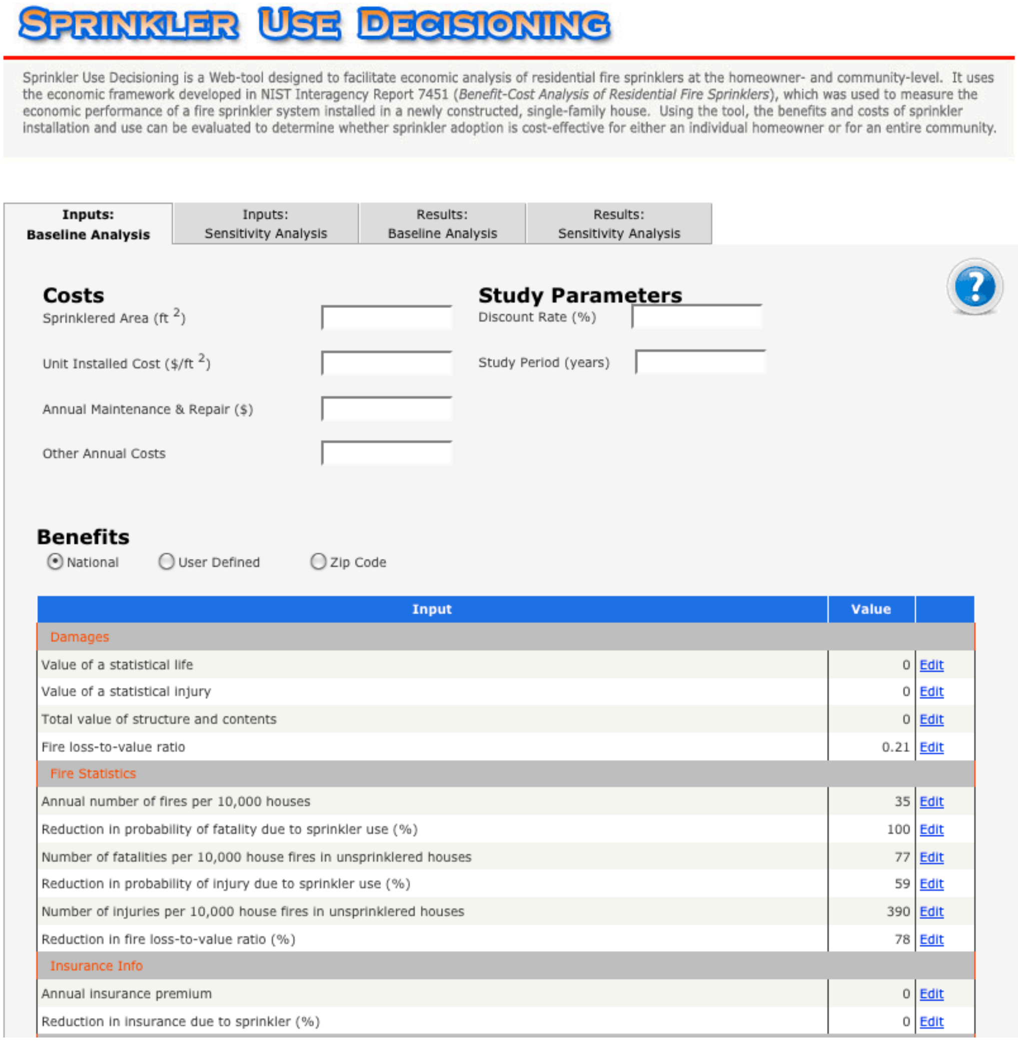



**Figure 2.10:** NIST Sprinkler Cost Tool

is using, makes this tool extremely flexible. It allows users of different operating systems and/or with access to a conventional piece of software installed on the machine to make use of the tool.

The tool is laid out well and it follows a natural progression - for example, the input boxes are related and it leads on from the previous question. Data is validated and you cannot progress to the next page if an item of information is missing or has been entered incorrectly (such as the addition of characters rather than digits). Wrongly entered sections are highlighted by red text until the correction has been made. Help for the user is provided by clicking a question mark icon on each page - however, this downloads a PDF document which then needs to be opened in a different program and then the help section for the application page then needs to be found. A more streamlined help system would be able to direct the user straight to the help section in the help file for the page the user is interested in. A javascript pop up or similar would have been able to provide the information *in situ* and thus require less swapping between programs. Again, this breaks rule 8 of Shneiderman's GUI design rules.

The tool allows the user to use the default settings that NIST have specified for the tool or they are able to put in their own settings. If the settings are changed, the user can easily return the settings to the defaults. This allows the user a greater control of the settings, whilst allowing allowing them to return the program to it's default state in case of error.

Whilst the online access may make the tool more viable for larger organisations (no need to do massive roll-outs of IT software), it may also present a security risk. The tool does not contain any disclaimers saying that the data entered into the form will not be kept or used for any other purpose. For some firms, whilst no personal information is being uploaded, there may be issues regarding privacy because there are no disclaimers or even because the tool is a cloud application (cloud refers to the software not being present on the users machine but in the internet "cloud"). As NIST is American, the website is assumed to be hosted in America and thus falls under US data protection laws which differ from UK and EU rules - this again may cause concern, especially if the tool is updated and in the future asks for more details.

Finally, the last downside of the tool is that it does not allow for download of the data entered. To allow others to be able to replicate the results, it might be beneficial for the tool to allow users to export and import a plain text file with various settings the user might have customised. This would mean the tool does not have to be reprogrammed with data should custom values be required. It might have been possible to store data on this in a cookie (a small text file that most websites leave on your computer) but this does not occur so therefore a manual import/export system could have been implemented.

When viewed on a wide-screen monitor, it can be seen that the tool has been designed for a smaller, 4:3 ratio monitor - the sides of screen are taken up by large amounts of white space. This is something to bear in mind for designing of the tool.

#### 2.4.1.3 Active Fire Protection Systems

Work at Loughborough University (Bird *et al.*, 2012) investigated the creation of a DSS tool for the selection of active fire protection measures within the built environment. This tool, in development with insurance companies and the FPA sets out to help match an active fire protection system with the hazard within the building in question. This tool sets out to help mitigate the damage from the misspecification of fire protection systems.

The questions it aims to answer are:

1. Is the technology intended to be used in this application?
2. Is the extinguishing media compatible with the application?
3. Is there sufficient experience or evidence of technology used in this application?

This should help the end users specify the correct fire safety system for the intended use (i.e. not specifying a sprinkler system for a data centre where the activation of sprinklers would cause the same, if not more, damage to the electrical items present).

Bird states that the each fire protection system is ideally suited to a specific type of application, rather than a specific type of application (Bird *et al.*, 2013) and that the tool will help match the correct system to the correct application.

## 2.5 Software Design

As the outcome of the research is a proposed methodology for a DSS system, then a brief literature review should cover the design of the software. The proposed tool is designed to be used by fire engineers and possibly fire engineering clients, so the tool will cater to the needs of the fire engineers. The definition of tool in this research follows that given by Lockley and Sun which is -

> *"A computer program that is used by engineers to perform analysis of a building or its services (prior to realisation) for the purpose of making, modifying or evaluating design decisions."* (Lockley and Sun, 1995)

### 2.5.1 User Interface

As discussed in 2.4, Keen (1981) puts forward the areas a DSS should follow to allow the best use. These were that it should be flexible, easy to use, responsive and communicative. These aspects are met in the coding of the software. For example, ease of use comes down to the design of the Graphical User Interface (GUI). A well developed GUI will allow users to navigate the program intuitively. In the design of GUIs, Shneiderman and Plaisant lay down 8 "golden rules" of interface design. These are:-

1. **Strive for consistency** - Program design should be consistent throughout, such as layout, fonts, design and where possible, user actions and terminology.

2. **Cater to universal usability** - Recognise the needs of the users and design accordingly. Different users will use the tool differently (further discussed in a paper by Udema (Uduma and Morrison, 2007) and also mentioned by Sprague in his paper setting out the framework for DSS creation (Sprague, 1980).) which stated that different skill levels of users would use the tool differently, depending on the users level of experience in the field the tool is designed for). This means adding help for novice users and shortcut keys and faster pacing for more experienced users.

3. **Offer informative feedback** - For each user action, the software should provide feedback though the feedback should follow the scale of actions (minor feedback for minor actions, major feedback for major actions)

4. **Design dialogues to yield closure** - Sequences of actions should be organised into groups and should have a beginning, middle and end. Feedback should be given at the completion of a set of actions so the user knows the item is complete (for example, e-commerce sites show a checkout completion screen to let users know this set of actions has been completed)

5. **Prevent errors** - Design the program to prevent errors, such as only allow numbers to be entered into a field that only needs numerical data entered. If an erroneous value is entered, provide feedback to the user and let them correct it. Allow them to only have to correct the erroneous value rather than redo the entire form.

6. **Permit easy reversal of actions** - As much as possible, allow for easy reversal of errors. This allows users a sense of relief, knowing they can undo any error - this allows for exploration of unfamiliar options.

7. **Support internal locus of control** - Experienced operators desire the sense that they are in command of the interface and the interface should be designed accordingly. Surprising interface actions, tedious sequences of data entries or the inability to gather information will build dissatisfaction with the product.

8. **Reduce short term memory load** - Human short term memory means that displays should be kept simple and short. Where appropriate, online access should be provided to command-syntax, abbreviations, shortcuts and other information.

These rules will lead to the optimised GUI design that all parties, regardless of experience can use.

Whilst the tool should cater to the needs of both experienced and inexperienced, reducing the need for expert users will allow the tool to reach a larger range of engineers - however, the use of the tool by an inexperienced user should still be checked by an experienced user before the details can be relied on, though this is down to the quality management procedures of the end user. Work on tools for the construction industry are already focusing on machine learning and reducing the need for expert users (Dibley *et al.*, 2010). This tool, aimed at facility management, uses a number of different different inputs to help Facilities Management (FM) managers understand the use of the building and knowledge of the building itself.

### 2.5.2 Software Methodologies

As DSS tools are software programs, they can be designed following any of the current software design methodologies. A design methodology is the method of software creation, following a set system.

Design methodologies often fall into one of two categories, Sequential or Iterative methodologies (Whitten *et al.*, 2003). Figure 2.11 demonstrates a sequential methodology. All development steps in a stage are completed before progressing onto the next step. This kind of methodology results in a longer time before the end user gets to use the software as all steps are completed before the final product is released. This means that input from the user is not gained until the end so the specification of the program has to be fully agreed at the start of programming so that the programmer(s) are able to complete the program to this specification with little to no changes during the programming phase.

Figure 2.12 shows an iterative step methodology. This methodology means that the end user can see progress on software throughout the design of the software as he will be involved in the testing of each partial system produced. This allows for more constant communication between the end users and the software programmers, meaning that the end product is likely to be more thoroughly tested than a sequentially designed piece of software. The software can also be changed throughout the process as the end user is involved and can voice opinions and concerns regarding the software itself and this allows

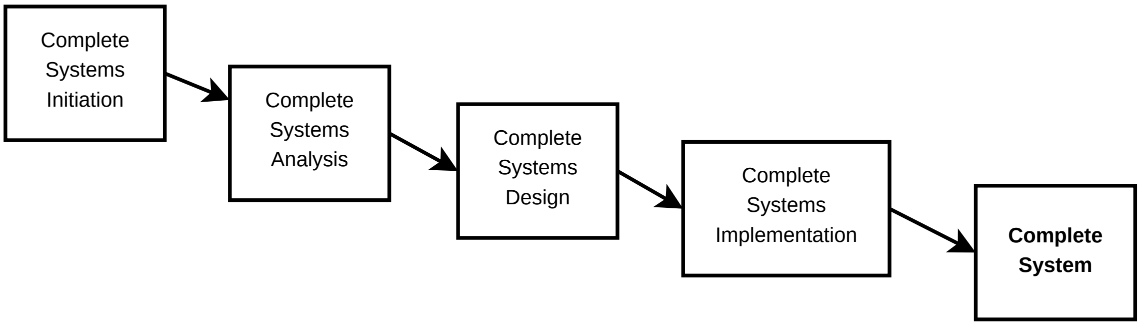



**Figure 2.11:** Sequential/Waterfall Methodology
*Taken from (Whitten* et al.*, 2003), Pg 41*

the finished product to more closely replicate what the end user wants from the software.

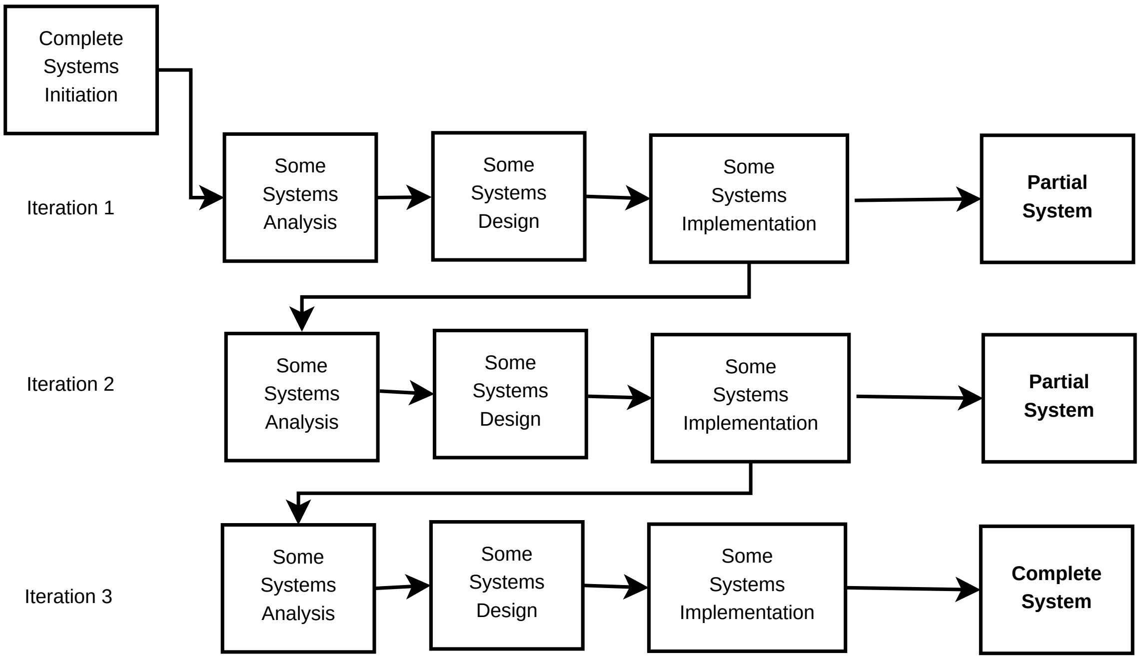



**Figure 2.12:** Iterative/Incremental Methodology
*Taken from (Whitten* et al.*, 2003), Pg 41*

Iterative methodologies can be further split down into different methodologies that share similar aspects (in that programming is done in similar steps to Figure 2.12) but they all have a few differences that make them different to the alternative methodologies.

#### 2.5.2.1 RAD

Rapid Application Development or RAD, is an iterative design methodology as it name implies, for the rapid development of software. It focuses on getting the end users interacting with the program during the development so that each cycle or iteration can be tested. The principle behind the beta versions and prototyping is that users will have a better idea of what they want when they see part of the program already working. RAD focuses on a few main points.

- focus is on reducing time therefore phases of design and programming are consolidated and accelerated.
- In each iteration, only some design specifications will be considered.
- Assumption is that errors will be corrected in the next iteration.
- After each iteration, end users are invited to test the software.
- Based on feedback, designers will make changes until a version is deemed worthy of implementation.

The design phase within a RAD methodology is very short - the majority of design is done during each iteration.

#### 2.5.2.2 Agile

In 2002, a publication by VTT Publications stated that agile software development was an umbrella term for various different software methodologies (Abrahamsson *et al.*, 2002). All of them share the same principles of quick iterative design, similar to the RAD methodology described above. In 2001, an manifesto was setup to document what an Agile methodology should consist of. This can be found at the Agile manifesto page (Beck *et al.*, 2001). This states the following principles:

1. Individuals and interaction over process and tools
2. Working software over comprehensive documentation
3. Customer collaboration over contract negotiation
4. Responding to change over following a plan

These principles mean the various methodologies that fall under the Agile umbrella all share common roots.

Of the Agile methods, there are a few which stand out as being more common than other methodologies (Cohen *et al.*, 2003). One of these is XP or Extreme Programming, put forward by Beck (Beck, 2000) and the other is Scrum, first described in 1986 (Takeuchi and Nonaka, 1986).

#### 2.5.2.3 XP

Extreme programming is focused on small team developments, with 2-10 people involved in the design team. XP seeks to prevent schedule slips by having short release cycles on software (Beck, 2000). However, due to the nature of the methodology, of inter team communication and the need for co-location of the the design teams. It also has a very short iteration time of of about 2 to 4 weeks.

#### 2.5.2.4 Scrum

Scrum is another team driven methodology that relies on an iterative, incremental steps. Scrum relies on:

- Transparency - Ensures that all aspects that affect the outcome are visible to those managing the work.
- Inspection - Work must be inspected frequently.
- Adaptation - If an inspection determines something is outside acceptable limits, the inspector will adjust the process.

This list was taken from (Schwaber and Sutherland, 2010). The roles in a Scrum are those of the team (the programmers) and the ScrumMaster. The team are designed to optimise flexibility and productivity. Iterations are called sprints and these sprints are time boxed (done within a set time limit). During the sprint, the ScrumMaster makes sure that no changes are made that would affect the Sprint Goal. As the Sprints progress, the iterations come together to form the final product.

### 2.5.3 Design Summary

Whilst iterative software methodologies appear to offer greater benefits and flexibility for the design of the software and work, this research takes a more sequential approach. Section 2.6 details the language that the DSS tool could be written in and the reasoning behind some of the design choices, such as disconnecting the software from the actual statistical analysis of the data, to reduce the need for distributing the large datasets.

In his paper in 1980, Sprague recommends an iterative approach to the design of a DSS tool (Sprague, 1980). However, as this research will be splitting the DSS tool from the statistical analysis, it fits in better with the sequential methodology and calculating each step before proceeding with the next step. The DSS tool cannot really be put into place and programmed before the statiscal analysis is complete and therefore the iterative methodologies do not fit how this research and anaylsis has been conducted. Whilst most of the methodologies laid out above focus on team efforts and this work is a single person, this isn't considered to be an issue, espcially as a sequential methodology has been chosen.

## 2.6 Language

A computer language is the method by which the program itself is programmed. Each language has its own strengths and weaknesses. This section details the potential languages that could be used by the author to construct the tool. However, these languages discussed below are fairly basic and a better tool could be constructed using a more efficient programming language, such as Python, C+ or .NET. Whilst this would provide additional benefits to the tool, the skills required for using such a language is beyond the current skill set of the author and therefore only the very basic languages and tool sets have been considered. It was considered beyond the scope of this PhD to learn and program the tool itself and therefore this can be considered for future work.

The statistical analysis is considered to be completed separately to the program and therefore the final tool would only have to display the information that was programmed into it from the statistical analysis. This would reduce the computation that the tool would have to do on the fly and would therefore allow a lower system requirement for the design.

The benefit of disassociating the final program from that of the program that performs the statistical analysis is that the database of the fire incidents does not have to be distributed alongside the program. If this was the case, the database takes up a large amount of disk space. If the right language was chosen for constructing the tool, then the database could be hosted centrally, either by the programs creator, or even by CLG or whoever is providing the data and the individual programs could link back into the statistical database via the internet. However, this could add unnecessary delays to the data processing if the internet connection is poor and would prevent any off-line analysis, which may prevent people on the move from accessing and performing statistical analysis.

Therefore, whilst the languages discussed here are fairly basic, the end program isn't considered to need to link to the database and therefore doesn't need to be programmed using a such a programming language or require further discussion on API's or other access methods.
The tool will be programmed in either Microsoft Excel or in Visual Basic. Excel was chosen as the Microsoft Office suite is a common software within the corporate environment, with around 80 percent of companies using a version of it (McLeish, 2009). This allows the tool to be used by the maximum amount of people without purchasing extra software. Visual Basic was also chosen as a potential language as it can provide very easy

to use GUI programs quickly and simply. The programs created in Visual Basic can be downloaded and run with no additional software, allowing anyone running a version of Microsoft Windows to run the final program. The following show the pros and cons about each language:-

*Microsoft Excel*

✓ Easy to program basics

✓ Graphing functions built in

✓ Tabbed function built in due to worksheets

✓ Cross Platform - Microsoft Office runs on Mac OS X and Microsoft Windows so potentially the tool can be cross platform

✓ Easy import/export of data - just save the file

✗ Security concerns with macro functions in a corporate environment

✗ Restricted functions in Excel - however, are expandable with Visual Basic coding

✗ GUI limited - The graphical user interface is limited by layouts

✗ Potentially difficult to export imported data and results into a different format

✗ Change in screen resolution could potentially change layout

*Visual Basic*

✓ Doesn't require Microsoft Excel to be installed or present

✓ Fully customisable layout

✓ Easy to hide parts of the program that the user does not need to access

✓ Easy to set size of layout - should look the same on all systems

✓ Easier to keep open source so others can look at source code and continue work/check for security concerns

✗ More difficult to learn to program and very little prior knowledge

✗ Possibly difficult to graph

✗ Possible reliance on third party tools (gnuplot for example)

## 2.7 Screen Resolution

Screen resolution describes the screen size that a user will be using the tool on in terms of pixels. Figure 2.13 shows the worldwide screen resolution trends over the past 12 months. The data for this was taken from Statcounter, an online tracking service that collects information about web browsing via code on websites (Sta, 2011). The code can track at what resolution a user is browsing the web - whilst this might be skewed towards the home users where web browsing may be more common, Statcounter provides this information freely and allows a reasonable picture of common screen resolutions to be built up so that web designers (and in this case, programmers) to design to suit the most common resolutions.

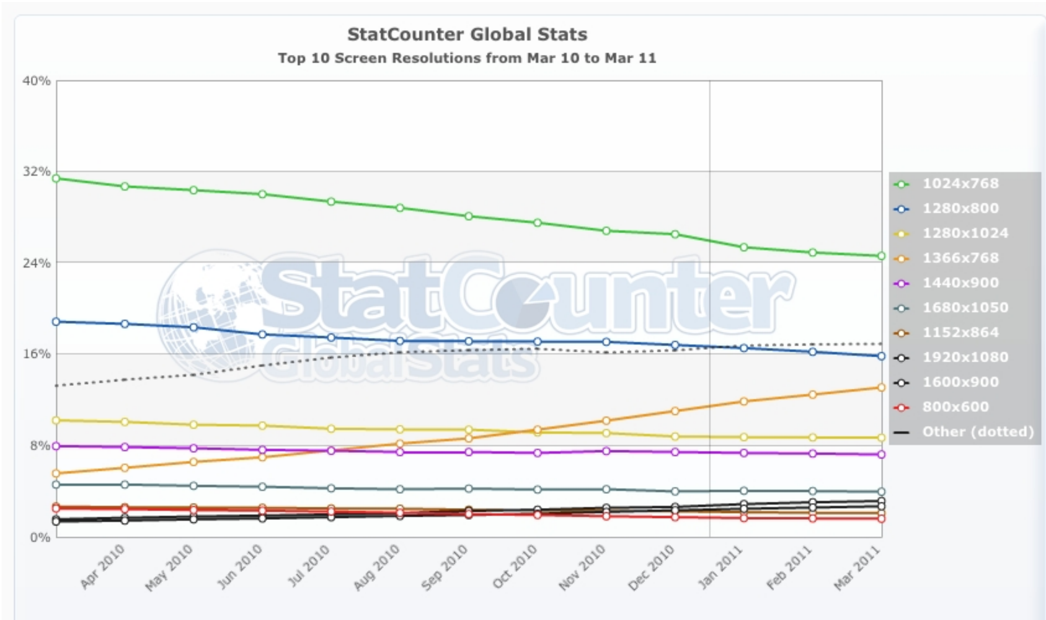



**Figure 2.13:** Worldwide Screen Resolution From March 2010 Until March 2011
*Taken from http://statcounter.com/*

Statcounter also allows for the screen resolution to be split further down into countries (this will be done by looking up IP addresses and finding the country the IP resides in). Due to the method of collection, these figure will be subject to different variables and may potentially be misleading due to people within the UK browsing through a proxy and thus not appear in the UK stats whilst they would appear in the worldwide stats, whilst conversely, people in non UK countries may be browsing through a proxy situated in the UK and thus will appear on the UK statistics instead of their country of residence.

As can be seen from the UK specific results, there is a difference between the resolutions used in comparison to world wide though the spread between the resolutions used is lower,

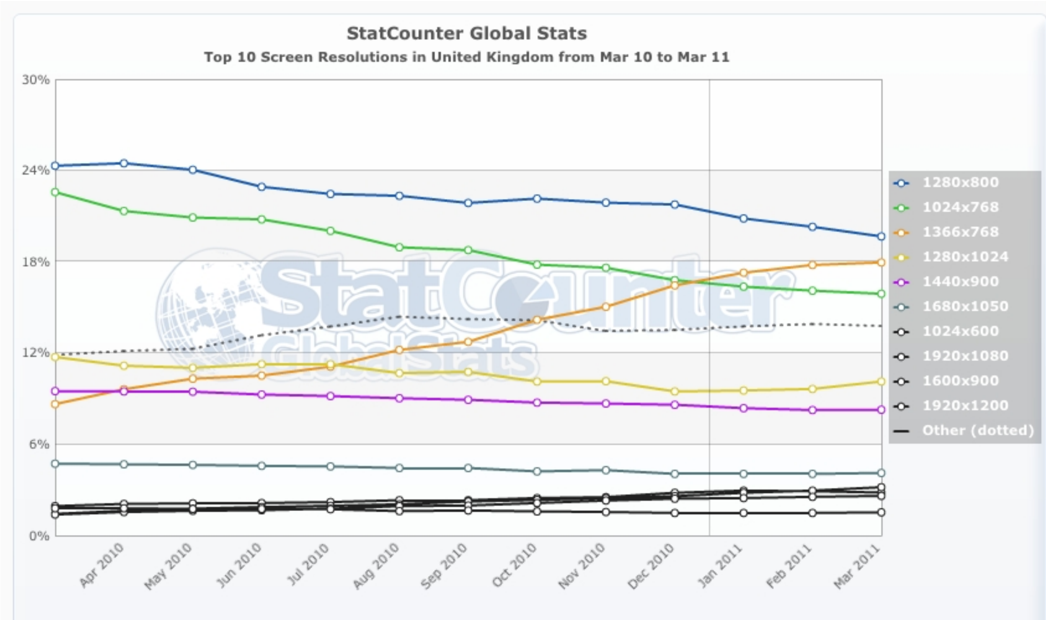



**Figure 2.14:** United Kingdom Screen Resolution From March 2010 Until March 2011
*Taken from http://statcounter.com/*

with the most popular resolution in the UK (1280x800) being used by less than the most popular one worldwide (1024x768).

The most common resolution in the UK are wide-screen formats - 1280x800 and 1366x768 - this could potentially be attributed to the large laptop market compared to the desktop market, as laptops tend to have widescreen format screens. However, this hypothesis can be challenged as news of laptops outselling desktops has been reported at least 3 different years with different figures (NYT, 2003, Singer, 2005, Murphy, 2008) from different studies.

From this, it can be seen that the major trends show that 1366x768 laptops are beginning to increase in number (another reason is possibly the fact that Blu-Ray and High Definition TV are increasingly being sold) and that other resolutions seem to be in decline or of little relevance due to the low percentage share.

## 2.8 Summary

The above literature review covers the previous research done in the area of economics of fire protection, details the past research in regards to statistical analysis of fire incident data and identified areas of potential research. From the literature, it can be seen that whilst economics of fire systems have been investigated, there has been no attempt to statistically analyse the entire fire process with the intention to construct a DSS tool for those who are responsible for the design of fire safety systems within buildings.

Therefore this research aims to fill this gap by developing a DSS tool, using the evidence base provided by the UK FRS fire incident database. This DSS tool would cover the installation of fire protection measures over and above that required in the Building Regulations and detail the costs savings that a building owner would be likely to receive from the installation of extra protection measures.

# Chapter 3

# Methodology

## 3.1 Introduction

The objectives of this research were set out in Section 1.4 and 1.5. This chapter sets out the process that was followed throughout the research to achieve these. This includes data collection on the background of the state fire engineering in the UK Architecture, Engineering & Construction (AEC) industry and how this will affect the research, detailed discussion on the fire incident data that provides the basis of the data analysis and basis of the PhD and lastly the cost data that was used to estimate the costs from a fire and a comparison between the different cost datasets available to calculate the costs of fires in the UK.

## 3.2 Literature Review

The initial step of the research was to identify a gap in the research. This was done by extensive reading into the subject area. Initially, from experience, there seemed to be a research gap into the cost effectiveness of passive protection. This was gathered from experience within the fire engineering design industry so further work was required to identify whether or not this was the case within the academic community. Reading was undertaken, focusing mainly on the fire based journals such as The Journal of Fire Protection, Fire Technology and Fire Safety Journal. After these, the scope of the reading was extended to Civil Engineering articles and research referenced by previous papers. From this reading, it was confirmed that there was a lack of research about passive fire protection methods and costs. However, various papers such as Moeller's report about protection in Denmark (Moller and Danish Emergency Management Agency, 2001), suggest that this is due to a lack of data, though not assumed to be an issue in the case of this research considering the amount of data provided by Department of Communities and Local Government (CLG) and the Fire Protection Association (FPA). For many years, researchers have been suggesting that there exists an optimum combination of passive and active fire protections measures (Baldwin and Thomas, 1974, Factory Mutual Research Corporation, 1991, Haack, 2004), however research and data collection on passive protection hasn't been a major focus and these studies recommended that more data was collected on passive protection measures.

Fire incident data for the UK was acquired from the CLG and this was the basis of this research. On analysis, it was found that data on passive fire protection and building construction was either not included on the original FDR 1 form and therefore not recorded in the electronic database, as discussed later in Section 3.5.1.1 or the FDR 1 form did not question the protection within the property, other than the alarm system and extinction system. These fire incident records were taken from FDR 1 forms filled in by fire fighters attending the scene of the incident and often the forms are incomplete. Further data was collected from the Fire Protection Association (FPA) and this data, whilst appearing more complete and more accurately filled in (potentially as its source is from loss adjusters attending a fire incident, post clean-up and insurers being more concerned with accuracy and costs than fire fighters might be at the time of recording), also failed to detail any passive fire protection measurements that could be used in analysis, though did include some details on the methods of construction that are of current importance to the insurance industry, such as timber framed buildings, buildings using Structural Insulated Panels (SIPs) and other constructions viewed as a 'high risk'.

However from reading and from previous experience, it was apparent that fire engineers in the UK only designed buildings to meet the functional requirements of the Building Regulations. Life safety requirements within the regulations were met but no consideration was given for the building structure itself in a fire incident. Previous research by Ramachandran had investigated the cost benefits of installing extra protection measures into a building at the design stage (Ramachandran, 1998) but little change appeared to have filtered through to the industry. Further reading on the subject, Ramachandran states that the calculations can be used in a cost benefit tool but nothing more is mentioned on the construction of the indicated tool. Yet, a report published in New Zealand (Page, 2005) states as a recommendation that cost benefit tools should be constructed to help designers consider property protection within the design so that sustainable and safe building design can be achieved (through less frequent and smaller fires and therefore reduced need for rebuilding and repairs). No other data could be found that suggested that this recommendation had been taken on board and the aim achieved. Therefore it was considered that one of the main outcomes of this research should be a methodology for a cost benefit tool.

Fire engineering is a costly procedure and is not undertaken lightly. The reason a fire engineer is employed is to save money on buildings where the architect wishes to cut costs in relation to meeting fire safety requirements specified in prescriptive building regulations or to validate potential departures from the prescriptive guidance and demonstrate that alternative methods of meeting the Building Regulations. The guidance within Approved Document B (ADB) is restrictive and force architects to make sacrifices in terms of aesthetics and other features to meet these recommendations. With the help of a fire engineer, a different method of meeting the regulations can be engineered and thus allows the architect more freedom. This cost and effort means that the type of projects fire engineering designs tends to be associated with are larger, non residential projects. This is because it is far easier to construct affordable housing to meet the Building Regulations through the use of ADB (Communities and Local Government, 2006). As such, fire engineering is not widely in residential buildings and therefore, residential buildings were not considered as part of this project.

## 3.3 Methodology

Chapter 2, the Literature Review, discussed a number of methodologies that previous studies in similar areas used. This research followed the sequential software design methodology, as discussed in 2.5.3. This methodology was chosen, as based on the project aims and objectives, discussed in Section 1.5, it was felt that this methodology better suited the aims and objectives of this research. For example, Figure 3.1 shows the methodology of this research, following a sequential software design methodology, chosen because the main outcome of this research is a Decision Support System (DSS) tool.

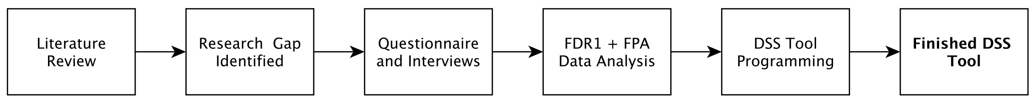



**Figure 3.1:** Methodology Visualised

This figure shows how the steps of the research will be undertaken. As can be seen from the diagram, the methodology relies on a sequential process, waiting for one process to be complete before moving on to the next process. This method of work was chosen as it was felt that the various steps of the research relied on the previous steps. Without the previous step being complete (or at least, almost complete), the additional steps could not be started. Therefore, even though DSS tools are considered best built using an iterative methodology (Sprague, 1980), the research was conducted using a sequential methodology. It was felt that the iterative approach would mean that the final DSS tool would have been started without the statistical analysis being fully complete and the statistical analysis was to help influence the design of the tool. Likewise, the questionnaire and initial research with the UK fire engineers and AEC industry was to influence the analysis of the data and the final DSS tool and therefore the sequential approach was adopted. This approach can be seen to follow the research questions discussed in Section 1.5. These objectives follow on to the next objective, with each objective needing to be completed before the rest of the objectives can be completed and therefore the objectives of this research follow a sequential order and the sequential methodology is the best suited for this work.

This research follows an follows an *a posteriori* standpoint, in that the knowledge gained is the result of previous experiences and is empirical in nature. It takes a Positivist ideal as the research focuses on the application of empirical data and that the observations of the statistical analysis can be tested. The model describes the observations made in the analysis.

## 3.4 Collected Data

Data provided by the FPA and CLG can provide an evidence base for a design tool but whether or not a current tool existed currently and would it be used should one be created, needed to be determined. Reviews from literature suggested that such a tool did not exist (Page, 2005) and that any decision making tool would prove valuable to the decision making and design process (Meacham, 2004). This meant that questionnaires and interviews needed to be conducted with members of the fire engineering industry to help guide what route the research should focus on and whether or not a DSS tool would be used in the AEC industry. This data collection needed to focus on 4 key areas:

1. Current practise in the fire engineering design process
2. Views on costs of fire protection methods
3. Views on active and passive fire protection measures
4. Views on British Standard 9999: Code of Practice for Fire Safety in the Design Management and Use of Buildings

Understanding current practise within the fire engineering industry would allow a more targeted approach to this research, understanding what aspects could do with improvement and who would benefit the most from the work. Understanding views on costs was essential to see if these were considered at all during the design process and if not, why not? The views on active and passive measures are conflicting in industry journals (Mountford, 2003, Rowan, 2010) with people reporting that not enough passive fire protection is being used, whilst others are stating that sprinklers aren't being used enough.

Both sides of the argument are supported by commercial interests so both sides of the argument have vested interests. However, whilst there has been a large number of studies into the effectiveness of sprinklers (Melinek, 1993a,b, Poh and Bennetts, 2005, Bennetts *et al.*, 2008, Butry, 2009) to name a few, there has been relatively little research into passive fire protection in buildings (Baldwin and Thomas, 1974, Cozzani *et al.*, 2007) and where this has been the case, it has often been in a very specialised area such as the work done by Shetty, (Shetty *et al.*, 1998), Tyldesley (Tyldesley *et al.*, 2004) and Haack (Haack, 2004). Therefore the questions had to find out exactly what the engineers and members of the fire engineering industry that weren't connected with the protection manufacturers thought.

### 3.4.1 Pilot Study

To gauge interest in a cost benefit tool in the fire engineering industry, a pilot study needed to be conducted to investigate current fire engineering practise and to assess the interest in a cost benefit tool for fire engineers. This pilot study needed to cover the broad range of activities that dealt with fire engineering - from architects to fire engineering consultants to building control officers and the fire brigade. A small pilot study questionnaire was initially constructed and then made available to fire engineers and on the professional social network, LinkedIn.

The pilot study questionnaire can be found in Appendix A.1. It follows the bullet points set out above in Section 3.4 of investigating current practise in the fire design process, costs of fire protection methods, views on protection measures and view on BS 9999. The addition of the personal questions section meant that it could be seen what parts of the fire engineering community were answering the questionnaire and what sort of experience they had within their sector. This would show if the whole sector of fire engineering was responding to the questionnaire and whether or not the views differed in different sectors and allow changes and follow up questions to be completed if it was found that this was the case. This questionnaire was placed on the professional social network LinkedIn to allow respondents to return the questionnaire easily. There were six responses to the questionnaire.

Feedback from the questionnaire was that it was to open ended and the questions were to vague. With this in mind, the questionnaire was rebuilt for distribution to a wider audience and made more closed.

### 3.4.2 Questionnaire Design

As described in Section 3.4, the questionnaire was designed to answer 4 points. Therefore the questionnaire was split down into 4 different sections to answer these 4 questions. As well as these 4 areas, the respondent was asked what area of the AEC industry he or she was part of and the level of experience they had in this area. This would allow the results to show if the different levels of experience and areas gave similar responses.

#### 3.4.2.1 The Design Process

The first section that the questionnaire addressed is the the design process that fire engineers and other stakeholders undergo to get a building designed and built. This section attempted to understand how, if and when fire engineers got involved in a building design. As the questionnaire was aimed at a cross disciplinary range of respondents, the

Royal Institute of British Architects (RIBA) schedule of work was adopted as the standard for naming the different phases of the buildings design and construction. These were taken from the RIBA Outline Plan Of Work 2007 (Royal Institute of British Architects, 2007) and chosen because these phases of work should be common knowledge across the AEC industry and therefore every respondent should be able to relate their answers to the phases named within. A summary of the RIBA plan of work can be found in Table 3.1. The full RIBA plan of work can be found in their published guidance (Royal Institute of British Architects, 2007).

It should be noted that the RIBA plan of work has been updated in 2013. This new plan of work (Royal Institute of British Architects, 2013) can be found online on the RIBA website. The main difference between the new plan of work and the older edition is that the stages are no longer alphabetised but are numerical stages. Each stage has been slightly altered. Stage 3 is the developed design phase and is similar to the design development phase in the previous version. This is where planning applications tend to be made for a building, so the main bulk of the design work has been completed. The new plan of work suggests that tendering is done within the developed design (stage 3) and technical design (stage 4) stages, depending on the individual project requirements. The newer stages also promote the handover and close out phase in comparison to the old stages, which would have seen this role performed in Stage K or L.

Whilst the plan of work has changed, this work was conducted before the changes were finalised and announced by RIBA and therefore this work has made use of the old RIBA stages. The change will mean that the following results collected by this work will differ from the RIBA stages going forward and the implications could mean that the research is already dated. However, the stages between the new and old, are fairly interchangeable and the descriptions of each stage are very similar. Therefore, it is considered that whilst the changes will mean the research follows the old stages, the change will not adversely affect the research as the stages are very similar and the readers of the research will be able to follow where the respondents to this questionnaire fit into the design process.

When asked when they got involved, respondents were asked if they thought that this was the best time for them to get involved.

Respondents were asked if they conducted fire risk assessments and if they did was there a methodology they followed. This was asked to see if there was a specific way that fire hazards were identified in the design process and then to see if that method could be made part of the proposed DSS tool.

**Table 3.1:** RIBA Work Stages
*Taken from (Royal Institute of British Architects, 2007)*

| Summary | Stage | Name |
|---|---|---|
| Preparation | A | Appraisal |
| | B | Design Brief |
| Design | C | Concept |
| | D | Design Development |
| | E | Technical Design |
| Pre-Construction | F | Production Information |
| | G | Tender Documentation |
| | H | Tender Action |
| Construction | J | Mobilisation |
| | K | Construction to Practical Completion |
| Use | L | Post Practical Completion |

The next few questions focussed more on the fire safety expert involvement in the design process. This may have been the respondents themselves, or if they did not deal with the fire safety themselves, when the fire safety expert got involved. These questions asked if life safety was the sole consideration of the fire safety design as the ADB and other building codes mainly focus on life safety - ADB states:

> *"Building Regulations are intended to ensure that a reasonable standard of life safety is provided, in case of fire. The protection of property, including the building itself, often requires additional measures and insurers will, in general, seek their own higher standards, before accepting the insurance risk." (Communities and Local Government, 2006), Page 10*

This question was asked to be able to determine what other factors were considered in the building's design phase. From personal experience, it was expected to find that cost would be one of these instances as normally the main reason for hiring a fire engineer is to interpret building codes and advise on the use of alternative methods of meeting the building regulations that will reduce project costs and allow architects greater flexibility in the design of the proposed building. Therefore, the respondents were also asked if they thought that the cost of the project would be affected by the stage of the involvement of the fire safety expert be that a cost increase if employed to late or a cost reduction from early entry into the project to avoid late fire safety errors in the design.

Finally for this section, the respondents were queried on the nature of code compliance in the building designs. In fire engineering, code compliance means following the Building Regulations (through the recommendations of ADB or following an alternative solution such as BS 9999) to meet the requirements. A non code compliant building will use fire engineering and be based on first principles of fire science (or could be using BS 7974 which essentially sets out the guidelines for a fire engineered solution, such as the use of qualitative design reviews and probabilistic risk assessments). If a building is code compliant, the UK Building Control services will likely have very little problem with approving the design with just the information in the design, as the design has followed a prescriptive approach. However, if it contains areas of non code compliance, then it is up to the fire engineer to prove that this design is safe, through the use of calculations, fire science and computational models. The questions were designed to see how the fire safety experts worked - did they use the fire regulations to design the majority of the building and use fire engineering to prove safety in the areas where the architects didn't want to use code compliance (such as in the width of staircases or ceiling heights) and if this was the case, how did the fire safety experts validate or verify these designs to prove to the Building Control officers that the design they were proposing was safe.

The final questions within this section considered the knowledge of fire safety within the Building Control authorities and Approved Inspectors. Building Control or Approved Inspector approvals are needed before any design can begin construction. Therefore getting the approvals on the approving authority is the final step in the design process for the fire engineering design. A delay in the approvals process, from rejections and delays by the approval authorities can introduce additional costs onto a project. Approving authorities may feel that they don't have the fire safety expertise to accurately judge the safety levels of a proposed design and may gather a second opinion from another fire safety expert or ask for my specific evidence that a design is safe, perhaps by asking for Computational Fluid Dynamics (CFD) models to be run. Alternatively, it might be possible for an inexperience control officer to pass off the fire safety design as safe, even if the design is flawed in some way. Therefore these questions were aimed at investigating if respondents felt that the approving bodies had sufficient experience with fire safety and would reject bad designs and allow safe designs to be accepted within a reasonable time frame, preventing additional costs and delays.

#### 3.4.2.2 Cost

The cost section of the questionnaire was designed to get the respondents views on the costs of fire protection and how these were considered during the design process, if they were considered at all.

The first questions asked the respondents if cost was the most critical design factor or if they considered the costs of the protection measures that were specified. This was to see how important the role of cost was to the respondents and to see if changing the protection system for an alternative fire protection system would be considered depending on the cost. If the costs of the fire protection systems were not considered, then a cost tool would be counter-productive.

The last group of questions asked more about the types of systems installed and if the respondents would change their decision on the fire engineering if it was easier to find out the cost effectiveness of the solutions that were being proposed in the design process. Installing protection measures over and above that required by the building codes is a method of potentially reducing insurance premiums (RISCAuthority, 2008) and preventing as much damage (providing cost savings) so the respondents were asked if additional protection measures would be considered for installation - either extra passive fire protection or the addition of sprinklers.

#### 3.4.2.3 Fire Protection

This section focussed on the respondents views on the fire protection methods used in the building design process and these were considered in terms of effectiveness and if they were essential - it mainly focussed on passive fire protection as views from industry journals were that passive fire protection levels and effectiveness is suffering due to focus on active measures like sprinklers and other systems (Parlor, 2009, Rowan, 2010) and it would prove beneficial to see if this was the same view across the AEC industry.

The first questions asked if fire engineering solutions considered redundancy and inherent safety. This was to discover if the fire safety of a building would be reliant on a single system - it was assumed that this would not be the case (unless the system failed to safe) as failure of this single system could endanger the building occupants, however, making sure that this was not the case would allow the tool to not focus on one system to the exclusion of others. Inherent safety was discussed in the literature review in Section 2.2.2.2. In the case of fire engineering, inherent safety in the building would be attained through the use of passive fire protection and good building design - both reliant on being considered in the initial aspects of the building design process.

By installing additional fire protection systems, engineers are allowed additional benefits in the design of a the fire safety system within a building. BS 9999 allows for greater travel distances and smaller stair and exit widths if additional management levels and Automatic Fire Detection (AFD) systems are installed. Respondents were asked if they considered this during the design process and if they would install additional fire protection systems to gain additional benefits in the design or to provide additional property protection.

Finally, respondents were asked about passive fire protection and how effective and essential they thought it was within the fire protection role. Passive fire protection works by preventing fire spread from one area of the building to another by forming a barrier to fire and smoke. This prevention of fire spread will result in a lower damage to the property. ADB and BS 9999 both specify minimum requirements for passive fire protection levels, dependent on the use, as does regional design rules, such as Section 20 of the London Building Acts (Amendments) Act 1939 (UK Government, 1939). Respondents were asked if they thought these measures were essential to the protection of a building. However, as pointed out earlier in this work, there are concerns on the effectiveness of passive fire protection (Parlor, 2009, Rowan, 2010) as to be effective in preventing fire spread, the protection has to form a complete barrier to fire products and be 100 percent resistant. If the barrier isn't complete, through installation errors, poor workmanship or incorrect fire rated materials used, then the passive protection may not work for as long as specified or as intended, which may mean the fire spreads far more quickly than was anticipated. This is likely to cause a larger amount of damage and potentially cause a risk to life (especially in flats, where a stay in place evacuation strategy is employed). As such, respondents were asked how effective they actually thought the installation of passive fire protection is.

#### 3.4.2.4 BS 9999

The final section of the questionnaire investigated the use of the British Standard 9999, which replaced the old British Standard 5588 for use of fire engineering of buildings in the UK. This new standard was introduced in 2008 and was different to BS 5588 in that the occupancy type and management level of the building are taken into account at the design stage and therefore the risk profile of the design is known and the building fire safety design tailored for the purpose of the final occupancy. This had never been done in the past within the regulations. BS 9999 also considers the fire safety management of the building as well and allows extra benefits in the design in recognition of better management levels being specified. As such, it proves beneficial to see how the standard had grown since its release in terms of usage and what practitioners thought of it.

Respondents were asked if BS 9999 was used more than other design standards and if it had changed their methods of working - as the code included extra considerations of the risk of the building and the management levels, it was expected that extra steps might have to be included into the work flow of AEC practitioners.

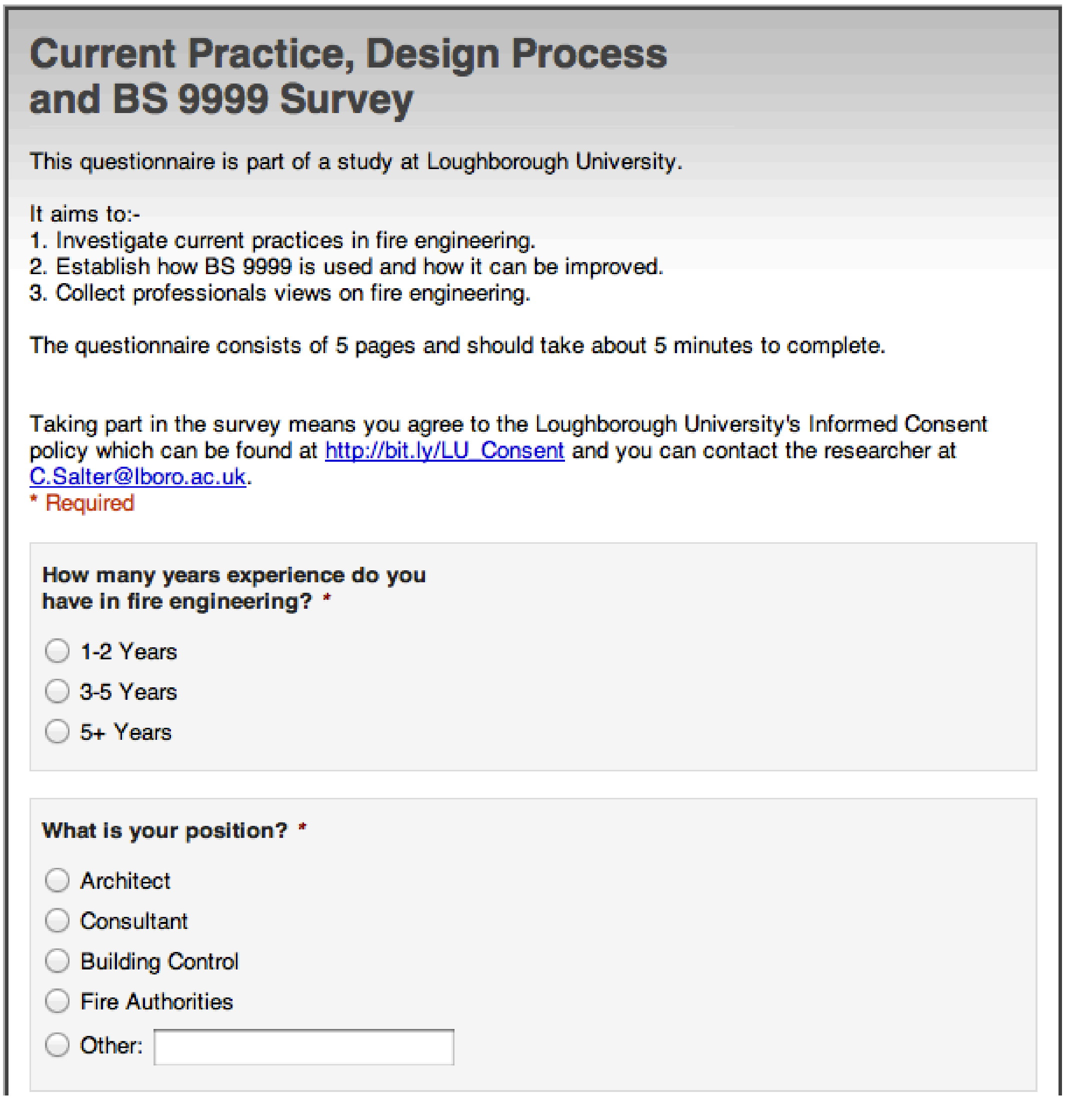
A complaint of BS 9999 was that it was too complicated and would potentially reduce the scope for fire safety engineering (Hedges, 2009). This section of the questionnaire was aimed at seeing if that was the case in the AEC industry as a whole or if the feeling was localised to specific areas of fire safety engineering or individuals and therefore respondents were asked if they thought BS 9999 was to complicated. They were also asked if BS 9999 affected the design time of the fire safety design over previous fire safety codes. If the design time was affected, it could be seen if the code was more or less complicated than previous codes as a more complicated code would be assumed to take longer to use than one not as complicated.

As mentioned above, BS 9999 allows for some design decisions to be based on the building management levels specified in the building. By allowing a more intensive management regime and safety level, the building can have less fire protection and different size fire exits and exit widths. However, this is a decision that must be taken at the design stage so that the fire design can reflect the management level chosen. However, whilst the fire safety expert may set out the benefits of the extra management level, it wasn't clear if they had to set out the actual management plan themselves. Therefore by asking the respondents who provided these plans, it would be possible to see how well this was considered at the design phase. Finally, in 2008, the Regulatory Reform (Fire Safety) Order (RRO) was introduced which meant that management of the fire safety of the building was the responsibility of a responsible person within the organisation using the building and therefore the onus of responsibility shifting from the UK Fire and Rescue Service (FRS) to the companies occupying and using the building on a day to day basis. By specifying the management levels in the design stage of the building, this could potentially help the final occupiers comply with the RRO and therefore respondents were asked if they thought that this would be the case.

### 3.4.3 Questionnaire Distribution

The questionnaire was initially designed to be completed by just fire engineering consultants within engineering firms. However after the pilot study, it was found that the number of fire engineers within the UK was small (The Institute of Fire Engineers stated in a meeting at Loughborough University on the $18^{the}$ February 2011 that they only had 230 chartered fire engineers internationally, with only about 50 percent of those being in the UK) and with the average response rate of a questionnaire, the numbers of completed questionnaires from engineers would be statistically insignificant. Therefore to collect more data and a representative sample of data across the whole fire engineering industry, the questionnaire was edited and sent out to architects, building control representatives and approved inspectors as well as fire engineering consultants.

After the pilot study, the questionnaire was changed to a more closed style survey, with mainly check box answers and scale questions. This would allow for an easier analysis of the completed questionnaires. This questionnaire was then designed and created in Google Documents as a form which allowed respondents to complete the questionnaire electronically without any additional paperwork. The Google Documents questionnaire form automatically saves the answers from the forms into a file on the server which be easily downloaded and read with other programs such as Microsoft Excel.


Current Practice, Design Process and BS 9999 Survey

This questionnaire is part of a study at Loughborough University.

It aims to:-
1. Investigate current practices in fire engineering.
2. Establish how BS 9999 is used and how it can be improved.
3. Collect professionals views on fire engineering.

The questionnaire consists of 5 pages and should take about 5 minutes to complete.

Taking part in the survey means you agree to the Loughborough University's Informed Consent policy which can be found at http://bit.ly/LU_Consent and you can contact the researcher at C.Salter@lboro.ac.uk.
* Required

How many years experience do you have in fire engineering? *

- 1-2 Years
- 3-5 Years
- 5+ Years

What is your position? *

- Architect
- Consultant
- Building Control
- Fire Authorities
- Other:

**Figure 3.2:** Google Documents Webform

A version of the questionnaire was also created in Microsoft Word and sent out via email. This file was protected by a password and would therefore, only allow the respondents to reply by ticking the check boxes and writing in the given text areas. This was made as this would allow the form to be printed as well should a respondent feel that they would prefer to complete the questionnaire on paper. The Word questionnaire contained exactly the same questions as the online version and was distributed with the Loughborough University informed consent form. The Word questionnaire can be viewed in full in Appendix A.

Questionnaires were sent to the local building authorities where it was expected that the building work present would encompass the use of BS 9999. The control authorities in the UK's larger cities were assumed to be in the areas where larger and less code compliant designs using BS 9999 would be employed. Building control offices were initially contacted to see if they would be able to fill in a questionnaire and once they responded, a questionnaire was sent out. The full list of who received the questionnaire and the outcome is shown in Table 3.2. A "no reply" means that the initial request for the questionnaire was left unanswered. In the case of London Building Control, they felt they weren't in a position to answer the questionnaire. Birmingham and Leeds replied that they felt they could answer the questionnaire and one was sent to both offices. However, even after chasing up of the replies, neither managed to return the questionnaire.

**Table 3.2:** Outcomes of Emails to Building Control

| **Building Control Authority** | **Outcome of Contact** |
|---|---|
| Birmingham | Questionnaire Sent - No reply |
| City of London | No reply |
| Leeds | Questionnaire Sent - No reply |
| Leicester | Returned Completed |
| London Building Control | Replied - Unable to answer |
| Manchester | No reply |
| Nottingham | No reply |

The architects that were contacted for the questionnaire were chosen due to the large size of the firms in question. This list had already been compiled by Loughborough University from architect offices that had expressed an interest in helping research undertaken by the university. It was assumed that these larger firms would have had a greater amount of experience with larger projects where fire engineering solutions would be more widely used. It was also assumed that the response rate would be better as there are more architects in these companies and thus multiple architects within the same firm could reply.

**Table 3.3:** Outcomes of Emails to Architect Firms

| Company | Outcome of Contact |
|---|---|
| ADP | Initial Email |
| Aedas | Uncontactable |
| Assael Architecture | Initial Email |
| Aukett Fitzroy Robinson | Initial Email |
| Austin-Smith:Lord | Initial Email |
| Barton Willmore | Initial Email |
| BLS (Hamiltons) | Initial Email |
| Bond Bryan Architects | Initial Email |
| BPTW Partnership | Returned |
| Broadway Malyan | Initial Email |
| Building Design Partnership Ltd | Returned |
| Carey Jones | Initial Email |
| Chetwoods | Initial Email |
| Cooper Cromar | Initial Email |
| David Wilson Partnership | Questionnaire Sent |
| DLA Architecture | Initial Email |
| DLG Architects | Initial Email |
| Donald Insall Associates | Initial Email |
| EPR Architects | Questionnaire Sent |
| Eric Parry Architects | Initial Email |
| ESA | Initial Email |
| EWA Architects | Initial Email |
| Feilden and Mawon | Initial Email |
| Fellden Clegg Bradley Studios | Initial Email |
| Fletcher Priest Architects | Initial Email |
| Foster and Partners | Initial Email |
| GHM Group | Initial Email |
| Glenn Howells | Initial Email |
| Hadfield Cawkwell Davidson | Initial Email |
| Haskoll | Returned |
| Hawkins/Brown | Initial Email |
| HKR Architects | Initial Email |
| HLM Architects | Initial Email |
| HOK | Initial Email |
| Holder Mathias Architects | Initial Email |

**Table 3.3:** Outcomes of Emails to Architect Firms

| Company | Outcome of Contact |
|---|---|
| Holmes Partnership | Initial Email |
| Hopkins | Initial Email |
| HTA | Initial Email |
| Hunter and Ptnrs | Initial Email |
| Ian Simpson Architects | Initial Email |
| John McAlsan and Ptnrs | Initial Email |
| John Thomspon and Ptnrs | Initial Email |
| Justico and Whiles | Initial Email |
| Levitt Bernstein Associates | Initial Email |
| Llewellyn Davies Yeang | Initial Email |
| MAKE | Returned |
| Michael Laird Architects | Initial Email |
| NBBJ | Initial Email |
| Pascall and Watson Architects | Initial Email |
| Paul Davis and Partners | Initial Email |
| Penoyre and Prasad | Initial Email |
| Pick Everard | Initial Email |
| PTE Architects | Initial Email |
| Powell Dobson | Initial Email |
| Pozzoni | Initial Email |
| PRP Architects | Returned |
| RH Partnership Architects | Replied - Cant help |
| RHWL Architects | Initial Email |
| Roger Stirk Harbour and Ptnrs | Initial Email |
| Rolfe Judd | Initial Email |
| SHCA | Questionnaire Sent |
| Sidell Gibson | Initial Email |
| SOM | Initial Email |
| Stephen George and Ptnrs | Initial Email |
| Stock Woolstencroft | Initial Email |
| Stride Treglown | Initial Email |
| Taylor Young | Initial Email |
| Wilkinson Eyre Architects | Initial Email |

68 different architect companies were contacted as part of the questionnaire. The major-

ity didn't return the email, whilst a small minority replied stating that they were unable to help. In one case, the email sent was undeliverable and contact couldn't be made with the company.

With the fire engineering consultants, questionnaires were sent to various firms. The fire engineering consultants used in both the interview and questionnaire were chosen as they advertised publicly via literature and websites that they undertook fire engineering work. From the writers experience, some engineering firms do not advertise fire engineering consultancy to the public and keep the consultancy "in house". Therefore this made it slightly harder to find consultants to answer the questionnaire.

**Table 3.4:** Outcomes of Emails to Fire Engineering Consultants

| Fire Consultant | Outcome of Contact |
|---|---|
| Arup | Returned |
| BRE | Returned |
| Buro Happold | Returned |
| Hoare Lea | No reply |
| Jeremy Gardner Associates | Returned |
| Trenton Fire | No reply |
| WSP | No reply |

These consultants were asked to give the questionnaire to as many engineers within the company as possible, however, all of the companies only returned one questionnaire each.

As well as the email distribution method and the online survey, the questionnaire was also distributed to all delegates at the First Integrated Risk Management Planning Conference at Loughborough University on 14$^{th}$ April 2010. This conference was attended by delegates from various FRS's, insurance companies and fire engineering consultants. All delegates received the questionnaire in the delegate pack, along with a stamped, addressed envelope to return the questionnaire if they didn't get a chance to fill it in during the conference itself. Sixty six delegates attended the conference.

The last distribution method was by placing the questionnaire in an FPA email newsletter - a link to the online version of the questionnaire was sent out in this email to all FPA members. It is unclear the potential audience of this newsletter as the FPA did not share the size of the distribution list. The target audience of the FPA email is varied with members being in a multitude of different areas relating to fire, such as fire safety management, fire safety officers in the FRS and fire safety consultants, as well as FPA members that are responsible for fire safety as part of the RRO.

### 3.4.4 Interviews

With the poor response rate from the questionnaire, more in depth detail needed to be gained. From reading the responses, it became apparent that the fire design consultants were the ones who were the main point of contact for dealing with fire safety engineering issues and therefore the decision was made to conduct in depth interviews with fire engineering consultants.

The interviews followed a structured approach, basing the questions on the same questions in the questionnaire sent to members. This meant that answers given in the interviews could be compared to those given in the questionnaires by other respondents. However, the benefit of the interviews is that answers could be elaborated on, rather than just the multiple choice answers in the questionnaire. This would mean that extra clarification of points and extra explanation could be gained on how the fire engineers work. By basing the interview on the already sent out fire safety questionnaire, it meant that the answers to these interviews could be used alongside the questionnaire results for more in depth analysis.

The interview candidates were chosen by contacting the fire engineering firms mentioned in Table 3.4. These consultancies were contacted and asked if any engineers would be available for an interview and a time and date were arranged. In addition to the consultancies above, interviews were conducted with two consultants that were not involved in a large organisation and were involved in smaller consultancies. These were found by speaking to the other consultants and approached to see if they wished to be involved in the interview stage.

Once the interview was setup, the interviews were conducted at a place of the choosing of the interview candidates. The interviews were recorded and transcripts made of the interview process. These were later used in the analysis of the data.

Interviews were anonymised to protect the identity of the respondents, in the same way that the questionnaires were returned in an anonymous form so that individual respondents could not be identified in the research.

Six interviews were carried out, all with consultants. One interview consisted of two interviewees so a total of seven different consultants were interviewed as part of this data collection process. One consultant was an independent consultant, whilst the others worked for an engineering consultancy firm. All six consultants had not previously seen the questionnaire and had not previously completed it, therefore the responses they gave would mean that the results from these interviews and questionnaires would not be influenced by the same person more than once, which considering the small number of respondents, would have potentially heavily weighted the results.

## 3.5 Data

Previous methods of data analysis were covered in Section 2.3 in this chapter. This section details the methodology undertaken in using the statistical data to create a DSS tool and it's methodology. The DSS tool can be seen to be split into three parts - estimating the potential damage from a fire, estimating the costs of the fire and estimating the costs saved by installing additional fire protection methods. These parts are covered below.

### 3.5.1 Fire Damage

This section details the different datasets that were made available for use by the project.

#### 3.5.1.1 FDR 1/Government Incident Records

The FDR 1 data was provided by CLG and is the result of filling in (paper) FDR 1 forms by the FRS at every fire incident attended. The data covered by the given dataset dates from 1998 until 2008, where it was replaced by the new, computerised Incident Reporting System (IRS). These records were collected by each individual FRS and were stored locally until sent to CLG who would then computerise and collate the results.

These forms are completed by the ranking fire officer at each attendance of the fire brigade and are completed for all call outs that involved an incident, separate forms are completed for FRS attendance at false alarms. The forms record various details about the fire, such as if the fire was in a building or vehicle, what occupancy the building was, the estimated damaged area, whether first aid fire fighting and extinction systems operated and other statistics for later analysis. The data from the FDR 1 forms are then used to inform UK Government policy and to help identify areas that the FRS could improve, both in proactive and reactive measures as the statistics will show the most likely causes of fire and the most likely place where a building occupant is likely to suffer an injury or fatality.

The statistics collected from the FDR 1 forms are the basis of the fire statistics published each year by the CLG. The latest statistics released to the public are for 2011 (Department for Communities and Local Government, 2011a) using the FDR 1 data. However, later years will now use the data collected by the new IRS data collection process which is similar to the FDR 1 form but is collected by the FRS in an electronic format (rather than paper and then computerising it) and contains a few extra questions such as damage on attendance to the fire (to be used alongside damage when the fire is extinguished) to allow for more statistical analysis to be carried out.

**3.5.1.1.1 Sampling** The dataset that that this work has access to does not contain all the FDR 1 records or all of the data collected in the FDR 1 forms. Some was restricted under the data protection act in the UK and not all the data was entered into the electronic database when collated by the Government statisticians. A sampling system meant that only some data was inserted into the electronic database kept by CLG. This sampling varied year by year. All incidents that contained a fatality or injury to an occupant or fire fighter was kept and then the rest of incidents were then sampled and entered into the database. Table 3.5 shows the sampling rates used in the FDR 1 data set over the past decade.

**Table 3.5:** FDR 1 Sampling Rates

| Year | Sampling (%) |
|---|---|
| 1994 | 10 |
| 1995 | 40 |
| 1996 - 2004 | 20 |
| 2005 | 100 |
| 2006 - 2008 | 20 |

This sampling method would allow an estimate of the full results to be calculated, however, a weighting factor is also applied to the results. This weight value is the aggregate weighted value of the total number of fires in the FRS area. This weighting was carried out according to Equation 3.1.

$$\text{Weight} = \frac{\text{Non Sampled Returns} + \text{Sampled Returns}}{\text{Sampled Returns}} \tag{3.1}$$

Based on this equation and the weighted returns, it should be possible to calculate the full number of records for each year. The full explanation of the sampling method can be found in the published fire statistics from CLG. The most recent publication has the method on page 65 (Department for Communities and Local Government, 2010). This explanation is the same in previous years publications, as the sampling method has not changed and the new IRS dataset is not used in the latest statistical analysis (the statistics are published 2 years after the year in question). However, even with discussion with CLG statisticians, the guide in the fire statistics publications and the weighting formula, the method of calculating the full dataset from the weighted, sampled values remained unclear and the decision was made to make calculations *only based on 2005 data* due to the fact the data for 2005 is represented in complete fullness (no samples were taken, all data was entered into the FDR 1 database and all weighting values are 1). This would allow for the most accurate statistical analysis. However, it is understood that differences in the years data in comparison to other years could mean that the data is skewed and might potentially cause volatile results, something that was considered whilst analysing the FDR 1 data for the Fire Service Emergency Cover (FSEC) toolkit (Greenstreet Berman Ltd, 2010).

This decision does mean that the number of incidents available to investigate is lowered, however the incidents can be analysed, confident that the results are as accurate as entered by the original FRS as no further errors have been introduced by sampling errors. Yet it should still be considered that data errors could be possible from the original entry by the attending FRS. However, there is currently no data on the accuracy of the stored data and in this research, it will be taken as accurate. This is due to the fact that this is the only large dataset of it's kind in the UK and no alternatives are available. Should a more accurate database be kept (which is the reasoning behind the introduction of the IRS data collection form replacing the FDR 1 forms), then the methodology behind the analysis of this data should allow for more accurate results from more accurate data.

**3.5.1.1.2 Filtering** The FDR 1 dataset also contains data on all fires in the UK that the FRS attended. This means that records in the dataset contain information on fires in residential properties, vehicles and outdoor fires, amongst the commercial and public buildings that this PhD is focussed on. Therefore the FDR 1 data needed to be filtered so that only the building occupancies that are being studied remained in the dataset. This was achieved through filtering the FDR 1 data according to its TOP codes (TOP codes correspond to the incidents building occupancy), which are described in the document published by the Home Office to accompany the FDR 1 form (Home Office Research, Development & Statistics Directorate, 1998). All data in the FDR 1 dataset has been coded according to the values in this guide so it is essential for deciphering the FDR 1 dataset.

Because this study is not concerned with vehicle fires or fires in residential properties, the FDR 1 data was filtered to remove the unwanted data records. The TOP codes that apply to this study are shown in the appendix, Table B.2 on page 211. These codes were separated from the data using a Windows Batch script, making use of the open source software, Awk and Sed. These utilities are used to manipulate text data and allow the FDR 1 dataset to be easily split up according to rules without having to launch SPSS or Excel. This was of benefit because the original dataset is a 179MB Comma Separated Value (CSV) file that would crash both SPSS and Excel on importing, due to the file size.

This original dataset contained approximately 1 million records and was split down into separate files only containing the filtered buildings. The buildings that were only considered for this research are shown in Appendix B , Table B.2. The batch file script can be found in the appendix on page 224. It should be noted that to run awk and sed on Windows, the programs need to be downloaded and installed - they are not on the system by default, unlike Mac OSX or Linux.

Further filtering was then done to the data to get just the 2005 data. This was done within Excel as the dataset was reduced to a more manageable size at this point. This left the fire incidents in 2005 that were the buildings that we were concerned with - leaving 35,250 records out of the initial 978,494 records in the complete dataset. These records then formed the basis of the statistical analysis.

The main variable being investigated within the dataset is the damage variable. The FDR 1 records contains two different damage variables, which are AREABURN, the area damaged by burning and AREATOT, the total area damaged by fire, smoke, water and fire fighting actions. After some initial investigating, it was found that the AREATOT variable had more records with this variable recorded - records with the AREABURN variable recorded were a very small percentage of the dataset. As such, it was decided that the AREATOT variable should be used in the statistical calculations as it would allow more records to be considered than if the AREABURN variable was used. It can be argued that this research should be investigating the damage burnt in a fire, however considering the buildings under investigation in this work (commercial and public buildings), it is the assumption that these buildings will require *all* damage to the property to be fixed before the building can fully reopened again and therefore the AREATOT variable is in fact the better value to use for calculating the damage to property. For that reason, the statistical analysis will use AREATOT as the value for damage.

#### 3.5.1.2 Fire Protection Association/Insurance Dataset

The FPA data is a collection of fire incident records, collected by loss adjusters visiting the scene of a fire and submitted to an insurance company. This is then submitted to the Fire Protection Association for collating and statistical use. This database mainly consists of commercial, public and heritage data, though it does include some instances of residential properties where the fires meet the criteria for entry into the dataset.

Like the FDR 1 forms, the FPA dataset is used for statistical analysis and informing policy decisions. However, as the data is collected by the insurance industry and is for use by the insurance industry, the questions it asks are different to the FDR 1 but with a few similarities. In the FPA data, the questions in the form are designed to find out about the costs of the fire damage. The cost is measured for the building, the contents, the business interruption and other - this is then totalled to give a value for the true cost of the fire. Another section details the buildings construction in a very basic sense. The insurance industry are concerned with different types of new building methods and want to investigate if these pose a large risk than other properties so the form asks if the building was of a timber frame construction, SIPs, light steel frame, volumetric building materials or hybrid. These are under the group of modern methods of construction. It shares the same basic questions as the FDR 1 form such as occupancy type, area damaged, how the fire started as well as the address and location of the fire (withheld from Loughborough University for Data Protection reasons).

**3.5.1.2.1 Sampling** The data made available for this project was provided "as is", meaning that a live snapshot was taken of the database (as it is continually being updated) and made available for analysis. The only changes to the data was the removal of all information that could have potentially identified an insurer, an incident or a claimant. Data was not sampled or changed in anyway and the data was provided as a raw data dump. The FPA data collected by loss adjustor's was provided to the project as Microsoft Excel file, which allowed import into SPSS and work to be carried out in Excel itself. However, it was also saved as a CSV file to allow the data to be manipulated by awk and sed again should it be required.

The FPA does not collate all records into the dataset it keeps however. It only takes records that meet certain criteria. These are incidents that meet any of the following criteria:

- Material damage for all interested parties estimated at £100,000 or more *and/or*
- Business interruption damage estimated at £100,000 or more *and/or*
- A fatality *and/or*
- Sprinkler actuation occurred *and/or*
- Where the combined figure for material damage and business interruption is expected to exceed £100,000

This list is taken from the FPA incident loss report form which is used to report the data to the FPA. These limitations in the dataset mean that the data within the set are not fully representative of fires across the UK and the data would have to be analysed bearing this in mind. For example, having access to only large fires means that potentially smaller, less damaging fires are not included in the dataset which could potentially skew the results gathered from this dataset. Not all small fires are excluded - on initial viewing, there are numerous 'small' fires in the dataset (under $5m^2$) but which still met the criteria above.

**3.5.1.2.2 Filtering** In comparison to the FDR 1 data, the FPA database is much smaller. Initially the dataset contained 963 incident records. On analysing the data further, it was found that the database contained both data on fire and explosions - these were in the database as the source of the incident. The cause of the incident was not mutually exclusive in the database and therefore some records were recorded as having started by fire and also an explosion. For this research, only the incidents caused by fires are of concern and so the incidents that were caused by an explosion were removed. The ones with both an explosion and fire recorded were also removed - this is because in the authors view, fires either start and then lead to or cause an explosion or an explosion happens and a fire is a by-product of the explosion. Therefore the incident cannot start with both - it would have started with one and then progressed to the other. However, which incident happened first is unclear in the data and therefore these records were removed to prevent them from skewing the analysis.

As described above, the research focuses on commercial and public buildings and does not include residential occupancies. As such, the records in the FPA dataset that occurred in residential occupancies are removed.

Unlike the FDR 1 data, the FPA data contains cost estimates for each incident. This will allow cost estimates of damage to be considered in the analysis section. These cost figures are estimates, based on the loss adjustor's experience and judgement. This means that the data submitted by each loss adjustor's is likely to differ in the cost estimates. However, as the database continues to grow and get updated and individual cases approach the conclusion, the actual cost of fires will be submitted into the database and thus would give more accurate results. The FPA give no information on how these estimates are calculated. The methods are left up to the individual insurance companies and loss adjustor's.

#### 3.5.1.3 Statistical Analysis

To use the two datasets as an evidence base for the model, statistical analysis will be performed on the datasets. The main statistics base will come from the FDR 1 database as it offers a much larger sample of data than the FPA dataset because the data was collected at every fire the UK FRS attended, rather than limiting the collection of data based on criteria such as cost or area damaged. The FDR 1 data however, will only use data for the year 2005 and even with restricting the analysis to only this year's worth of data, will provide more records to analyse than the database of the FPA (which only contains data since the database was started and therefore only contains about one years worth of data as well).

Based on previous research discussed in Section 2.3, a multiple regression analysis is planned for the data. Initial statistical analysis of the data will be able to indicate whether or not data is significant in affecting the size of a fire. If the data appears to offer a significance, it provides an indicator that it should be present in the final multiple regression model. Data on what is assumed to significantly affect the fire size can also be collected through the questionnaire and interview collection. By using these values perceived to be biggest factors, these can be tested initially to see if this is the case. However, the other factors, that aren't identified should be investigated as well to ensure that a critical factor is not accidentally left out of the analysis.

The use of multiple regression will allow the model to identify how each independent variable, such as if an alarm activates, affects the dependent variable, which in this study is the area damaged by the fire and it's associated products. By inputting the factors into the multiple regression model, this will then give an estimated fire size which will allow the cost of the fire to be calculated with data discussed in Section 3.5.2. The area damaged will then inform the cost of the fire and by comparing the results of the model by using the design fire with the same fire but with additional fire safety measures included such as the addition of a sprinkler system or additional fire resistance for passive fire protection measures, a cost comparison can be created between the initial fire and the more protected model. This will allow the additional protection measures to show how they affected the fire and therefore what money can be saved through the addition of a higher up front cost in fire protection measures.

### 3.5.2 Fire Costs

The aim of this work is to construct a methodology for a DSS tool to be constructed using the incident data as the evidence base. Therefore, part of this requires that the cost of a fire be calculated for an incident in a building, should one occur. As such, a method of calculating the cost needs to be considered.

As cost is an important consideration in most aspects of the world, there are various databases of cost data that can be applied to this research. These are detailed below. Where indicated, these costs are either collected from statistics or are actually calculated from real prices.

These costing methods will allow the methodology to show cost savings between different fire protection strategies and allows a cost benefit analysis to be carried out on the different strategies, something that currently isn't easily available to fire engineers.

#### 3.5.2.1 Rateable Values

The rateable value for a property is a measure of it's rental value. This data is collected by the Valuation Office Agency, and is updated every few years. This value, if used in a calculation for the the cost of a fire, would grossly underestimate the costs of a fire because this rateable value only covers the cost of the rent of the property - no measure of the internal fittings and fixtures is taken into account. It is split into the different building occupancies and also is searchable by location within the UK regions (i.e. South West, London, East Midlands, West Midlands). This would allow the use of a location aware pricing structure to be placed within the tool.

However, as it provides only the rental values, the data cost is to low and therefore, it isn't fit to be used as a method of calculating costs in this instance. However, it could prove useful as a baseline value with the results from another cost calculation being checked against this figure and compared - if the value of the alternative calculation is below the value of the rateable value, then that result can be looked at more closely as to why it's smaller than this value. This will add a layer of validation to the tool itself.

The advantage of the rateable values are that they are freely available and have already been calculated in a cost per $m^2$ format.

#### 3.5.2.2 Average from FPA Database

The FPA data is collected from loss adjustor's. The loss adjustor's visit the scene of a fire after it has occurred and estimate a cost of the fire based on experience and send this data to the FPA. However, this database only contains data on fires where a fatality occurred or the fires was over £100,000. If this was to be used, this could lead to an overestimation of costs as all fires within the dataset will be the larger, more expensive fires.

However, it can be argued that this is a positive. The more expensive fires will tend to be the non residential fires (which is mainly the case, as shown by the database as the majority are industrial, commercial and public buildings). Yet, smaller fires in these property types will not show up in the database and would not be represented.

To calculate costs from this data, a graph of cost against area damage can be plotted - the value for a specific area damaged could be calculated by using a trend line. Reading the graph from the area damaged up-to the trend line and then read across, a value can be given of an estimated cost. This can be simplified by using the equation of the trend line to give the formula to calculate costs.

A benefit to this method is that once the data is plotted and a trend line calculated, the formula is set and does not require any more data from the FPA database to continue to function. This means that aside from possibly yearly or quarterly updates, the tool would not need to contain the FPA data and further access to the FPA data isn't required. It is even possible to attach a function to the formula to increase the costs each year in line with inflation.

The downside to this method is that the data itself is estimated by the original loss adjustor's. The costs are not verified in anyway and as the database is still young, there are a lack of finalised, finished records (the records are entered initially and then insurance proceedings occur and then the database is meant to be updated on case closure) to see if the initial estimates were correct. With no finalised records, it is impossible to see if the initial estimates are anywhere near the final estimates. Therefore it has to be assumed that the loss adjustor's are estimating the correct data and the estimates are fairly accurate.

#### 3.5.2.3 BCIS Data

The Building Cost Information Service (BCIS) is a commercial service that records the cost of new and modification costs for building design. It's database and tools are designed to allow the construction industry to accurately estimate prices of a new tender.

The data is collected from AEC firms after construction is complete and is split into various values, the most important one for this research being the cost per m$^2$. The data within the database is split quite extensively into different categories under building occupancies. For example see Table 3.6, taken from the BCIS tool which shows the sort of detail the database can go into.
As can be seen, this splitting of data does allow very precise measurements if needed for specific uses, however, splitting the data across these categories mean that some of the buildings do not have enough costs associated with them to make it possible to statistically analyse them or rely on the data they provide. For example, some categories have only 1 data entry and therefore the average is the cost of that single project.

It should be noted that, ideally, a subscription to BCIS would be needed to update the values in the proposed fire safety tool as the values are only available to BCIS members. Therefore to get the most up to data costs, a subscription to the service would be required. Using this dataset alongside other, such as the values in the FPA dataset can provide a validation step.

**Table 3.6:** School Data
*Taken from (BCIS Database)*

| BCIS Reference Number | Category |
|---|---|
| 710 | Schools |
| 711 | Nursery schools/creches |
| 712 | Primary schools |
| 712.1 | Middle schools |
| 712.12 | Primary/middle schools - specialised teaching blocks |
| 712.8 | Primary Schools - mixed facilities |
| 713 | Secondary schools (high schools) |
| 713.1 | Secondary schools - specialised teaching blocks |
| 713.8 | Secondary Schools - mixed facilities |
| 714 | Sixth form/tertiary colleges |
| 714.1 | Sixth form specialised teaching blocks |
| 714.8 | Sixth form - mixed facilities |

#### 3.5.2.4 Xactimate Software

Xactimate is a piece of software developed by Xactware, aimed at the insurance market. Of all the methods described here for calculating costs, Xactware is able to provide the most accurate cost estimates.

Xactimate is a full software suite designed to facilitate insurance claims from property owners. Input into the tool is done by loss adjustor's and insurance companies and is deigned to be used throughout the claim process.

The software gathers it's costs from data collected by the Xactware company which is updated quarterly. These price lists are taken from manufacturers and can also include labour prices - further more, the data can be split into local regions within the UK, allowing very accurate cost estimations of an incident to a property. The tool itself allows a sketch of the building to be created along with the building materials of each item (the cost can be detailed down to the price of screws if required) and this is then priced up and a report issued.

However, whilst incredibly accurate, it's use in this research is limited. As this tool is looking at estimating a cost for damage done to a building already in a fire, the tool is aimed at creating a cost estimate for that individual building and getting data from the program for a estimate of a fire for a wide range of buildings will prove to be difficult.

It is possible to create an estimate of a cost of a new build for various size buildings and

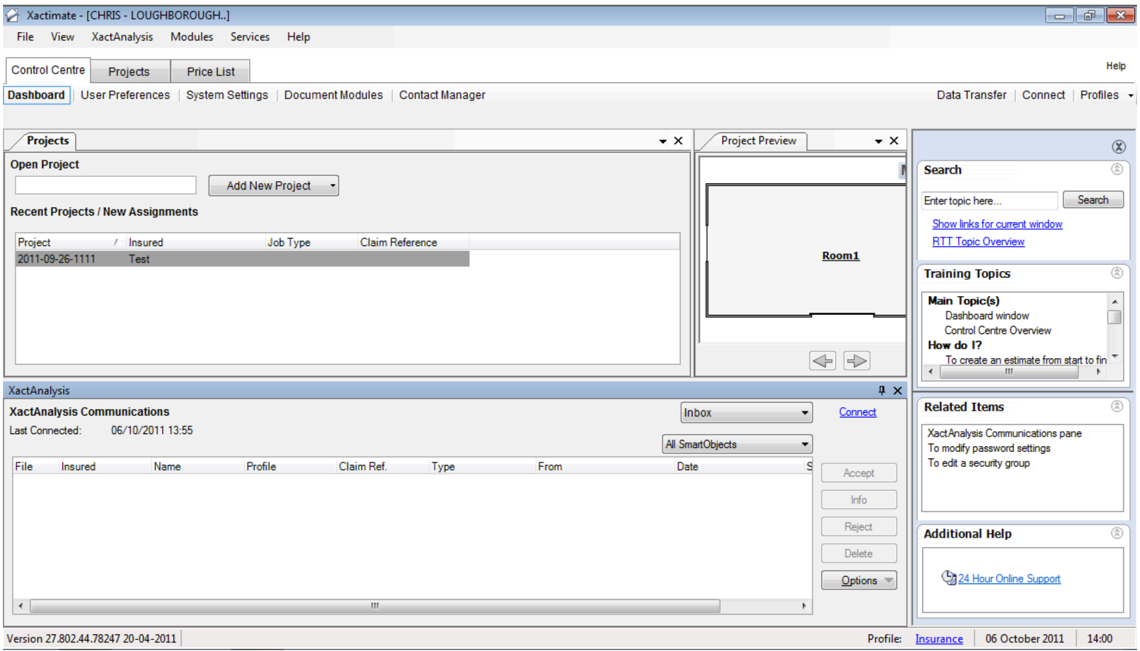


Figure 3.3: Xactimate Main Page

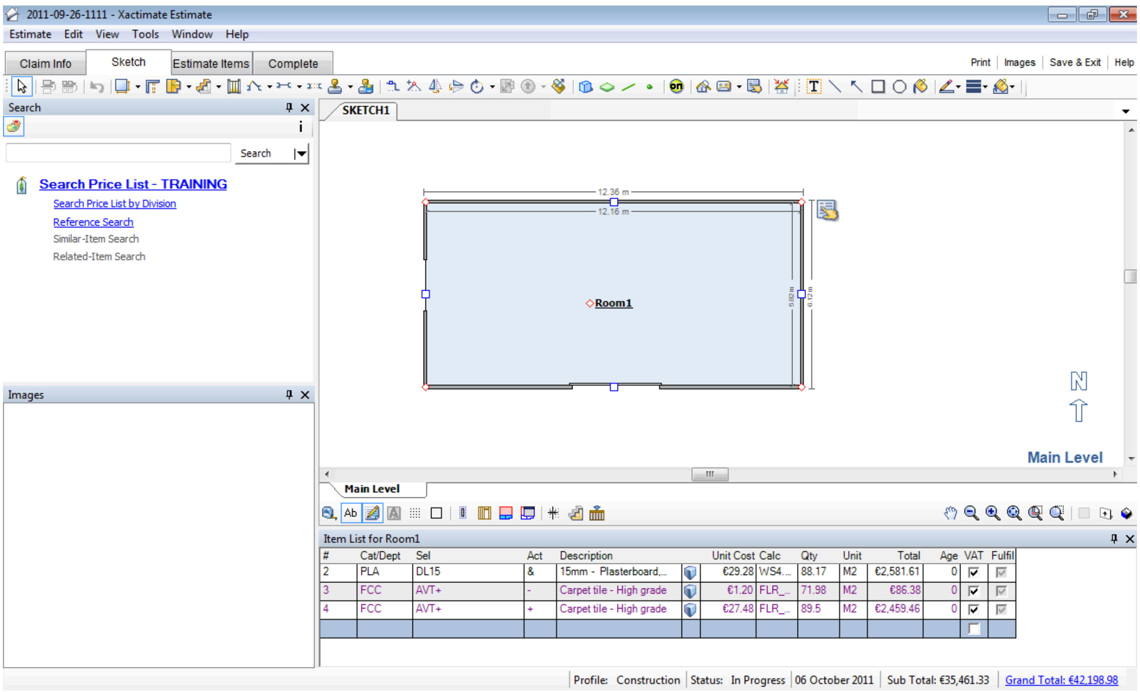


Figure 3.4: Xactimate Sketch Screen

then plot these on a graph to get a trend of cost increase in as size of building increases, however the construction of the building will play a large part in the costs of the building and therefore any building not matching the construction of the building used in the estimation will have a different estimate of the cost. Therefore, even though Xactimate is the most accurate tool here to predict costs, as it's focus is on individual buildings, it's use it severely limited in this research.

As commercial software, Xactware charge a fee for the use of it's software and updates - therefore changes to the costs would not be reflected in the tool if these updates are not purchased.

### 3.5.3 Additional Fire Protection

The aim of the DSS tool is to help fire safety designers consider the costs of the fire safety systems that they're implementing and suggesting for design codes. Therefore by adding the costs of extra protection measures into the DSS tool allows them to easily compare how the extra protection measures will affect the costs to the final outcome.
For calculating the costs of the extra protection, there are a few options that can be considered. This section details how these costs can be calculated and added to the system.

#### 3.5.3.1 Spon's Price Book

Spon's price books are a guide aimed at the AEC industry to estimate the costs of design and construction. These costs are calculated using tender prices in the UK by Davis Langdon and are updated every year, the current version being the 2012 edition (Davis Langdon, 2012). Prices are provided as a cost per m$^2$ value which allows for easy use when the area damaged in a fire is considered in the DSS tool.

These costs offer incredibly detailed breakdowns in the cost, similar to that of the Xactimate software, however, the guide is not a computer program and only offers the data in the form of a database in book form. As it offers the costs of the building materials, it can prove to be of limited use in this research as the exact building materials of the property would be required to be known and this data is not available, except the very basic information provided by the FPA dataset which would not be enough to consider using this database for the costs of the fire as it is not made clear in the FPA dataset what exactly was damaged, only that the property structure was constructed with one of the building materials of interest to the insurance industry.

However, whilst the cost database isn't suitable for the calculation of cost of damage to a building property, it can provide useful information on costs for a cost benefit analysis.

It provides the estimated costs of a sprinkler installation during the construction phase of a property (retroactively fitting a sprinkler system is can potentially be more expensive than fitting one in at the construction phase (British Automatic Fire Sprinkler Association, 2012)) which can be used in the cost tool to decide if a sprinkler system will save money.

The costs of the sprinkler system installation is shown in Table 3.7.

**Table 3.7:** Sprinkler Installation Costs
*Taken from (Davis Langdon, 2012), Pg 189*

| Sprinkler Installation | Range £ | |
|---|---|---|
| landlords areas; supply to shop shells; including fire alarms; appliances etc. | 9.50 | 12.30 |
| single level sprinkler systems; alarms and smoke detectors; low hazard | 14.40 | 18.70 |
| single level sprinkler systems; alarms and smoke detectors; ordinary hazard | 13.30 | 17.30 |
| double level sprinkler systems; alarms and smoke detectors; high hazard | 24.00 | 31.00 |

This data will provide the costs of a sprinkler system installed to the specification required in BS EN 12845 (BSI, 2004). The sprinkler system required for a building depends on the building occupancy type, building storage and also the insurance requirements - yet the insurance requirements are often not considered at the design stage (hence the production of ADB with insurance requirements (RISCAuthority, 2008)) and it's assumed that sprinkler systems are installed fit for purpose, maintained and risk appropriate which isn't often the case (Watkinson, 2011). Keeping this in mind, the costs for the tool cannot be represented by just one figure from this table - it should be left up to the user of the DSS tool to state which sprinkler system will be installed within the building and therefore the most applicable cost value can be applied in that scenario.

Considering the fitting and installing of the sprinkler system, it cannot be seen from the cost data in the Spon's database if the sprinkler system is installed correctly or is risk appropriate. Assuming the guidance in BS EN 12845 is followed correctly, it is assumed that the sprinkler system the DSS user inputs will be both risk appropriate and installed correctly.

Spon's guide can be used to calculate the costs of extra passive fire protection as well, however, this is slightly harder due to the different factors that make up a passive fire protection. For example, passive fire protection can include materials such as plasterboard, fire doors, intumescent paint or treatments to make materials more fire resistant. Therefore differences in the cost of these materials need to be considered in the cost calculations.

## 3.6 Summary

This chapter detailed the steps that this research project took to achieve the aims and objectives set out in Sections 1.4 and 1.5. The chapter starts with a summary of the findings of the literature review and what the gap in the research was and how this research could fill this gap. It discussed the availability of research and data to support the methodology discussed in the rest of the chapter. It then moved onto the methodology section which highlighted the methodologies that previous studies, discussed in the literature review, had used and how this research would differ from those studies. A diagram of the sequential methodology that this research followed is presented, allowing the reader to visualise how the study progressed. A positivist standpoint was taken for this research. The final sections of the chapter covered the data used within the research. This covered the data collection undertaken for this research in terms of the questionnaires and interviews carried out and who was approached and when. This then moved on to investigate the databases analysed later in Chapter 5. This covered how the FPA and FDR 1 data was collected and the issues associated with each database. Finally, the different alternative methods of calculating the cost of a fire were discussed and it was deemed that the cost estimates within the FPA or BCIS data was the best method of calculating probable costs in event of a fire.

# Chapter 4

# Questionnaire and Interview Analysis

## 4.1 Introduction

The data from the questionnaires and interviews was aimed to influence the direction of the research conducted and to decide if a cost tool would be beneficial to those in the UK Architecture, Engineering & Construction (AEC) industries. Therefore, the analysis of the results will allow an understanding of what exactly the industry is after and whether a Decision Support System (DSS) tool would be of use to the AEC industry. Once this analysis was carried out, the results would identify completed fire engineering work and who would gain the most from the use of the DSS tool and design tool methodology. This would also allow the end user to indicate whether or not the addition of a cost model to their workflow would be beneficial and would they make use of such a tool, should one exist.

## 4.2 Questionnaire

Section 3.4 detailed the method of data collection from those within the AEC industry through questionnaires and interviews and targetted those within the UK AEC industries. This section details the analysis of the data that was collected through the questionnaire and interviews as set out in Section 3.4.

Twenty two questionnaires were returned, giving a response rate of only twelve percent. Of these, six were returned from the conference held at Loughborough University in April 2010, nine were collected from direct mailing and the last seven were filled in on the on-line form - giving a response rate of nine percent from the conference and eight and half percent from the direct emailing of questionnaires. A counter installed on the website allowed the number of people visiting the site to be counted. The counter tracked twenty visits to the website and nine responses were received. The website appeared to be the most effective method of recieving responses to the questionnaire, with a response rate of forty five percent. However, it should be noted that the tracking code on the site can be fooled by repeat visitors and can be opted-out of or blocked by the browser, meaning that additional visitors might have visited the questionnaire but not completed the questionnaire indicating that the forty five percent response rate might be an optimistic value.

This response rate of twelve percent appears to be a low figure. However, it should be pointed out that the number of fire engineers in the UK is low - in a meeting at Loughborough University on 18$^{\text{th}}$ February 2011, the Institute of Fire Engineers stated that they had “about two hundred and fifty chartered fire engineers” globally, around half of that in the UK. This implies that there are only about one hundred and twenty five fire engineers in the UK and, therefore, the population available to answer the questionnaire meant that the low response rate still covers a reasonable percentage of the fire engineering population. However, some of the responses were from others within the AEC industry, such as architects. Some of these respondents did not feel they could answer the questionnaire, and in these cases, they made it clear that they did not have the experience or knowledge necessary to complete the questionnaire - it can therefore be assumed that in these instances, the questionnaire was not aimed at the right audience. Based on the responses to the questionnaire, fire engineers should have been the main target.

It should also be noted; where large fire engineering consultancies were approached, they were asked if more than one member of the engineering team could respond to the questionnaire to cover a larger selection of the UK fire engineers. However, in all cases, this did not happen and only one questionnaire was received from each company that returned a questionnaire. From experience, engineering consultancies can have ten to fifteen people in an engineering group and this therefore reduced the penetration of the questionnaire to these members of the engineering teams. However, the replies were gratefully accepted and the companies were not asked to provide additional replies as not to cause unwanted hassle to the company.

In the analysis of the questionnaires and interviews, the term fire engineers and consultants are used. In this instance, unless otherwise clearly defined, the terms are considered interchangeable. From the interviews, it was seen that fire engineers could consider themselves consultants as they worked for engineering consultancy firms. Even though they are qualified fire engineers, usually with a degree in the relevant subject area, they also fulfil the role of a consultant. Therefore, when the term consultant is used, it is assumed that the respondent can also be classed as a fire engineer.

As discussed in Section 3.4.3, the Building Control areas chosen for the questionnaire were approached because it was considered that they were involved in areas of regeneration and growth, and would have experience with the larger type of buildings that fire engineering is more commonly used in. These also happened to be in the larger cities of the UK as this is where the UK development was assumed to be. This is not to say that that smaller towns and cities do not have areas where fire engineering is used; but the experience of fire engineering in these smaller locations may not be as widespread as in the larger areas where it is considered that the main bulk of fire engineered buildings are.

The delegates attending the conference at Loughborough University were from a variety of different backgrounds relating to fire engineering, and this provided a useful opportunity to get a broader view of fire engineering. It was always assumed that the fire engineering consultancies would do the majority of work in regards to the fire engineering of the design process and therefore would be the main focus for this research. However, getting the views of others within the periphery of the fire engineering would prove beneficial in seeing if this was indeed the case.

### 4.2.1 Analysis

Analysis of the questionnaires and interviews were conducted concurrently. The interviews followed a structured interview format, using the same questions as the questionnaire. The interview responses were incorperated into the questionnaire analysis using template analysis. Template analysis takes the data from an interview or questionnaire and creates a template using the themes being developed from the data - this template is then used to analyse the rest of the data. The advantages are that the analysis method is very flexible to the addition extra themes and trends appearing in the data. As the interviews were conducted using the questionnaire as a guide, the “template” of the questionnaire is used in the analysis of the interviews.

This method was chosen because the interviews already followed the template of the questionnaire. Had the interviews been conducted separately, using different questions to those already in the questionnaire, then a different method of analysis would have been used.

Combining both the interviews and the questionnaires together give a combined record of the responses from across the different occupations that took part in the data collection. The results of this data collection formed the basis of the conference paper for the 2011 International Conference on Building Resilience held in Sri Lanka (Salter and Bouchlaghem, 2011). Drawing from the combined data allows the data to accurately reflect all the results from both the questionnaire and the interviews.

### 4.2.2 Design Process Results

According to the Royal Institute of British Architects (RIBA) Outline of Work (Royal Institute of British Architects, 2007), shown in Table 4.1, the Design Process covers the concept, design development and technical design phases of the overall design and construction of a building. This section of the questionnaire focusses on this small section of the construction cycle of the building to allow a profile to be built up on whether fire engineers get involved in a project, and at what point in the RIBA stage of work.

From PD 7974 (BSI, 2003a), it is recommended that in fire engineering solutions, a detailed assessment of the potential fire is needed to allow the building to be designed with this worst case design fire in mind. However, it is less clear whether this process occurs

**Table 4.1:** RIBA Work Stages
*Taken from (Royal Institute of British Architects, 2007)*

| Summary | Stage | Name |
|---|---|---|
| Preparation | A | Appraisal |
| | B | Design Brief |
| Design | C | Concept |
| | D | Design Development |
| | E | Technical Design |
| Pre-Construction | F | Production Information |
| | G | Tender Documentation |
| | H | Tender Action |
| Construction | J | Mobilisation |
| | K | Construction to Practical Completion |
| Use | L | Post Practical Completion |

in buildings where fire engineering is considered for the entire safety of the building; or just for areas of non code compliance. A later question attempts to find out if the fire engineers mainly use fire engineering throughout a building; or if they use fire engineering only in areas that the client does not want to, or is unable to, follow the recommendations in Approved Document B (ADB) to meet the Building Regulations for a specific reason. This type of design would be regarded as code compliant with areas of non-compliance. Understanding how the fire engineers consider the type of fire that the building is likely to suffer would help inform how the design tool should consider the fire as well - should it be possible for the fire engineers to set their own parameters for the fire or should they be able to only pick from a few set fires, possibly ones described in literature, such as the 3m x 3m 5MW fire (Morgan *et al.*, 1999)?. Understanding how the risk assessment and quantification of the design fire was carried out would allow the design tool methodology to reflect this.

From the responses, it was seen that the majority of risk assessments were carried out by the consultants that were spoken to. Seven out of the nine questionnaire respondents identified themselves as consultants and undertook risk assessments. The other two respondents identified themselves as a Building Control officer and a Head of Fire Protection and Procedure in a fire safety management company. Therefore it can be concluded that fire engineers conduct risk assessments for consideration of the design fire. When questioned on how these were undertaken, no clear response was gathered. The respondents stated that a mixture of fire engineering guidance, such as "*PAS 79 - Fire Risk Assessment: Guidance and a Recommended Methodology*" (BSI, 2007a), "*PAS 911:2007 - Fire Strategies - Guidance And Framework For Their Formulation*" (BSI, 2007b) and " *HTM 05-03:*

*Part K - Guidance on Fire Risk Assessment in Complex Healthcare Premises*" (Department of Health, 2008) were used, whilst others stated that internal methods were used. From the responses, it seemed that both approaches were used and that some respondents used both an in house method of risk assessment and the guidance from the Government.

It was hypothesised that the inclusion of the fire safety engineer could potentially affect the costs of the final project - involve them at a stage that is too early in the project and you risk paying the consultants more than the engineering costs save. Alternatively, if you involve them at a later stage, the design may have reached a point where the input of the fire engineer can have little effect on the design, or the design has progressed to a stage where costly redesigns need to be made and cause the project to exceed budget. However, were UK fire engineers being involved at a time where they could provide the optimum economic impact? To find out if this was the case, the respondents were asked when they got involved in the project and if this was the correct time for them to get involved.

By asking the main stakeholders that are affected by the fire engineering design when they typically got involved in a project and when they thought they should be involved would allow a comparison to be built up on when each stakeholder had the biggest effect on the fire engineering design and what had already been put in place before the fire engineer was appointed. This would indicate which stakeholders would need to take on board the advice of the fire engineer at the earliest possible time. At the time of the questionnaire, it was not considered that other engineering disciplines would be affected by the work of the fire engineer - after the interviews and discussions with fire engineering professionals, this is clearly not the case as other engineers, such as the mechanical and electrical engineers designs can be severely affected by the systems specified by the fire engineer.

Table 4.2 shows the RIBA stages where the respondents got involved in a project. Respondents were able to mark all the stages that they were involved in a project and the phrasing was not specifically defined to make sure that only the instance where the respondent got involved in the *majority* of designs. This is shown clearly, particularly in the case of the architects; where the three respondents clearly stated that they are involved in a design project at all stages of the RIBA Plan of Work, rather than identify at what stage they got involved at the start of a project. This included the Operations and Use of the building. It was unclear of the full involvement of the architect was in this stage as the questionnaire, as shown in Appendix A, is a simple check box questionnaire.

Table 4.3 shows when respondents thought they should get involved in a project. As can be seen, the majority of respondents felt that they got involved at the correct time. How-

**Table 4.2:** Table Showing When Respondents Get Involved In a Project

| **Job Title** | **RIBA Work Stage** | | | | |
|---|---|---|---|---|---|
| | Preparation | Design | Pre-Construction | Construction | Operation/Use |
| Fire Safety Management | 2 | 4 | 3 | 2 | 4 |
| Building Control | - | 1 | - | - | - |
| Fire and Rescue Service | - | - | - | - | - |
| Architect | 3 | 3 | 3 | 3 | 3 |
| Fire Engineer | 2 | 7 | - | - | - |

**Table 4.3:** Table Showing When Respondents Felt They Should Get Involved on a Project

| **Job Title** | **RIBA Work Stage** | | | | |
|---|---|---|---|---|---|
| | Preparation | Design | Pre-Construction | Construction | Operation/Use |
| Fire Safety Management | 2 | 2 | 3 | 2 | 3 |
| Building Control | 1 | - | - | - | - |
| Fire and Rescue Service | - | - | - | - | - |
| Architect | 2 | 2 | 1 | 1 | 1 |
| Fire Engineer | 4 | 5 | - | - | - |

ever, the Building Control respondent identified that they wished to get involved at an earlier stage of the design process. This seems that it would allow additional input from the Regulatory Body on the design of the building before the design phase of the building has actually started. However, from experience of the author, Building Control are contacted and appointed to a project, as and when they are required by the consultants or project management. Contacting them earlier would allow them a greater degree of flexibility, but does not change the fact that the consultants would probably not approach the inspector without having first conducted some work.

The fire engineers would additionally like to get involved at an earlier stage of work. Two of the respondents felt that they were involved at the Preparation stage but this doubled to four respondents who felt that this was the ideal time for the fire engineers to get involved. When questioned if they thought the stage of the fire engineers involvement would affect the final project cost, all respondents stated that yes, this would be the case - one respondent stated no but explained his answer with:

> *"in some instances, it saves money in the long run"*

This explanation conflicts with the initial answer of no and the answer was taken as a yes, it does affect costs, as in the explanation, it was clearly stated that involvement would reduce costs. This was taken as a failure of the question to discern as to whether the question implied a cost saving or extra expense, rather than it's current form that stated that the involvement would affect the final costs, the implication of the question being that the costs could be affected either way.

The main focus of fire safety designs stated is life safety according to the majority (71 percent)f respondents. This backs up the fact that the Building Regulations main (some respondents stated, it's only) purpose is for life safety. In addition, thirteen respondents (62 percent)tated that designs that they worked on also considered numerous other factors such as property protection, insurance risk and compliance and to a lesser degree, heritage concerns. The heritage concerns were from only a few respondents and were from the fire safety management rather than the fire engineers, again, providing evidence that fire engineering is mainly considered in the design stages of a new build, rather than in retrofitting an existing building. Nine of the thirteen respondents that stated that additional aspects other than life safety were considered, stated that property protection and compartmentation were very important aspects. One stated:

> *"there is an attempt to resist further building damage therefore providing an economic consideration"*

implying that whilst the main focus is life safety, engineers do also consider the costs of fire protection and the effect the protection methods they specify will have on the building in a fire.

As stated previously, the main focus of ADB is to meet the functional requirements of the Building Regulations (Crown Copyright, 2010) and which focuses on life safety, though as stated in Section 2.2 ADB states:

> *"There is no obligation to adopt any particular solution contained in an Approved Document if you prefer to meet the relevant requirement in some other way"* (Communities and Local Government, 2006)

Therefore any method of meeting the requirements of the regulations can be used, including one that provides property protection. Code compliance in relation to fire engineering, means that the design follows the recommendations set out in ADB or a different British Standard, such as BS 9999 to meet the Building Regulations. In designing the building, the respondents stated that the majority of buildings are code compliant solutions, with only small sections of the building that are non code compliant. This implies that the building mainly follows the recommendations in ADB but where the building deviates away from this, this area is deemed as non code compliant. It was stated that these areas of non code compliance need to be validated (or verified) to prove that these areas of non code compliance achieve the same standard of safety (or better) than the requirement in the Building Regulations. Depending on the respondent, the method of validation differed. The non fire engineers stated that they would employ a fire engineering consultant to validate these areas for them whilst the fire engineers responded that they used first principles of fire engineering (calculations) alongside published building codes and guidance, such as BS 7974 (BSI, 2003a) or CIBSE Guide E (The Chartered Institution of Building Services Engineers, 2003) to aid in the validation of the results and that these were discussed with Building Control authorities. These calculations focussed on getting occupants out of a building to safety, through the use of Required Safe Evacuation Time (RSET) and Available Safe Evacuation Time (ASET) calculations (discussed in more detail in Section 2.2.2.1). One consultant responded that if you are not meeting the recommendations in ADB then:

> *"You've got to state the reason for non compliance and what your strategy is to mitigate a perceived additional risk."*

This validation and verification is used to prove to Building Control officers and Approved Inspectors that the design does meet the requirements of the Building Regulations. Therefore, Building Control (and Approved Inspectors) should have a consideration of fire safety knowledge to ensure that the design and validation methods they are being presented with are correct and accurate. Yet, it was felt by twenty of the respondents that Building Control officers would accept fire engineering designs without fully grasping the fire engineering principles behind the design. This is of concern for the building industry at large if the company submitting a plan can "pull the wool" over the eyes of the Building Control officer that gives the final approval on the building plans. Sixteen respondents stated that the Building Control officers can reject plans from a lack of knowledge of fire engineering principles - this is less concerning (in regards to the safety of occupants) as if the Building Control officer is unsure, progress on the building will not be completed until they are happy with the safety of the occupants and the fire safety design. However, it can add unnecessary delays to the building process and therefore effect the final cost of the buildings construction and design, especially in relation to the fire engineering consultants scope, who will have to conduct additional work to prove that the design meets the functional requirements of the Building Regulations, potentially through labour intensive and costly procedures such as Computational Fluid Dynamics (CFD).

### 4.2.3 Design Costs Results

The next section of the questionnaire and interviews focussed on the costs of the fire protection design.

Cost could potentially be seen as a critical design factor and was thus the reason for inclusion in this questionnaire to verify if this was indeed the case. One of the reasons for employing a fire engineer is to help in value engineering a property - reducing costs whilst keeping the property safe for occupants. However, only fifteen (71 percent)f the respondents responded that cost was a critical factor in their role within the fire engineering industry. However, the respondents that stated that this was a critical factor were the fire engineering consultants and the architects - respondents that started it was not a critical factor, were for the majority, Fire and Rescue Service (FRS) personnel and those in Building Control with a few from the fire safety management side of the AEC industry. This could confirm that cost is a critical factor in the early stages of the project and reflect on the work undertaken by fire engineers and consultants, rather than the work conducted by the FRS and Building Control whose main role is to provide regulatory judgement on the building design.

The benefit of sprinklers to reduce building damage and fire spread is recognised in the Building Regulations, with ADB allowing additional benefits in the design of the building, such as larger building compartments, if sprinklers are installed and BS 9999 allows greater travel distances for escaping occupants and a reduction in risk profile for the building, if sprinklers are fitted and maintained to British Standard 12845 (BSI, 2004). As such, insurance companies also offer insurance premium discounts for certain buildings that have sprinkler installations and for some other properties require that sprinklers are installed to allow insurance of the building and contents. Therefore, when questioned on the cost effectiveness of a sprinkler installation, only two respondents indicated that they didn't think that sprinklers were a cost effective measure, even over the lifetime of the building to reduce costs. However, in terms of using passive fire protection and compartmentation to achieve the same aim (cost reduction in insurance premiums), only sixteen respondents (76 percent)tated that this would be achieved - most of those stating that they wouldn't consider this method of reducing premiums were involved in the fire safety risk management job role. The reasoning behind this wasn't clear but one respondent stated that they are never aware of the insurance premiums at the design stage and therefore they couldn't be sure it would be a cost effective investment. Articles in the industry journals regarding the potentially poor state of installation of passive fire protection ((Parlor, 2009) and (Schulz, 2009)) could potentially provide indicators as to why those involved in risk assessments and managing properties aren't keen on just using passive protection measures to mitigate costs. The unwillingness to use passive protection might also be due to a lack of research (in comparison to sprinklers) to the cost effectiveness of passive fire protection.

As part of the aim of this research was to create a cost benefit tool, using the fire incident data from FDR 1 as a statistical evidence base, respondents were asked if they would make use of such a tool if one existed (they were also asked if they knew of any tools that did exist currently in case one had been overlooked during the literature review). The respondents unanimously replied that if there was a tool that enabled them to make better cost effectiveness decisions, they would make use of such a tool. Therefore, if such a tool could be constructed using statistical analysis of the UK fire incident data, it appeared that such a tool would prove to be a useful addition to the fire engineering consultants toolbox.

### 4.2.4 Fire Protection Results

This section of the questionnaire dealt with how the respondents viewed the fire protection measures within buildings. As mentioned in Section 4.2.3, there seems to be concerns in the fire engineering industry on the installation of passive fire protection whilst other raise concerns about the effectiveness of sprinkler installations (Gottuk and Dinaburg, 2012). Therefore it can be clearly seen that there is a difference in opinion in the AEC industry on the effectiveness of the various different fire safety systems. Therefore this section intended to discover the respondents views on the types of protection systems and would they consider installing extra systems over that recommended in ADB if the results of the statistical analysis and this research proved that to do so would allow a more cost effective design to be implemented.

Passive fire protection through the use of compartmentation and fire separation is a common part of the building fire safety design and ADB gives guidance on the sizes that each fire compartment should be within a building. As mentioned previously, the Building Regulations recognise the benefits of sprinklers and the guidance in ADB allows a building to have larger compartment sizes in areas where sprinklers are installed. However, no such benefits are given if the compartmentation is installed to a higher fire resistance level than that recommended in the design guidance being used. This installation of sprinkler systems means that a larger compartment is allowed and therefore any fire occurring in that space, if not contained by the sprinklers, will cause a larger damage than one in a smaller compartment. The Building Regulations assume that the sprinkler system will operate as expected and does not take into account the failure of the system. This is true with all fire protection measures within the design of the building, yet research indicates that potentially, real life activations of sprinklers is not as effective as initially thought (Frank *et al.*, 2012).

Respondents were asked about the installation of fire safety systems and if redundant systems were installed - for example, if the sprinklers don't operate, then the damage will be larger than in instances where the fire occurs in a non sprinklered compartment, *if* the sprinklers don't operate. This trade off in compartment size could negatively affect the ASET time for escaping occupants if the sprinkler system does not activate and therefore a redundant system (either a built in system at the design stage, such a venting or additional active systems) would mean that if a system failed to operate, then the occupants would be able to escape safely. By seeing if these systems were installed, it could be seen if the AEC industry was beginning to focus on the use of active systems which if don't activate, could pose a potential life and additional property risk. The majority of respondents stated that redundant systems were considered which was wide spread across the respondents questioned, including many of the consultants and architects involved. It can therefore be assumed that even though active fire safety systems are being installed, additional measures (or existing measures required by regulations) are being installed alongside the active systems to allow the ASET to remain greater than the RSET for the buildings occupants. Improving the ASET should, in theory, also have the knock on effect of preventing damage to the property via a reduced amount of damage due to containment of the fire and fire products.

Inherent safety is safety through the design of passive protective measures and the actual building design itself. It relies on no active measures to provide additional protection or additional increases to the ASET for occupants.

When asked about passive fire protection, respondents overwhelming (60 percent said is was essential, 27 percent said is was fairly essential)tated that they thought it was an essential part of a fire engineered design however not as many respondents thought it was as effective as it was essential only 9 percent thought it was effective, and the majority, 54 percent, thought it was fairly effective Table 4.4 shows the responses given. The scale is on a scale from one (not very essential or effective) to five (being very effective of essential).

**Table 4.4:** How essential and how effective is passive fire protection?

| | **No. Of Respondents** | |
|---|---|---|
| **Scale** | Essential | Effective |
| 1 | 0 | 0 |
| 2 | 0 | 1 |
| 3 | 3 | 7 |
| 4 | 6 | 12 |
| 5 | 13 | 2 |

It clearly shows that respondents thought that passive protection was required even though they were not as confident that it was effective. It was not made clear why they thought the protection was not as effective as it was essential. However, articles in industry journals, such as Parlor's article in Fire Safety Engineering, (Parlor, 2009) Schulz's and Rowan's articles in *Fire Risk Management* (Schulz, 2009, Rowan, 2010) raise issues regarding the correlation of the satisfactory installation of passive protection and the lack of inspection during construction of a building to ensure that fire safety provisions are constructed correctly.

Even though all respondents viewed passive fire protection as essential (to a degree), about a third responded that they would not install more than the required amount of passive fire protection measures within a building, over that required by codes. One respondent stated he would only do it "where required by insurers". However all respondents stated that they considered inherent safety within the building.

#### 4.2.4.1 BS 9999 Results

Regarding BS 9999, half the respondents thought the code was too complicated. This was across the range of respondents questioned and included architects, consultants, building control and fire safety/risk management respondents. Therefore it can be concluded that many people within the fire industry find the code difficult to follow. This problem may have already been recognised as earlier this year, BSI Global published a handbook for the use of BS 9999 (Green and Joinson, 2010). Half the respondents stated that they favoured BS 9999 over other current design codes but, of the respondents who use the code less often, not all of them think that the code is too complicated so there does not appear to be a clear link between finding the code complicated and using it less often.

The majority (81 percent)f respondents stated that they still saw or used non code compliant areas within buildings designed to BS 9999. The majority also believed that BS 9999 did not impact on the scope for fire engineers - only three respondents thought that it would reduce fire engineering practice. A small number (38 percent)aid that it had changed their methods of working for the better, all of whom stated that it helped them justify their own fire engineering decisions as the decisions they would have made were now in a published code and thus allowed them to “support a case for alternative solutions”.

Opinion was split on whether BS 9999 offered a more cost effective method of design over previous design codes with eight experts believing that it offered no extra cost benefits. Again, this was from the broad range of experts so there is no one “field” of fire engineering/design that thought that it didn’t offer cost benefits.

## 4.3 Conclusions

The questionnaire set out to answer the following questions to influence in what direction this research would take:

1. Current practise in the fire engineering design process
2. Views on costs of fire protection methods
3. Views on active and passive fire protection measures
4. Views on British Standard 9999: Code of Practice for Fire Safety in the Design Management and Use of Buildings

From the results of the questionnaire, it was apparent that the majority of fire engineering was done by specialist fire engineering groups, either individually or through a multi disciplinary engineering consultancy company and that architects, building control and other members of the AEC industry would employ a fire engineering team as and when required.

These fire engineers were, and are, hired at mainly at the Preparation and Design stages of a building project. This is when most engineers are involved and this is when it is viewed that this is the best time for them to get involved in the design process. Therefore, it isn’t assumed that recommending that fire engineers change when they are appointed will affect the final outcome of this research. Each RIBA stage used in the chapter (and questionnaire) can be further split down - for example, the RIBA Design stage encompasses the RIBA stages C, D and E (which are Concept, Design Development and Technical Design stages respectively). Therefore to investigate further each stage could be broken down into this different grouping. From experience and from the questionnaires and interviews, the fire engineer is included at different stages of the project based on the requirements of the client, architect, project manager or other engineering services. Therefore, even if the it had been found that a particular group thought that fire engineers should be involved at any earlier stage, it is unlikely that the AEC industry would change over night to accommodate this change as the involvement of a fire engineer depends on a number of different factors that may or may not be directly influenced by fire requirements.

Fire engineers stated that they did consider the costs of what they were doing, though at present they were not aware of a tool that would allow them to fully understand the costs of what they were specifying at the design stage of a building. It was stated that they would make use of a such a tool, should one exist. Therefore, based on this and with the background statistics provided by the fire incident data from the FDR 1 forms and the Fire Protection Association (FPA) data collection, a cost benefit tool is proposed to be constructed to allow the fire engineers to better consider the costs of the fire protection measures they are specifying.

Use of the new fire safety standard in the UK, BS 9999, is mixed - half of the respondents felt that the code was to complicated for use which means that they struggled to use it. Whilst different to the previous design codes and standards that have gone before it (BS 5588), BS 9999 offers a range of different flexible options based on the design of the building. This flexibility is why fire engineers are using the code but they are also the reason that the document is perceived to be difficult or hard to use. In terms of cost benefits from the use of BS 9999, opinion was split as to whether or not this would be the case. It is assumed that by designing the building to match the intended occupancy of the building, through the use of risk profiles presented within BS 9999, then construction and design costs can be reduced through the ability to reduce the over engineering of the design that previous design standards may have introduced. This comes across in the talk by Torero (Torero, 2012), where he talks about the over engineering inherent in fire engineering and the additional costs this places on a project in meeting the Building Regulations using a non fire engineered approach to building design. The use of BS 9999 and cost benefits that could be gained from its use could prove to be the subject of a entirely different PhD, though as in this research it was not clear that the use of BS 9999 would conclusively prove a cost benefit (and the respondents not clearly agreeing that this was the case), BS 9999 will not be included within the proposed DSS.

From the questionnaire and interviews, it is apparent that fire engineers would use a DSS tool alongside current design practise and standards to help inform the client on the costs of the proposed fire engineering design and therefore hopefully provide additional fire protection to the UK building stock at the design stage to help in the reduction of property damage, insurance claims and therefore cost to the UK economy.

# Chapter 5

# Analysis of Fire Incident Data

## 5.1 Introduction

This chapter details the analysis of the fire incident data presented to the Integrated Risk Management Plan (IRMP) project and to this PhD by Department of Communities and Local Government (CLG) and the Fire Protection Association (FPA). It also includes the analysis of the costs of fire by using the Building Cost Information Service (BCIS) and FPA databases. Analysis of this data provides the backbone of the cost tool and is intended to provide the probabilities and the statistical evidence needed for the tool to estimate the differences in expected fire damage between two different building designs, and from there to calculate the cost of a fire within each building, allowing consultants to conduct a cost benefit analysis and clients to be informed of the cost benefits of additional fire protection.

To meet the aims and objectives of the research set out in Sections 1.4 and 1.5, a list of research questions has been drawn up. The answers to these questions will form the basis of the Decision Support System (DSS) tool.

Section 3.3 describes the methodology that this research followed and this represents the statistical analysis section of the research.

1. What is the probability of alarm activation?
2. What is the probability of extinction systems operating?
3. What is the probability of sprinkler system operating?
4. Is there a difference between the construction costs in the BCIS database and the FPA database?
5. What factors effect the area damaged by a fire?
6. How does the area damaged change with time?

These questions all inform the the final DSS tool. By performing the statistical analysis of this data, this allows the DSS tool to be constructed.

In addition to these questions, which need to be derived from the analysis of the FPA and FDR 1 data, the costs of fire need to be calculated. The analysis of the two fire incident datasets will provide the statistical evidence base but this will only provide an estimate of the loss in terms of area damaged. To get a complete picture and allow comparison between proposed fire engineering solutions, the tool needs to include the costs of fire damage and the costs of extra fire protection installation. Various sources of costs for the tool were identified in the methodology chapter, but some analysis needs to be carried out on the datasets identified to check how they compare to each other and to see if they can accurately provide the cost of damages caused by a fire.

It should be noted here that statistical analysis of the data assumes that future performance of fire and fire protection is assumed to be the same or similar to the current performance when analysing data. This is raised by Ramachandran in his book (2011) with David Charters (Ramachandran and Charters, 2011). The assumption that past performance of fire protection will remain similar is considered reasonable in this instance as the data used in the data collection are all taken from the FDR 1 data. As noted in Section 3.5.1.1, the FDR 1 data used within this research is only taken from the year 2005 due to the sampling used by CLG. Therefore it is not assumed that advances in fire engineering within that single year was a factor in the safety of buildings. Taking into account the entire dataset in the future may need to consider the effect that advances in fire engineering, such as the removal of BS 5588 and the replacement of it with BS 9999 has on the number, size and effect of incidents in the future. In his paper in 2012, Frank states that

> *"Data on the past performance of systems in real fires is on the best sources of information to estimate future performance"* (Frank *et al.*, 2012)

and this remains the viewpoint of this study. Past performance is not always indicative of future performance but it does provide an evidence base that can be built upon, assuming that future performance does remain similar. Therefore the results from this statistical analysis will form the basis of the research. However, this is with the provision that the results from this data analysis may differ with advances and changes in fire protection technology and safety measures in the future.

### 5.1.1 Analysis Assumptions

Various assumptions have been made in the analysis of the fire incident data - these assumptions are detailed here so that they don't have to be repeated at each step of the analysis where these assumptions might affect the analysis.

The damaged areas used in this analysis were taken from the AREATOT category in the FDR 1 dataset which details the total area damaged in the fire and fire fighting operations. This was used instead of AREABURN (the area damaged by burning) as AREATOT has more records completed than AREABURN. Using the values of AREATOT, about ninety five percent of the FDR 1 records has a completed value, AREABURN had less than twenty percent completed records. Therefore, for statistical reasons, the value of AREATOT was chosen as it would give a greater number of records to analyse. This meant that the data can be analysed more effectively as there are more incidents to analyse and use as an evidence base. It is also assumed in the building types that are being studied (non dwellings), that all building and contents damage will be required to be repaired before the building can be reopened or used fully. Therefore it is considered that the area damaged is a more representative figure to be used in this instance. This distinction between area damaged by burning and area damaged by total fire fighting operations means that potentially the results of this study may be different to other studies, if the studies focussed on only area damaged by direct burning - however, where this is the case, the study should make this clear.

As previously discussed in Section 3.5.1, the fire incidents datasets (both the FPA and FDR 1 databases) have been filtered to exclude residential properties and to only focus on the Commercial and Public buildings. This is because fire engineering is seldom used in residential properties where it is easier (and cheaper) to follow the guidance in Approved Document B (ADB) (Communities and Local Government, 2006). Section B.1 in Appendix B shows the FDR 1 occupancies that were used within this study. Each database of information (the FDR 1, the FPA and the BCIS data), all use different occupancy types and therefor to compare data between the different datasets, the different occupancies were consolidated into a smaller number of occupancies. All the data was matched to the same occupancy types as the FPA data. Conversion tables of how each occupancy type is converted to the FPA occupancy types are detailed in Appendix B. The FPA occupancy types were chosen as the base of types, due to the smaller number of occupancies within the FPA dataset. The FPA only has eleven occupancy types, and therefore it was more accurate and sensible to merge the other datasets, that contained far more occupancy types, down into the FPA data categories, rather than try to extrapolate the other databases to match each other.

## 5.2 Probabilities

To estimate the size of a fire in a given building type, the probability of factors that could potentially affect the fire size need to be calculated. To calculate the most probable fire damage scenario, the DSS needs to be be able to know the probabilities of these factors and what affect they have on the fire damage.

### 5.2.1 Probability of Alarm Activation

ADB requires all buildings to be fitted with an alarm system, the standard of which depends on the complexity of the building, ranging from manual call points to fully addressable alarm systems. These alarm systems are installed to notify building occupants that there is a fire and to take appropriate action - normally the evacuation of the premises (though this depends on the fire strategy of the building as different occupancies will have different evacuation methods - for example “double knock” systems in some public buildings such as theatres and phased evacuation in tall buildings). Once the alarm has been raised, the occupants are then aware of a fire and can (though, not always) inform the local Fire and Rescue Service (FRS) of a fire in the premises. Some alarm systems may inform the local FRS that an alarm activation has occurred - local FRS policy may be to attend these alarms or it may wait for another signal to be received (such as a phone call) before sending crews to attend.

If the fire alarm activates sooner, the FRS should (in theory) be notified of the fire quicker and should therefore attend quicker. Therefore, the hypothesis in this instance is that the quicker the alarm activates, the smaller the fire damage. Figure 5.1 shows the fire growth rates associated with fires, depending on the fuel being burnt in the fire. These growth rates are the basis of the risk profiles used in BS 9999 and are used to show how the fire grows over time. The timing before fire fighting operations start (assuming at this point, that fire fighting operations stops the fire growth as soon as the FRS start the fire fighting operation) can be critical in affecting the size of the fire and therefore the damage caused to the property.

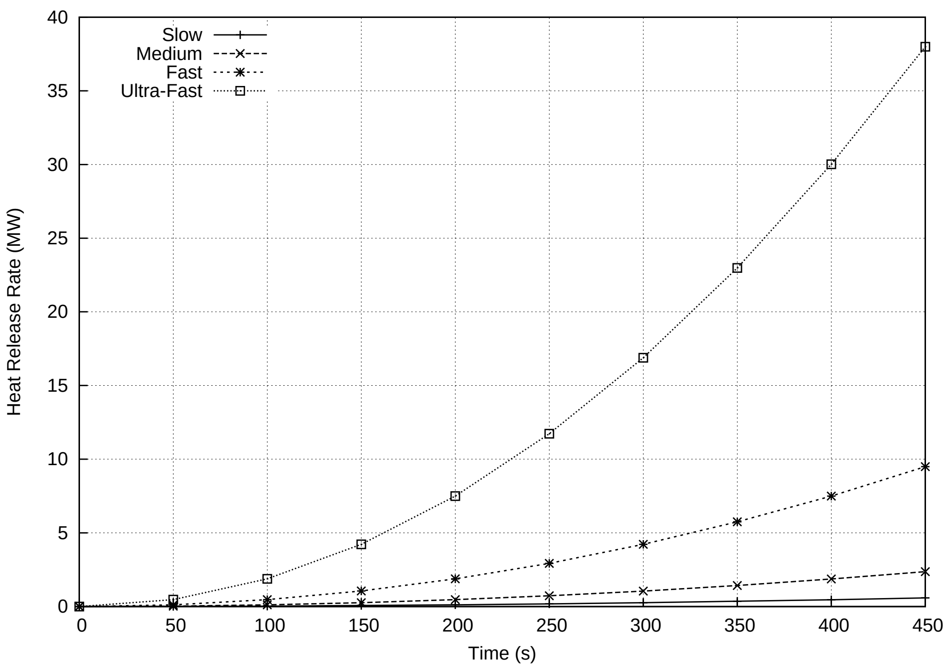



**Figure 5.1:** Comparison of $t^2$ Fire Growth Rates
*Taken from (Heskestad, 1984)*

The FDR 1 forms record whether or not the building contains a fire alarm. This is done in the ALARM field with a 1 result meaning no Automatic Fire Detection (AFD) installed or

2, meaning AFD was present. Table 5.1 details the number of buildings with AFD present in the FDR 1 data. As can be seen, the number of fields missing data is insignificant in this regard.

**Table 5.1:** Number of Buildings with AFD Present

| Alarm Present | Frequency | Percentage |
|---|---|---|
| No | 21,727 | 61.6 |
| Yes | 13,521 | 38.4 |
| **Total** | 35,248 | 100.0 |

From these results, it can be seen that only 38.4 percent of buildings that had a fire incident in 2005 had AFD present. From this, the probability of the alarm actually activating can be calculated. This is done by taking the number of instances where the alarm activated in the instances where an alarm was present within the property. Table 5.2 shows the instances of alarm activation where an AFD system was present. In this table, "No" and "Yes but did not raise the alarm", are treated as a failure to raise the alarm - either though not activating or because an alarm system not raising the alarm can be seen as a failure to complete the purpose it was designed for. Without notification by the alarm system, the occupants are unlikely to discover the fire until the fire has reached a sufficient size that fire products are visible. If a fire occurs in a premises that is empty over night, this time could be sufficient that sizeable areas of damage have been caused before the alarm is raised.

**Table 5.2:** Alarm Operation in Buildings Where AFD was Present

| Alarm Operation | Frequency | Percentage |
|---|---|---|
| No | 2,519 | 18.6 |
| Yes but did not raise the alarm | 983 | 7.3 |
| Yes and raised alarm | 10,019 | 74.1 |
| **Total** | 13,521 | 100.0 |

From Table 5.2, it can be seen that the categories "Yes" and "No" give a combined total of 25.9 percent chance that an alarm system fails to operate as it should. Therefore, the probability that an alarm system activates is 74.1 percent.

This figure may differ from figures quoted from alarm systems installed by manufacturers but from analysis of the FDR 1 figures, this is the “real life” probability of the system activating.

#### 5.2.1.1 If alarm activates, will this cause a lower fire damage?

This section details the calculations to see if the alarm activation has any affect on the size of a fire. As mentioned above, the hypothesis is that an alarm activating and raising the alarm is likely to cause a lower fire damage by decreasing the time it takes for the FRS to be notified and to begin fire fighting operations.

This data was split into area damaged groups. The area groupings are shown in Table 5.3 and these groupings are defined in the FDR 1 database.

**Table 5.3:** Area Groupings in FDR1 Data

| Group | Area ($m^2$) |
|---|---:|
| 11 | Under 1 |
| 12 | 1-2 |
| 13 | 3-4 |
| 14 | 5-9 |
| 15 | 10-19 |
| 16 | 20-49 |
| 17 | 50-99 |
| 21 | 100-199 |
| 22 | 200+ |

This data was then filtered again into incidents where the alarm operated and the alarm failed in the same method as discussed in Section 5.2.1.

A total of 10,000 records are present that contain data on area of AREATOT and that the alarm systems activated successfully and raised the alarm. 19 results did not have both the required information and therefore appear in the table as the values marked down as missing and are excluded from the analysis.

The missing values are ignored as the number of missing cases is insignificant to the number of incidents for which there is data present - as the table shows, only 0.2 percent of the records are of the incidents have data missing in this analysis. The number of fires where the alarm failed to activate were then analysed.

Table 5.4 shows the number of incidents and the spread of fires when the alarm failed

**Table 5.4:** Table Showing Alarm Operation and Area of Total Damage

| | Alarm Activated | | Alarm Failed to Activate | |
|---|---|---|---|---|
| **Area Group** | **Frequncy** | **Percentage** | **Frequncy** | **Percentage** |
| 11 | 3,258 | 32.5 | 1,305 | 37.3 |
| 12 | 780 | 7.8 | 295 | 8.4 |
| 13 | 918 | 9.2 | 304 | 8.7 |
| 14 | 1,151 | 11.5 | 294 | 8.4 |
| 15 | 1,323 | 13.2 | 332 | 9.5 |
| 16 | 1,107 | 11.0 | 336 | 9.6 |
| 17 | 683 | 6.8 | 235 | 6.7 |
| 21 | 412 | 4.1 | 178 | 5.1 |
| 22 | 368 | 3.7 | 214 | 6.1 |
| **Total** | 10,000 | 99.8 | 3,493 | 99.7 |
| **Missing** | 19 | 0.2 | 9 | 0.3 |
| **Total** | 10,019 | 100.0 | 3,502 | 100 |

to activate. With these two sets of data, these can be compared statistically to investigate if there is a correlation between a fire alarm activating and the area damaged. Plotting this data into a graph, it can be seen that the data is non normal and is positively skewed implying that smaller, less damaging fires are far more common than larger fires. This is shown in Figure 5.2. This shows that there are far more fires where the alarm does activate, than incidents where the alarm fails to activate. However, direct comparison between the two categories cannot be undertaken straight from the graph as whilst both categories have different frequencies of incidents, the number of incidents where the alarm activated are approximately three times more common than incidents where the alarm failed.

To compare the data, the percentages of the fire size as a total of the dataset are investigated. This is shown in Figure 5.3. This shows both datasets in percentage form allowing for a visual comparison.

From looking at Figure 5.3, it appears that there isn't much difference between the two results. However, to get a proper comparison, a statistical test needs to be performed. In this instance, an unpaired $t$-test was carried out to compare the data. Equation 5.1 is the formula for the t-test. $\bar{x}$ is the mean of the figures, $S$ is the standard deviation and $n$ is the number of incidents.

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{(n_1+n_2)}{(n_1 n_2)} \times \frac{(n_1-1){S_1}^2+(n_2-1){S_2}^2}{n_1+n_2-2}}} \tag{5.1}$$

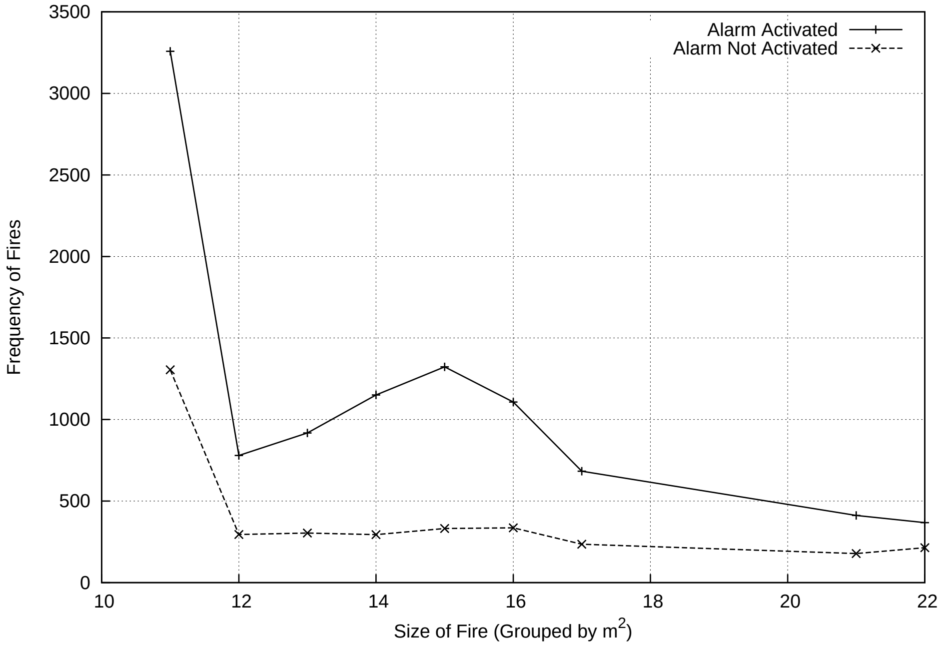



**Figure 5.2:** Alarm Activation Against Fire Size in Area Categories - Frequency

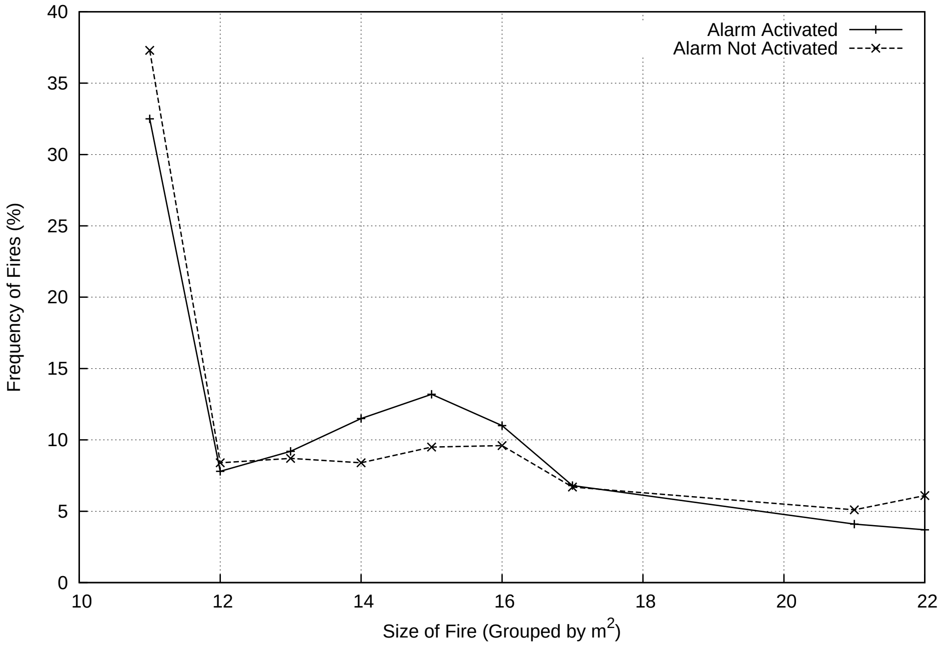



**Figure 5.3:** Alarm Activation Against Fire Size in Area Categories - Percentage

An unpaired $t$ test was chosen as it allows the two datasets to be compared and will numerically prove if the results are significantly different. The null hypothesis is that there is no significant difference between the two datasets. Using the values in Table 5.5, the statistical difference can be calculated between the two datasets.

**Table 5.5:** Figures for T Test Based on Grouping

| Alarm Not Activated | Alarm Activated |
|---|---|
| $\bar{x}_1 = 13.96$ | $\bar{x}_2 = 13.92$ |
| $S_1 = 3.36$ | $S_2 = 2.98$ |
| $n_1 = 3493$ | $n_2 = 10000$ |

Putting these values into Equation 5.1, gives us Equation 5.2.

$$t = \frac{|13.96 - 13.92|}{\sqrt{\frac{(3493+10000)}{(3493\times10000)} + \frac{(3493-1)3.36^2+(10000-1)2.98^2}{3493+10000-2}}} \tag{5.2}$$

Calculating this, gives a $t$ value of 0.6602 which when compared to a table of degrees of freedom, gives us the result that the different incidents are not statistically different.

However, the results are grouped into different areas as stated previously and the area group 22, is the collection of all the fires over 200m². Therefore to incorporate these properly into the analysis, the groups must be split down into the actual area damaged and a statistical test performed on them. However, the data in the FDR1 dataset is only stored in groups, with the exception of those fires over 200mm² which are recorded with the actual fire size. Therefore to get an estimate of the actual fire sizes, an average needs to be taken of the smaller fires and then added to the larger fire set. As the groups are not of equal sizes, a geometric mean will be taken, as a geometric mean takes into account the group size as in this instance, the groups are not of equal distribution.

Table 5.6 shows the geometric mean and arithmetic mean of the data set to illustrate why the Geometric mean is chosen. With this calculated, the Standard Deviation and $t$ test are calculated using these results. Working this out, the following values are calculated and are ready to be tested.

$$t = \frac{|43.156 - 32.079|}{\sqrt{\frac{(3493+10000)}{(3493\times10000)} + \frac{(3493-1)185.56^2+(10000-1)179.02^2}{3493+10000-2}}} \tag{5.3}$$

**Table 5.6:** Geometric Mean of Each Area Damaged, Arranged by Group

| FDR1 Group | Group ($m^2$) | Mean ($m^2$) | Geometric Mean ($m^2$) |
|---|---|---|---|
| 11 | $>1$ | 0.5 | 0.5 |
| 12 | 1-2 | 1.5 | 1.414 |
| 13 | 3-4 | 3.5 | 3.464 |
| 14 | 5-9 | 7 | 6.708 |
| 15 | 10-19 | 14.5 | 13.784 |
| 16 | 20-49 | 34.5 | 31.305 |
| 17 | 50-99 | 74.5 | 70.356 |
| 21 | 100-199 | 149.5 | 141.067 |
| 22 | 200+ | Actual Size | Actual Size |

**Table 5.7:** Figures for T Test Based on Area

| Alarm Not Activated | Alarm Activated |
|---|---|
| $\bar{x}_1 = 43.156$ | $\bar{x}_2 = 32.079$ |
| $S_1 = 185.56$ | $S_2 = 179.02$ |
| $n_1 = 3493$ | $n_2 = 10000$ |

The results of Equation 5.3 gives a result of $t = 3.11$ which, when compared to a table of degrees of freedom, is found to be statistically different and therefore the results are different and show the alarm activation affects the area damaged.

The same test was again carried out but this time, the log values of area were taken. This was done as the difference between the largest area and the smallest area is significant and could affect the results. Taking the log values of the data would bring the numbers closer together in order of magnitude and see if the large distribution of the data affected the results. With the logged areas, the values gave a $t$ value of $t = 9.709$ which again means the data is statistically different.

#### 5.2.1.2 Mann Whitney Test

The data above is not normally distributed and is positively skewed, as can be seen in Figures 5.2 and 5.3. To perform a reliable $t$ test, it is normally assumed that the data is normally distributed. For this reason, a Mann Whitney test was undertaken to compare against the $t$ test values. If the Mann Whitney test shows the same statistical difference, it can be concluded that alarm activation does have an effect on the fire size.

The Mann Whitney test was performed in SPSS. The data for ALARMOP (whether or not the alarm operated), AREATOT (total area damaged) and ATOTOTH (actual figure of total area damaged if greater then $200m^2$+) was extracted and placed in Microsoft Excel, where additional data manipulation and creation could be achieved to create a new record. A new record was created, ALARMOP(CALC) which was given a value of either 0 (where the data record was missing), 1 (for an alarm failing to operate or raise the alarm) or 2 (for successfully raising the alarm and activating). Algorithm 1 shows the methodology behind the creation of this new column of data.

**Algorithm 1** Code for Sorting of Data

```
if ALARM=0 then
    ALARMOP(CALC) = 0
else if ALARM = 1 OR 2 then
    ALARMOP(CALC) = 1
else if ALARM = 3 then
    ALARMOP(CALC) = 2
end if
```

Another new record of data is created, ALARMTOT(CALC) which replaces the value of the area from it's group with the geometric mean of the group size - this allows group 22 (fires greater than $200m^2$) to use the actual values recorded in ATOTOTH and be compared with the grouped values in the groups under $200m^2$.

This data is then imported back into SPSS where the data can be successfully analysed with a Mann Whitney test.

The data is first filtered using the code ALARMOP$_\sim$=0 which filters out all the data where ALARMOP does not equal 0 (meaning only fires for which data is recorded is used in the analysis). The NULL hypothesis for this test was that the distribution of AREATOTAL(CALC) is the same across categories of ALARMOP(CALC).

Using the Mann Whitney test function in SPSS, a significance figure of 0.012 (significance level of 0.5 used) was calculated and the NULL hypothesis can be rejected, therefore proving that the alarm activation does have an affect on the fire size.

### 5.2.2 Probability of Extinction Systems Operating

Calculating the probability of an alarm system activating provides a basis for future calculations. This is done by using Equation 5.4.

$$\frac{\text{No. of Times System Operated}}{\text{No. of Fires}} \tag{5.4}$$

Table 5.8 shows the extracted data from FDR 1 data. This table shows the number of incidents where an extinction system was not present in the fire area and those fires where an extinction system was present.

**Table 5.8:** Number of Incidents With an Extinction System Present

| | **Frequency** | **Percent** |
|---|---|---|
| No Extinction System | 34,252 | 97.2 |
| Extinction System Present | 978 | 2.8 |
| **Total** | 35,230 | 99.9 |
| **Missing** | 20 | 0.1 |
| **Total** | 35,250 | 100 |

The table shows that only 978 fires (or 2.8 percent) of fires in the FDR 1 database for 2005 had an extinction system present. A small number of fires (0.1 percent - 20 incidents) did not have a recorded data value. As this is a small number, it can easily be ignored. To find the reliability of the extinction systems operating, the number of incidents where an extinction system operated needs to be divided by the number of incidents which contained an extinction system.

In terms of operating, the FDR 1 data records the operation status for up to 3 extinction systems in a building. These are designated in the FDR 1 data as OPER 1, OPER 2 and OPER 3. These fields are given one of the following letters to designate how they operated.

- A - System operated and extinguished fire
- B - System operated and contained/controlled fire
- C - System operated but did not contain/control fire
- N - System did not operate

Table 5.9 shows the data for the operation of the extinction systems. Most systems only have one extinction system (four incidents have three extinction systems, 54 have two extinction systems and the rest, 920 incidents, have one extinction system). A blank in the OPER2 and OPER3 tables shows the system only had one or two systems respectively. However, due to the smaller numbers of results that had multiple extinguishing systems,

**Table 5.9:** Operation Status of Extinction System

| | OPER 1 | | OPER 2 | | OPER 3 | |
|---|---|---|---|---|---|---|
| **Status** | **Frequency** | **Percent** | **Frequency** | **Percent** | **Frequency** | **Percent** |
| - | - | - | 924 | 94.5 | 974 | 99.6 |
| A | 201 | 20.6 | 4 | 0.4 | - | - |
| B | 233 | 23.8 | 16 | 1.6 | - | - |
| C | 64 | 6.5 | 4 | 0.4 | - | - |
| N | 480 | 49.1 | 30 | 3.1 | 4 | 0.4 |
| **Total** | 978 | 100 | 978 | 100 | 978 | 100 |

analysis will only focus on those in the OPER1 category.

These values take into account all extinguishing systems and these can be broken down into each different system. By filtering the data, the most popular extinction systems can be found. The hypothesis being that sprinklers will be the most common extinguishing system in a building.

The FDR1 data shows the extinction systems present in the SYS categories (SYS1, SYS2 and SYS3). Each one records what extinction system was installed in the incident building. Firstly, all data where EXTSYS = 2 is filtered and then this dataset is filtered again, according to SYS1, SYS2 and SYS3. The results for SYS2 and SYS3 have the same number of incidents as the OPER2 and OPER3 data in Table 5.9 and so will be ignored due to the small numbers of records. The values for SYS1 can be seen in Table 5.10.

**Table 5.10:** SYS1 Data After Filtering

| System | Frequency | Percent |
|---|---|---|
| Drencher | 90 | 9.2 |
| Foam | 30 | 3.1 |
| Gaseous | 126 | 12.9 |
| Other | 45 | 4.6 |
| Powder | 9 | 0.9 |
| Venting | 100 | 10.2 |
| Water Sprinkler | 578 | 59.1 |
| **Total** | 978 | 100 |

As can be seen in Table 5.10, the most common extinction system is the standard water sprinkler with about 60 percent of the incidents having an extinction system present are fitted with sprinklers. Further analysis of the sprinkler systems would be beneficial as other studies are recommending them for use in building design (Butry, 2009, Fraser-Mitchell, 2010).

### 5.2.3 Probability of Sprinkler System Operating

**Table 5.11:** OPER1 Data For Sprinklers Only

| **Status** | **Frequency** | **Percent** |
|---|---|---|
| System operated - Fire extinguished | 82 | 14.2 |
| System operated - Fire contained | 115 | 19.9 |
| System operated - Fire not contained | 24 | 4.2 |
| System did not operate | 357 | 61.8 |
| **Total** | 578 | 100 |

If we only focus on sprinklers in the OPER1 category, then further data analysis can focus purely on the most commonly install fixed fire fighting system that is present within the buildings collected in the FDR 1 dataset (and then, by assumption, within the UK building stock).

Focusing only on the sprinkler instances in the OPER1 category (Table 5.11), it can be seen sprinklers only operate, activate and work as expected 197 times out of 578. This equates to 34.08 percent probability of activation. This differs significantly from the figures reported by Vaidogas and Šakenaite (Vaidogas and Šakenaite, 2011).

Even taking into account the instances where activation of sprinklers occurred but failed to contain the fire, this only gives an activation probability of 38.24 percent. The study by Rutstein and Cooke (Rutstein and Cooke, 1983) shows sprinklers operate effectively 95.6 percent of the time *but only in cases where fires activate the sprinklers due to the size*. 57 percent of the fires in the Rustein and Cooke study (1983) were not large enough to start sprinklers and therefore sprinklers only operated in 41 percent of the time overall (95.6 percent of the time they operate as expected in incidents where the fire is large enough to activate the sprinkler system, which is 43 percent of fires).

A sprinkler system is only designed to activate when a fire reaches a certain size (Melinek, 1993a) and therefore fires smaller than this activation threshold will not activate the sprinkler system. Ramachandran states in his paper in 1990 (Ramachandran, 1990) that a sprinkler system will operate at $3m^2$. Similar measurements taken by Hinkley (Hinkley, 1986) puts the activation value at $5\text{-}6m^2$. Using these figures, it can be shown how much of the sprinkler activations above would have been in fires above the required threshold to activate sprinklers.

Using the data, AREATOT, from the FDR1 form, the size of the fires can be estimated. AREATOT is the total area damaged within the fire incident, however, it is a more complete record than the AREABURN data which is a measure of the area burnt. The data for AREATOT can be narrowed down in SPSS to only show the data where sprinklers are involved with Algorithm 2. This code selects all instances where OPER1 is true (a system operated) and SYS1 is a is a water sprinkler (W).

**Algorithm 2** Selection of AREATOT Incidents Involving Water Sprinklers

```
OPER1 = "0" AND SYS1 = "W"
```

This gives the data in Table 5.12. If we use Ramachandrans value of 3m$^2$ as the figure for sprinkler activation, this means fires in group 13 will be large enough to activate the sprinklers. This figure was chosen over Hinkley's because the group that 3m$^2$ lies in (group 13) has a smaller range of values than group 14. Anything in group 11 and 12 can then be classed as being to small to activate a sprinkler system. Groups 11 (under 1m$^2$), 12 (1-2m$^2$) and 13 (3-4m$^2$) are under the 5m$^2$ that Hinkley suggests.

**Table 5.12:** OPER1 Data and AREATOT - Sprinklers Only

| | **OPER1** | | | |
|---|---|---|---|---|
| **AREATOT** | A | B | C | D |
| 11 | 13 | 4 | 1 | 123 |
| 12 | 8 | 5 | 1 | 36 |
| 13 | 12 | 10 | 0 | 27 |
| 14 | 9 | 13 | 1 | 34 |
| 15 | 8 | 13 | 1 | 35 |
| 16 | 11 | 14 | 4 | 31 |
| 17 | 11 | 16 | 4 | 22 |
| 21 | 8 | 13 | 4 | 16 |
| 22 | 2 | 26 | 8 | 31 |

From looking at Table 5.12, it is immediately clear that fires under the limits given by Ramachandran and Hinkley do in fact operate sprinklers, regardless of which value is used. Using Ramachandran's value, there are 32 (16.8 percent of fires) activations of sprinklers in groups 11 and 12. If Hinkley's figure is used, then this rises to 54 (22.5 percent of fires) activations. It should be noted that in fire sizes under 3m$^2$, the percentage of sprinkler activations is very poor.

The FDR 1 data does not differentiate between fast response and normal response sprinklers. A fast response sprinkler, by design, will activate at a lower temperature than a normal response sprinkler (BSI, 2005) and therefore there is less likely to be as much damage as the fire will be contained or extinguished quicker. This is one explanation as to how and why the sprinklers activated for a total area damaged of under the threshold areas considered by Ramachandran and Hinkley. Another explanation is that the fires in question burned hotter than an average fire and therefore the smaller fire generated enough heat to set the sprinkler off before it grew, causing less damage. However, without more information, this can not be calculated further.

### 5.2.4 Probability of Fire Starting

One of the points that has to be considered during the design of the tool is how to calculate the probability of a fire starting within a building. Work has been done previously by Ramachandran (Ramachandran, 1988) and he states that the probability of a fire starting in a building is given in Equation 5.5.

$$F(A) = KA^{\alpha} \tag{5.5}$$

where $A$ is the total floor area of the building and $K$ and $\alpha$ are constants for a particular building group.

Whilst this equation will give the probability of a fire starting in a building, during the design phase of the building the probability of a fire is not taken into account in a numerical sense. Consultants and fire engineers conduct risk assessments and consider the potential risks for the future of the building and design the fire safety systems appropriately. However, during the design phase, they assume that a fire *will* occur during the life time of the building and therefore the probability is 1 (or 100%). By considering the risks, the fire engineers can design the fire safety systems to deal with the most anticipated fire size, known in literature as the design fire (The Chartered Institution of Building Services Engineers, 2003).

As the designers take into account a fire will always occur in the building, logic dictates that the design tool should also consider the possibility of a fire occurring as a guarantee. This would mean the results from the tool are directly comparable to the other designs a fire engineer might investigate, assuming the design fire size is the same in all scenarios considered.

Therefore it is proposed that the tool does not include data on the probability of fire starting as this will not be required by those using the tool at the design stage of the building project.

## 5.3 Costs

In the previous section, a discussion on the different methods of calculating costs was described. It was decided in that report to use the BCIS data and the FPA data for costing as these two databases were more easily accessible and the cost methods would be best for the method of calculating costs per $m^2$. As described previously, the other options, whilst good in their own right, were unsuitable for the role of cost calculations in this project.

It was decided that the costs of both the FPA and the BCIS tool could be compared and if similar results were gathered from both tools, then the results of the costs could be trusted to be good estimates of the cost. However, the FPA data contains 18 different building occupancies whereas the BCIS is broken down into 8 main categories and then further in to 414 different occupancies (both datasets excluding residential). This means that whilst the BCIS could potentially provide very accurate results for differing buildings, it makes it harder to compare with the FPA data. Therefore the categories need to be matched together so that the BCIS data and FPA data can be compared. This does mean however, that some of the accuracy of the BCIS data is lost in comparison, however, the loss in accuracy should be made up for the larger number of samples present in the category (i.e. some BCIS categories only have a single data point present but grouping them will allow a greater sample size) - this will allow the results to be more statistically sound.

It was decided to merge the BCIS categories to match the FPA categories as the FPA data contained less categories and would make it easier and more accurate to merge. The FPA and BCIS datasets contain the occupancies listed in Table 5.13 .

As discussed above, converting the BCIS occupancies into the FPA occupancies would allow comparison between the two datasets and would either confirm or reject the idea that costs in each dataset are similar. Combining the two meant looking through all 414 BCIS categories and manually assigning them to an FPA code. The BCIS data was combined with the FPA data rather than the other way round as it was easier to assign an FPA category to one of the 414 different BCIS categories than try and combine the FPA categories into the smaller number of BCIS main occupancy groups. For example, where does the food and drink category from the FPA dataset go in the BCIS dataset? Would it fit in the Commercial group or in the recreational group? It was deemed easier to go through the

414 categories and assign them FPA categories individually.

The combined BCIS and FPA data can be found in the appendix - Table B.3. Now that this data is grouped, it is possible to extract data to compare.

**Table 5.13:** Building Occupancies in the FPA and BCIS Database

| FPA Occupancies | BCIS Occupancies |
|---|---|
| Car Parks | Administrative, Commercial, Protective Facilities |
| Education | Common Facilities and Other Facilities |
| Entertainment and Culture | Educational, Scientific and Information Facilities |
| Food and Drink | Health and Welfare Facilities |
| Industrial Processing | Industrial Facilities |
| Medical | Recreational Facilities |
| Non Residential -Misc | Religious Facilities |
| Other Residential | Utilities and Civil Engineering |
| Other outdoors (including land) | |
| Outdoor equipment and machinery | |
| Outdoor structures | |
| Permanent Agricultural | |
| Public Utilities | |
| Religious | |
| Retail | |
| Support | |
| Transport | |
| Unassigned | |
| Warehouses | |

### 5.3.1 FPA Data

The first step of the analysis is to calculate the cost per m$^2$ of the FPA data. This was done in PASW SPSS and was done by dividing the total cost figure by the area damaged. Records that did not contain a value for either the total loss or total damage were removed as these records would be unable to be used in this analysis. This gives the data shown in Table 5.14.
This database was then exported from SPSS into a Comma Separated Value (CSV) file so that it could analysed using other software.

To analyse the FPA data and the BCIS data and to compare the different categories, the FPA data was split into different files, depending on categories. The code for this is shown

**Table 5.14:** FPA Data Categories and Number of Incidents

| Occupancy | Frequency | Percent |
|---|---|---|
| Industrial Processing | 77 | 20.3 |
| Non Residential -Misc | 70 | 18.5 |
| Food and Drink | 48 | 12.7 |
| Retail | 45 | 11.9 |
| Warehouses | 37 | 9.8 |
| Entertainment and Culture | 19 | 5.0 |
| Permanent Agricultural | 18 | 4.7 |
| Education | 15 | 4.0 |
| Unassigned | 14 | 3.7 |
| Religious | 12 | 3.2 |
| Sport | 10 | 2.6 |
| Medical | 5 | 1.3 |
| Transport | 4 | 1.1 |
| Other outdoors (including land) | 2 | 0.5 |
| Other Residential | 1 | 0.3 |
| Outdoor structures | 1 | 0.3 |
| Public Utilities | 1 | 0.3 |
| **Total** | **379** | **100** |

in the appendix - Code Listing C.2. This code separates the initial database into separate files that contain only the categories that are of interest as not all the categories are used. This is because that some of the categories only have a few records and would therefore be unsuitable for statistical analysis due to the small number of results. Medical, Transport, Other Outdoors, Other Residential, Outdoor Structures and Public Utilities will not be analysed as they have to few results to be statistically significant. The unassigned category was also removed as it unclear what these building categories are and therefore cannot be used in the analysis.

After separation, the average cost per $m^2$ can be calculated. This value will allow an estimate the cost to be calculated by using the average. This is done by adding the cost per $m^2$ together and then dividing by the number of incidents. This calculation was performed using the average function in Microsoft Excel and gives the results in Table 5.15.

Assuming a linear relationship between cost and area damaged, it is possible to estimate the cost of a fire using Equation 5.6 to calculate the estimate, where

D = Total cost

C = Average cost per $m^2$ for that occupancy, taken from Table 5.15

**Table 5.15:** Average Cost of Fire Per m² - FPA Results

| Occupancy | Average Cost Per m² (£) |
|---|---:|
| Industrial Processing | 4,775.50 |
| Non Residential -Misc | 1,405.16 |
| Food and Drink | 1,980.61 |
| Retail | 1,941.96 |
| Warehouses | 1,662.49 |
| Entertainment and Culture | 1,273.74 |
| Permanent Agricultural | 785.82 |
| Education | 1,548.64 |
| Religious | 1,742.79 |
| Sport | 1,237.01 |

A = Area damaged by fire

$$D = CA \tag{5.6}$$

This allows a basic fire damage cost estimate to be calculated. However, this does rely on the cost of fire being linear which isn't always the case - for example, a fire in a warehouse may start in an office of the warehouse and then spread into the main warehouse building. The office area from the FPA data table shows that this cost is higher, at £1,941.96 per m² compared to the warehouses average price of £1,662.49 and therefore the fire costs would change (and no longer follow a linear equation) once the fire has spread beyond the office. However, if the values contained data on how much of the office area was damaged and how much of the warehouse was damaged, this could be calculated using a linear relationship equation for both areas and combining the two figures together for a total.

Figure 5.4 shows the data from Table 5.15 plotted in a graph to give an estimate of cost at a given area damaged, as calculated in Equation 5.6.

It shows that Industrial incidents have a far greater cost per m² than other building occupancies but this is to be expected considering the extra costs that industrial premises incur such as custom manufacturing equipment that might be custom built for that one factory.

With this done, the same process needs to be carried out for the BCIS data so a comparison between the two can be drawn.
The last report focussed on the classification of the BCIS data into the same categories as the FPA data and the initial analysis of the FPA data. This report carries on from that report with the initial analysis of the BCIS data and statistical analysis between the two

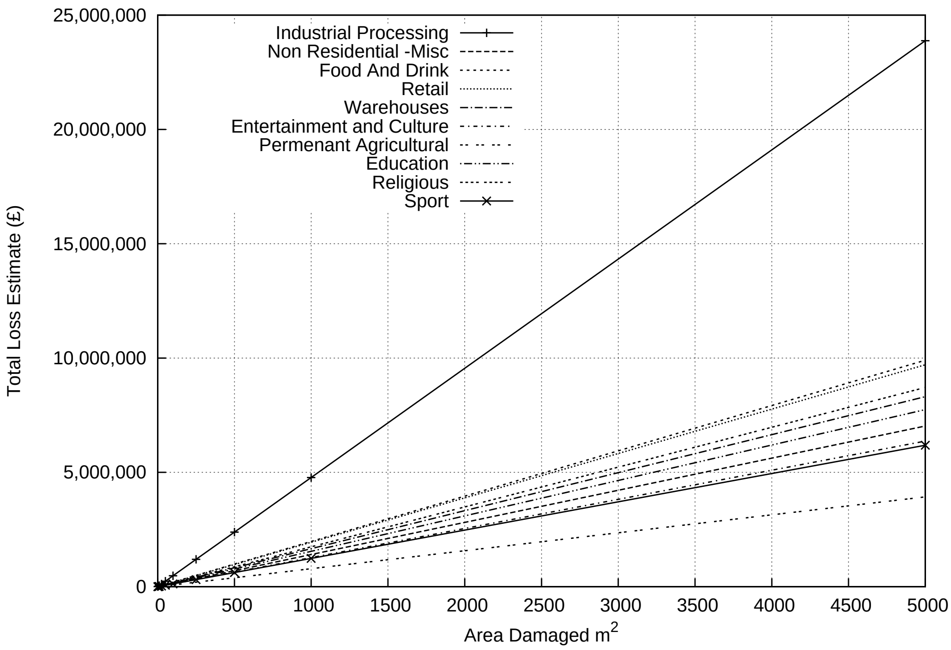



**Figure 5.4:** Average Costs of Fire - FPA Data

data sets to see if the results are similar.

## 5.3.2 Data Analysis

### 5.3.2.1 BCIS Data

The BCIS data was split into groups based on the FPA data as described in the last report. This means that the data is now in comparable categories and can be analysed in a similar fashion. Calculating the costs for this data gives the results in Table 5.16.

This data is then plotted in Figure 5.5.

In comparison to the FPA costs, shown in Figure 5.6, it can be seen straight away that the cost of fires in Industrial Processing occupancies and Warehouse occupancies appear to be significantly different. This can be explained by the fact that the FPA data is taken from insurance incidents and includes the price of both the fire damage to the property and of the contents. Both Warehouse and Industrial Processing occupancies are cheap to build - the buildings are essentially large empty sheds. The contents of these buildings however may cost more than the construction costs of the building, due to the large amount of specialised equipment (in regards to industrial processing) and large amount of storage capacity (in warehouses).

However, if both the FPA and the BCIS data sets are similar, then the FPA data can be

**Table 5.16:** Average Cost of Construction - BCIS Data

| Occupancy | Cost Per m² (£) | Number of Records |
|---|---|---|
| Car Parks | 442.00 | 2 |
| Education | 1,564.17 | 58 |
| Entertainment and Culture | 1,649.69 | 35 |
| Food and Drink | 1,788.56 | 9 |
| Industrial Processing | 743.79 | 33 |
| Medical | 1,611.75 | 65 |
| Non Residential | 1,452.21 | 19 |
| Other Outdoors | 2,102.00 | 1 |
| Permanent Agricultural | 875.20 | 10 |
| Public Utilities | 1,681.98 | 50 |
| Religious | 1,696.80 | 5 |
| Retail | 1,017.19 | 26 |
| Sport | 1,397.56 | 62 |
| Transport | 1,511.67 | 24 |
| Warehouses | 736.13 | 16 |

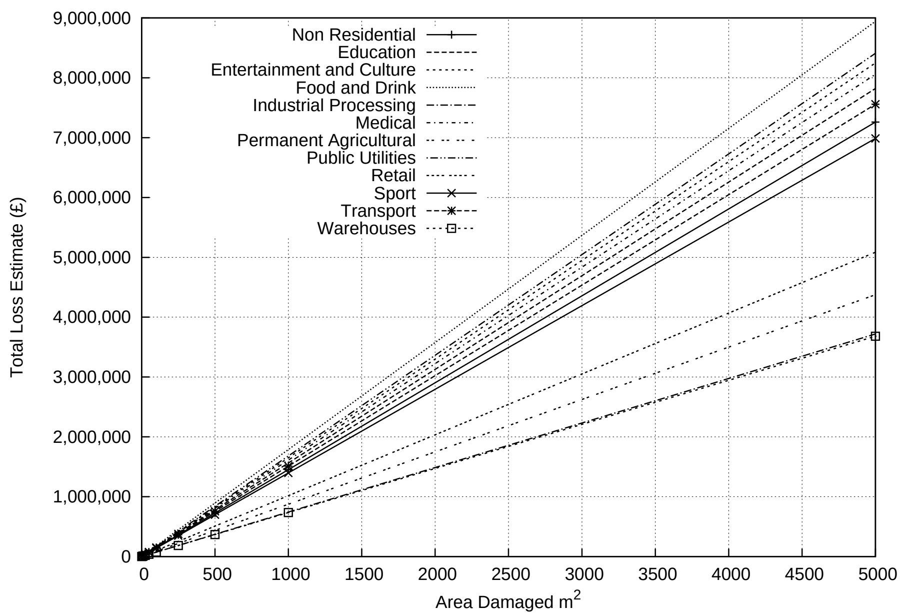



**Figure 5.5:** Average Cost of Construction - BCIS Cost Data

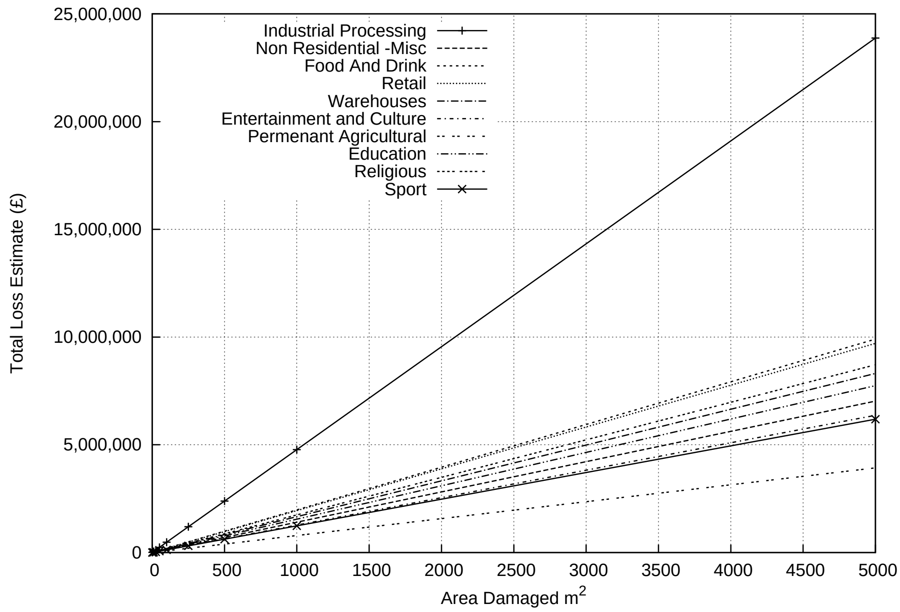



**Figure 5.6:** Average Costs of Fire - FPA Data

used as a statistical evidence base for calculating costs, taking the price per m$^2$ as the value for further cost calculations.

#### 5.3.2.2 T Test

Performing a $t$ Test on the two data sets will show whether or not the two data sets are significantly different. If they aren't, the FPA data set will be used to calculate the costs for later use in the research.

The formula for the $t$ Test is shown in Equation 5.7.

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{(n_1+n_2)}{(n_1 n_2)} \times \frac{(n_1-1){S_1}^2+(n_2-1){S_2}^2}{n_1+n_2-2}}} \tag{5.7}$$

where $\bar{x}_1$ is the average of the first data set, $\bar{x}_2$ is the average of the second data set, $n_1$ is the number of records in the first data set and $n_2$ is the number in the second and $S_1$ and $S_2$ are the standard deviations of the given data set.

From calculations, the variables are as follows in Table 5.17.

This gives a $t$ value of $3.014 \times 10^{-3}$. Looking at the table of degrees of freedom, $t$ is less than 2.09 and therefore the data sets are not significantly different to a probability of 95%.

However, for this test, data for Warehouse and Industrial Processing was removed to check

**Table 5.17:** T Test Variables With Data Removed

| Variable | Value |
|---|---|
| $\bar{x}_1$ | 1,294.67 |
| $\bar{x}_2$ | 1,835.37 |
| $n_1$ | 356.77 |
| $n_2$ | 1,037.19 |
| $S_1$ | 11 |
| $S_2$ | 10 |

**Table 5.18:** T Test Variables All Data

| Variable | Value |
|---|---|
| $\bar{x}_1$ | 1,351.8 |
| $\bar{x}_2$ | 2,525.36 |
| $n_1$ | 457.26 |
| $n_2$ | 3,864.54 |
| $S_1$ | 15 |
| $S_2$ | 15 |

the fit of the data without these seemingly significantly different results. Therefore a second T Test was carried out with the Warehouse and Industrial Processing occupancies still included in the data. These gave the values in Table 5.18.

Calculating $t$ for these figures gives a value of $t = 1.168$ which is below the threshold of 2.05 and therefore the results are not significantly different. This result means that by taking cost data from the FPA data set and converting them into a cost per m$^2$, these figures can be used and they will provide statistically similar results to the values given by the cost values in the BCIS tool. This means that the tool would not need access to a BCIS subscription and therefore the values could remain updated in future tools for free.

It should be noted that in a private conversation with Prof. G. Ramachandran it was mentioned that loss adjustor's would inflate the cost estimates of a building loss artificially so when repairs were completed, the end user would be happy it was under the cost originally quoted. Whilst this might be true, the data shows that the claims in the FPA data set (the majority of which are estimates), is very similar to that in the BCIS data set which is based on actual cost figures.

## 5.4 Damage Calculations

### 5.4.1 Numerical Conversion

This section details the attempts to calculate the figures for the damage before the fire brigade arrive on site. This allows the affect the FRS have on the final damage of a building to be calculated and an estimate calculated of the damage before the FRS arrive.

To calculate this, the arrival time of the fire brigade needs to be used, however this data is not included in the FDR 1 forms but is included in the Incident Reporting System (IRS) data. However, the IRS data that Loughborough has access to does not include this field (though this field gives an exact time for arrival) and the IRS data also includes the time the call was made. Therefore an estimate of the time is calculated by using the IGNTDISC (time from ignition to discovery) and DISCCALL (time from discovery to call). These fields are only *estimates* so the data from these calculations can *only be taken as an estimate* of the time.

The data is taken from the pre-filtered data set (where the data was filtered according to it's TOP (occupancy type) code so that the data set only contains the data on commercial, public and heritage buildings. The data for both records is given as a group number which is explained in Table 5.19.

**Table 5.19:** IGNTDISC and DISCCALL Codes Explained

| **Group Number** | **Timing** |
|---|---|
| 1 | Immediately |
| 2 | Under 5 minutes |
| 3 | 5 to 30 minutes |
| 4 | 30 minutes to 2 hours |
| 5 | Over 2 hours |
| 0 | Unknown |

Table 5.20 shows the frequencies of IGNTDISC and DISCCALL. For example, there are 205 cases where IGNTDISC and DISCCALL are unknown.

**Table 5.20:** IGNTDISC and DISCCALL Frequency Table

| | | **DISCCALL** | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 |
| **IGNTDISC** | 0 | 205 | 275 | 185 | 49 | 9 | 17 |
| | 1 | 8 | 3510 | 1286 | 148 | 14 | 19 |
| | 2 | 23 | 7434 | 5823 | 367 | 29 | 38 |
| | 3 | 54 | 5858 | 6038 | 1026 | 40 | 23 |
| | 4 | 11 | 695 | 930 | 146 | 47 | 10 |
| | 5 | 7 | 317 | 389 | 114 | 36 | 67 |

However, these values need to be given an actual time, similar to the alarm operation time frames. As with the fire damage figures used in the alarm activation calculations, the grouping of the estimated times mean that the accuracy will be restricted due to not knowing the exact figures. The fire damage in the alarm activation calculations were converted back into an average damage by using the geometric mean of the group range. This was chosen because the grouping sizes were uneven and the geometric mean gives a better indication of the group ranges. Whilst the time data here is in uneven groups, due to the splitting of the groups, the geometric mean is unsuitable. Using it would give two categories an average of 0 (the immediately category and the under 5 minutes category). Therefore, the arithmetic mean is used instead. The results of converting the groups into a given value is shown in Table 5.21.

**Table 5.21:** IGNTDISC and DISCCALL Converted to Actual Values

| Group | FDR 1 Meaning | Time (minutes) |
|---|---|---:|
| 1 | Immediately | 0 |
| 2 | Under 5 minutes | 2.5 |
| 3 | 5 to 30 minutes | 17.5 |
| 4 | 30 minutes to 2 hours | 75 |
| 5 | Over 2 hours | 120 |
| 0 | Not known | - |

As the table shows, the groups now have a value that can be used to calculate the times before the FRS arrive on site.

### 5.4.2 Fire Time Calculation

With the values from the FDR 1 data now given a complete numerical value, the fire time before the FRS arrival can be calculated. For this the formula in Algorithm 3 is used. This code filters out any data that is 0 or has incomplete records.

**Algorithm 3** PAWS SPSS Filter Code to Remove 0 Records

```
FILTER OFF.
USE ALL.
SELECT IF (IGNTDISC ~= 0 AND DISCCALL ~= 0).
EXECUTE.
```

A total of 843 records are removed and 34,004 remain. The database now only contains records with complete times so they can be analysed. The times are then added together (IGNTDICS + DISCCALL) to give the total time.

**Table 5.22:** Number of Incidents With Time Taken To Call the FRS

| Time (minutes) | No. of Incidents |
|---|---|
| 0 | 3,510 |
| 2.50 | 8,720 |
| 5.00 | 5,823 |
| 17.50 | 6,006 |
| 20.00 | 6,405 |
| 35.00 | 1,026 |
| 75.00 | 709 |
| 77.50 | 959 |
| 92.50 | 186 |
| 120.00 | 336 |
| 122.50 | 427 |
| 137.50 | 137 |
| 150.00 | 47 |
| 195.00 | 46 |
| 240.00 | 67 |

Table 5.22 shows the number of incidents and the time taken to call the FRS in this instances. These records were selected using the code in algorithms 4 to 18 shown in the appendix. This separates the data so that it can be analysed further.

The hypothesis is that the damage in a building will be larger the longer it takes the FRS to get to the seen so as the timing increase, the damage should also increase.

To investigate this, the timings above are compared to the area damaged (AREATOT) category in the FDR 1 data. To compare each category with each other, the number of incidents in each area damaged group needs to be converted to a percentage figure as the numbers of total incidents in each time category are different. This gives the graph in Figure 5.7.

This seems to back up the hypothesis that and therefore makes it easier to quantify damage before the call to the FRS is placed. However, a statistical test needs to be carried out to prove that the differences are significant.

### 5.4.3 Damage Increases With Time To Respond

In the last report, the damage before the fire brigade arrival was being calculated and Figure 5.7 was produced.

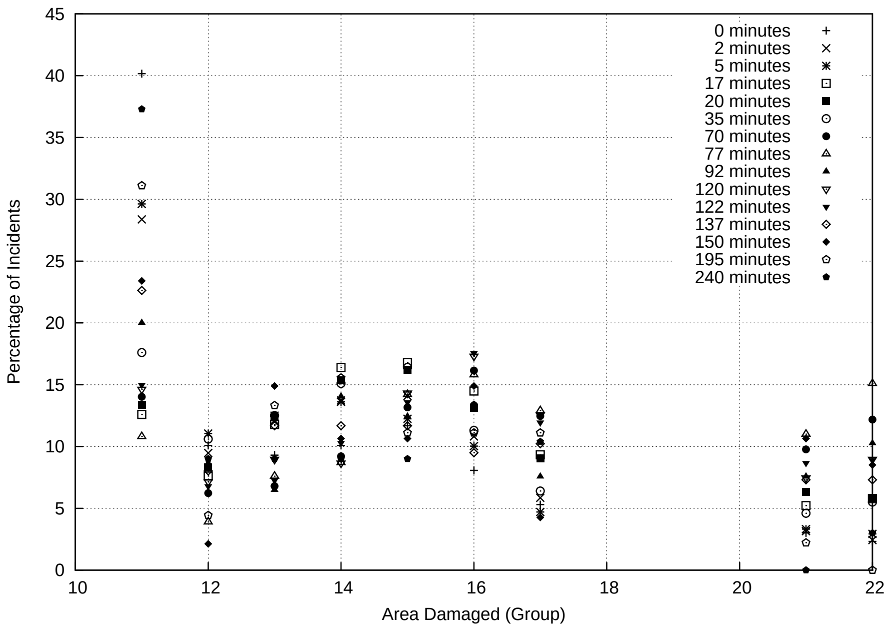



**Figure 5.7:** Time to FRS Call and Area Damaged

Figure 5.7 is particularly messy and makes it hard for any conclusions to be drawn from the data. It was decided to perform a statistical test on the dataset but this would prove inconclusive, as test would only infer that one part of the data was significantly different to the rest and would not identify which parts were statistically different. However, by grouping some of the values into a combined graph, this would show the differences between each group and based on the graph, if the difference was significant (if the data is different, the graphs would have a peak value and shape).

Therefore the data was combined back into different groups. The groups were combined into 0 minutes (immediate), under 5 minutes, 5 to 60 minutes, 60 to 120 minutes and over 120. Combining the data back into these groups gives Figure 5.8.
Figure 5.8 clearly shows a difference between the datasets, showing that as the time to call the FRS increases, the damage increases. Therefore as time goes on, the damage increases, which supports the initial hypothesis that that probability of damage increases with time.

Obviously, this is an estimate of the time and also an estimate of the time for damage to occur - the FRS cannot attend a fire instantly and therefore this only proves that fires that are detected earlier and the alarm raised earlier are more likely to be smaller fires.

The FSEC toolkit currently does not take into account damage that occurs to the building when the FRS arrive on the scene. This means that once the FRS arrive, the damage to the building is assumed to stop. However, the new IRS software does not assume this

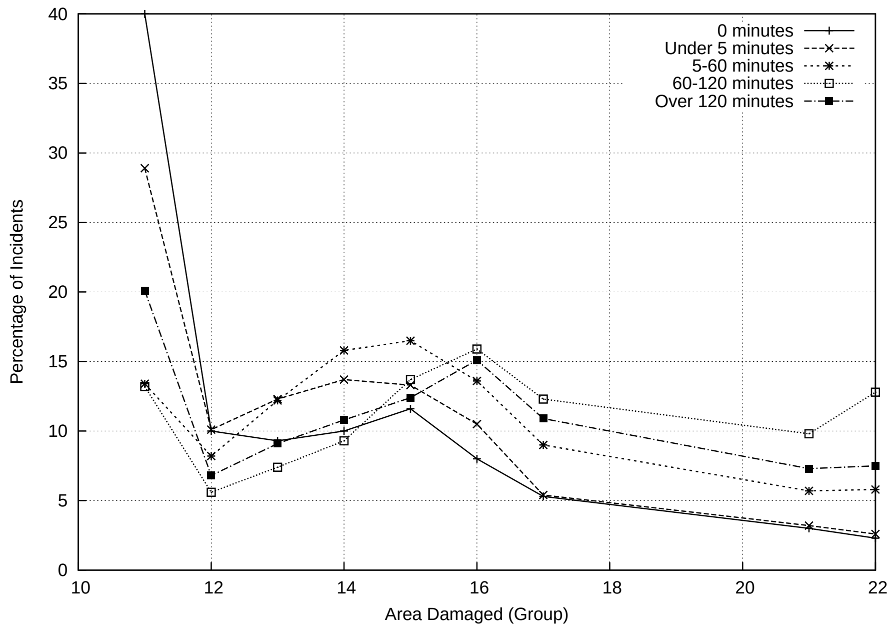



**Figure 5.8:** Time to FRS Call and Area Damaged - Grouped

and contains a question for the area damaged (size of the fire) on FRS arrival and the area damaged when the FRS finish fire fighting operations. Calculating the difference between these two values would allow for the damage rate whilst at the scene to be calculated. It should be noted that this could depend on a number of different variables, such as the combustible materials involved, the number of appliances that turned out and the type of appliances used. Yet, this figure could still prove a valuable figure for the estimation of fire damage, as long as the average time to fight a fire can be ascertained. As the IRS data also include the values for arrival time of the FRS and the time when the last FRS appliance left the scene, this could be calculated and a time function determined.

### 5.4.4 Quantifying Damage

The next step is to take the damage figures discussed in Section 5.4.3 and quantify how long a call to discovery actually is. However, with the data currently available, this would be hard to achieve. An easier method is to use probabilities to show the damage from the time from ignition to call to the FRS and present a case for each time frame used in Figure 5.8. As mentioned before, the difference between a fire in an office and an industrial unit could potentially be very different so this should further be grouped by occupancy type.

Previous work by Wright and Archer for Entec (Wright and Archer, 1999) calculated a loss model based on time for FRS arrival. In their work, the costs are calculated using the FPA public large loss results and results extrapolated. These public figures are averages from the whole database that the FPA keep and would not be as accurate as using the entire data set. A rate of damage is also calculated, leading to a figure for the loss cost per minute figure.

Wright's model makes reference to a report by Peaker *et al* in 1977 that states that consequential loss from fires is double the direct damage from fire and based on this evidence, the FPA figures that are used are doubled. However, this leads the results to be excessively higher than current day loss estimates (the Entec report is from 1999, even with 10 years of inflation, the costs are not comparable). Table 5.15 shows the costs that were calculated from the current FPA database.

Where a value is not covered in the FPA dataset shown in Table 5.15, the BCIS data can be used to provide a value as the datasets are comparable in costs, as shown in a previous report.

With these figures, a cost graph can be drawn (from which a formula derived that will allow for calculation of a damage rate and therefore cost of loss).

## 5.5 Regression Analysis

In Section 2.3.1, the regression model constructed by Lin *et al* (Lin *et al*., 2009) was discussed. This model used regression analysis to find the factors that affected the fire size. This data was based on questionnaires and interviews with fire fighters, those homeowners that had suffered from a fire incident and fire professionals. This is the opposite of this work, which has used previous, empirical, fire incident data as the basis of the data for regression analysis. In the Lin *et al* research, the research items were attributed variables based on how important the factors were ranked according to these questionnaires and interviews. However, this research has access to the fire incident data for the UK and it was hoped that analysis of this data would show the factors that affect the fire size, based on analysis of the data. Regression analysis of the fire incident data should identify the aspects of the fire incident data that affect the size of the fire and therefore how these values should be used in the DSS tool to affect the fire damage (and therefore cost), estimation.

Multiple regression analysis was initially chosen, as the analysis method for investigating if the factors discussed previously in this chapter and later in Table 5.23, would affect the fire size would allow an estimated area damaged to be produced as the output of the analysis (the dependant variable would be the area damaged, based on the multiple independent variables, the factors affecting fire size). As the outcome of the analysis is to provide an estimated area of damage, this method of regression analysis would provide that. Therefore it was considered to be the most appropriate method of data analysis for the proposed outcome of this research.

For the multiple regression model, the FDR 1 database was used. This database was chosen over the FPA dataset because it had a much larger set of records - the databases and how the data was collected was discussed in more detail in Section 3.5.1 The FDR 1 information can be found in a Home Office publication (Home Office Research, Development & Statistics Directorate, 1998).

The factors potentially affecting the fire that are contained in the FDR 1 data are found in Table 5.23. It should be noted that the full FDR 1 database contains more factors that could potentially affect the fire size but these were not provided by CLG in the dataset given to the project. Therefore the data fields contained in Table 5.23 detail the factors estimated to affect the total amount of damage caused by a fire that is recorded in the FDR 1 database and that the project has access to.

**Table 5.23:** FDR 1 Factors Potentially Affecting Fire Size

| FDR 1 Code | Description |
|---|---|
| IGNTDISC | Time from Ignition to Discovery |
| DISCCALL | Time from Discovery until FRS Call |
| ALARM | Was an alarm system present? |
| ALARMOP | Did the alarm operate? |
| TOP | Type of property where fire started |
| EXTSYS | Was an extinction system present where the fire started? |
| SYS1, SYS2 and SYS3 | What system was installed? |
| OPER1, OPER2, OPER3 | Did the extinction system operate? |
| FFBEFRE1 and FFBEFRE2 | Fire fighting before FRS arrival |
| DANGSUBS | Was a dangerous substance present? |

Initial attempts to use multiple regression analysis proved to be unsuccessful. It was unable to produce an estimate of the fire damage. This was considered to be due to the method of data collection and storage within the database. The data for the majority of factors identified in Table 5.23 are stored in the database as binary values (Yes or No) and multiple regression analysis struggled to differentiate between lots of binary values and therefore it was considered that multiple regression analysis would not provided the results required. Additionally, the database stores the resultant fire damage in terms of grouped data such as less than $1m^2$, $1\text{-}2m^2$, $3\text{-}4m^2$). Grouping the area damaged in this manner meant that multiple regression analysis was was made more difficult, as the dependant variable (the area damaged) ideally needs to be a continuous range. Therefore, a logistical regression analysis method was investigated.

Unlike multiple regression, logistic regression allows the use of binary values in the regression analysis. This means that the values from the FDR 1 dataset could be input into the analysis model. However, the dependent variable for a logistic regression model will only be between 0 and 1. Therefore this wouldn't give an estimate on the size of the fire - it could only estimate the probability of a fire reaching a certain size - a value of 200m² was chosen as the area damaged grouping in the FDR 1 dataset reaches 200m² and then the actual value of damage is used.

It was decided that whilst the occupancy might affect the size of the fire, it would be best to run the logistic regression analysis for each occupancy, giving a model based on the occupancy, rather than an overall figure which took into account the occupancy. This would allow for a more accurate logistic regression models for each occupancy, rather than a generalised model that attempted to consider all factors for all occupancies. This was confirmed by cross tabulating all the proposed variables against the dependant variable and investigating the chi squared values. This allowed the significant values to be identified and used in the model. Performing the cross tabulation overall showed that almost all results were statistically significant, with a $p$ value of 0.000. However, trying to perform a logistic regression model with all values present gave the results that the dependant variable (damage below or above 200m²) was a constant and therefore the logistic model failed.

Repeating the analysis for each individual occupancy resulted in cross tabulation results across the dataset that allowed the significant variables to be identified across the database. However, performing logistic regression modelling on each individual occupancy, using only the significant chi squared data again did not provide a model - the analysis would discard all variables and state that the model was a constant value. Having performed a chi square test for all the data, a model was attempted using the most commonly significant results across the occupancy which was IGNTDISC and DANGSUBS. Performing logistic regression on the overall dataset with just these two values (to see if a smaller, more discriminant model would be calculated) resulted in a model being constructed, however as seen in Table 5.24, the model can be seen to produce correct predictions 95.4 percent of the time but inaccurately predicts fires above $200\text{m}^2$ as it does not predict *any* fires in this category so is actually a bad representation of the actual work.

This is confirmed by the model's $R^2$ value which is 0.16 (Cox & Snell) and 0.052 (Nagelkerke) which indicates a poor model. It can then be seen then that logistic regression of the data gives a poor fitting model that does not accurately predict probability of a fire being

**Table 5.24:** Results of the Logistic Regression Model Using IGNTDISC and DANG-SUBS

| **Observed** | | **Predicted** | | **Percentage Correct** |
|---|---|---|---|---|
| | | Under $200m^2$ | $200m^2$+ | |
| **ATOT BINARY** | Under $200m^2$ | 32,720 | 0 | 100.0 |
| | $200m^2$+ | 1,568 | 0 | 0.0 |
| | **Overall Percentage** | | | **95.4** |

above or below $200m^2$.

## 5.6 Summary

This chapter details the analysis of the UK fire incident databases and the BCIS cost data to provide the empirical evidence for the proposed DSS tool.

Whilst the chapter did not investigate the probability of the fire's starting, as fire engineers in the UK assume that a fire will always occur for the design of the safety features (as discussed in Section 2.2.1, the probability of alarms and active fire protection measures were investigated and whether the activation of these items would affect the size of the fire. It was found that both the activation of alarms and sprinklers are likely to reduce the area damaged by fire. Interestingly, the sprinkler activation statistics show that sprinklers are perhaps not as effective as discussed in other research.

Analysis of the BCIS cost data and comparison to the FPA cost data showed that there was no statistical difference between the construction costs and the estimated rebuild costs. This means that the loss adjustor's do not tend to over estimate the costs and that either the data from the FPA or BCIS database could provide cost data to the proposed DSS tool.

Finally, regression analysis was carried out on the FDR 1 database to try and identify the estimate area damaged by fire by the analysing the different factors that could potentially effect the fire size. Multiple regression analysis was initially used but logistic regression was a better analysis method for the type of data used. However, the method of storing the data (namely in a binary format) meant that even a logistic regression analysis method proved to be unable to differentiate the differences between the factors.

# Chapter 6

# Decision Support System Model

## 6.1 Introduction

The proposed outcome of the statistical analysis of this work is a decision support tool. This tool would take data from the data sources indicated in Section 3.5. In addition to the statistical evidence gained from the analysis of the data, other sources of information are identified.

The design tool, or more precisely, the Decision Support System (DSS), will allow the end user to be able to determine the most cost effective method of fire engineering design and then allow them to display these results to clients and architects to help them make an informed decision in regards to the costs of the building and the costs of any losses that will be incurred from a fire. In the context of this research, a DSS is:

> *"a computer program that is used by engineers to perform analysis of a building or its services (prior to realisation) for the purpose of making, modifying or evaluating design decisions"* (Lockley and Sun, 1995)

With this in mind, the proposed DSS tool will be a computer program (though this thesis only deals with the framework and methodology of the tool) for a fire engineer to use within the design of a fire engineered building.

In the same paper as quoted above, Lockley and Sun state that a design tool should be user friendly but the model behind the tool must be transparent to the end user, as well as making the program user friendly. This gives the end user confidence in the results generated by the tool as they can follow the process the tool has taken to reach its conclusions.

## 6.2 Decision Support Tool Structure

This section details the structure of the proposed DSS. The previous chapters in this research detail the analysis of the fire incident data that was to provide the main source of data for the tool. However, as was shown in Chapter 5, the method of data and collection and storage made it difficult to analyse the data and draw meaningful conclusions, other than the database of fire incident data within the UK needs to be rebuilt for detailed statistical analysis in mind if the data is to prove useful. However, the methodology of the tool can be constructed so that if or when the data is available, the tool can then make use of this data for the DSS.
Figure 6.1 shows a data flow diagram for the proposed DSS.

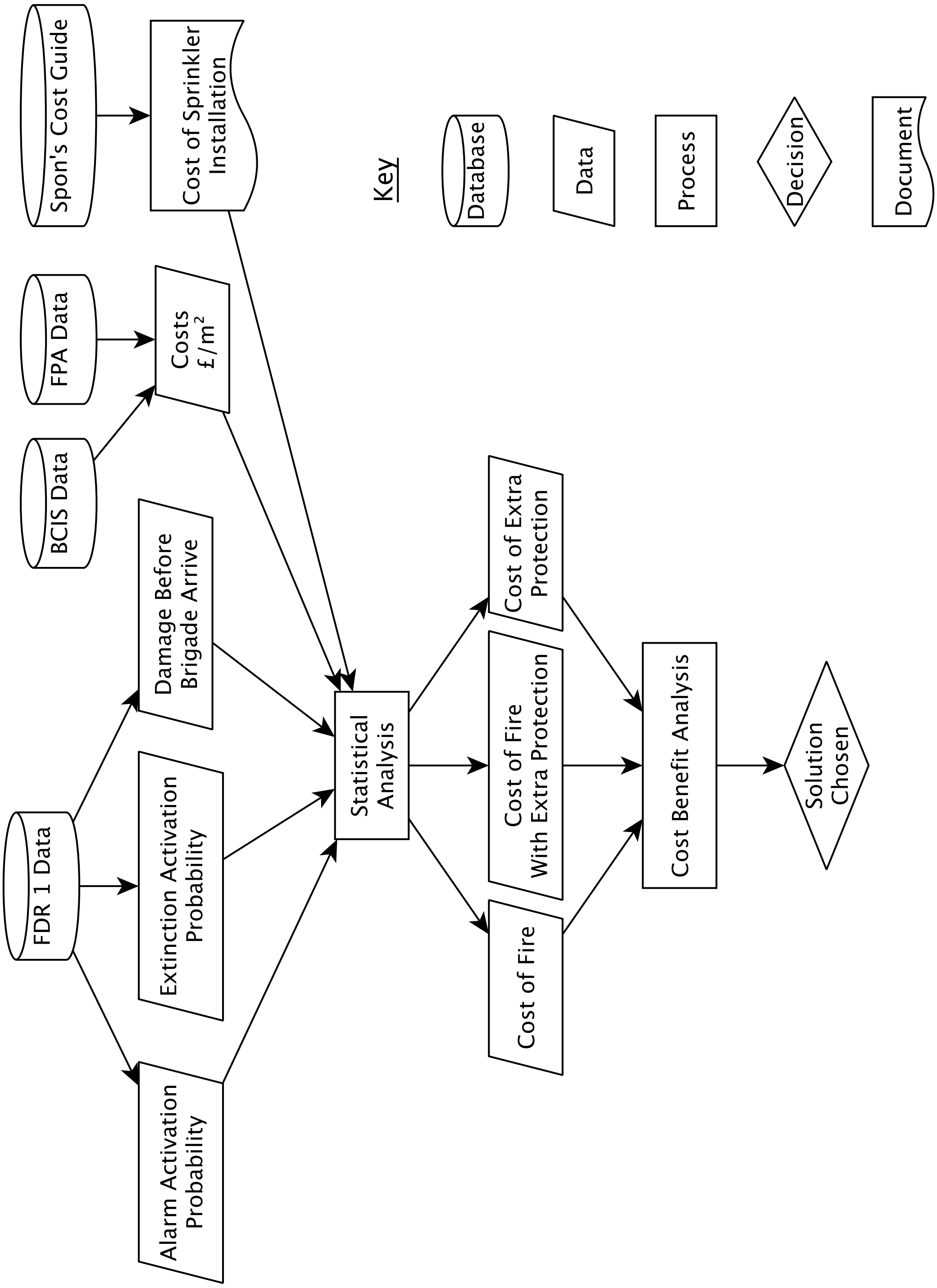



**Figure 6.1:** Data Flow Diagram of Decision Support Tool

### 6.2.1 Inputs

The main sources of data for the DSS tool are already identified in 3.5.1. These databases are the fire incident databases from the FDR 1 reports and the Fire Protection Association (FPA) insurance data. The main areas of data being extracted from these databases are the probabilities of different systems activating, the damage from the fire incidents and the costs of this damage. Additionally, costs from the Spon's Cost Book (Davis Langdon, 2012) (for the cost of additional fire protection) and the Building Cost Information Service (BCIS) cost database are input to allow a comparison of different fire safety plans to be considered. Figure 6.1 shows the main sources of data as databases and identifies the key aspects of that database that form the basis for the analysis processes.

The FDR 1 database will form the core part of the analysis. It suffers from a number of limitations, discussed in Sections 3.5.1.1 and 7.3.1 but even with these limitations, it forms the basis of the analysis because of its large size and its national representation of fires from across the UK.

The FPA dataset, also suffers limitations discussed in Sections 3.5.1.2 and 7.3.1. However, it contains cost estimates of the fire incidents and can therefore with some statistical manipulation of the data, provide estimates for the costs of the various occupancy types being studied within this research. Whilst it provides other data, due to the limitations imposed by the sampling, this data has not been used for the statistical analysis of fire sizes. It is however used in later analysis in consideration of the costs of fires. Case studies of actual fire costs could be used to estimate the costs of fire but this database provides an already collected estimate, which is supposed to be updated as the progress of the insurance claim is ongoing so that the final entry in the database should be the final cost. However the larger number of fires in this database should mean that the data represents a fairly accurate figure for the cost of fire in a particular property without future access to the database as access to the final costs of fires would be kept by insurance companies and this information is unlikely to be released for free in the future without being edited in some form. The costs in the FPA database are taken from experienced loss adjustor's. To ensure that that figures are reasonable, the figures will be compared to the data held by the BCIS which collect the costs of new build structures. Therefore comparing the costs to this database will allow a comparison to be made to see if the FPA results represent a similar value to a new build of a building. This method, does however, assume that the cost of a rebuild is similar to that of a new build, which is considered a reasonable assumption.

The databases used for the analysis were currently reasonably small - the FDR 1 data used was reduced by the weighting system employed by Department of Communities and Local Government (CLG) on the data (see Section 3.5.1.1.1) and the FPA dataset was restricted by the small number of fires it entered into the database and the small number of years it has been collecting data for (at the time the database was taken, the data within only covered incidents over a year and three months). Therefore the data used in the work to date covers a small section of the fires in the UK over the past 10 years. However as the database increases in size, potentially it could affect the calculation time for the model as the amount of data needed to be analysed increases. Future work can investigate using the Incident Reporting System (IRS) database that CLG collects currently - this database replaces the FDR 1 database and is the current method of fire statistics collection by the UK Fire and Rescue Services (FRS's).

This is not considered to be an issue in this instance. The database size should not affect the proposed DSS tool as the data is analysed separately to that of the tool and only the probabilities and the outcome data is included within the DSS tool and therefore periodic updates to the statistics would result in the model being updated, most likely by the author, and then an updated DSS tool issued to the end users of the tool. This way, scaleability of the database does not affect the final model being used by the end users.
In regard to the cost of the additional fire engineering solutions being installed within a building, Spon's Cost Guide (Davis Langdon, 2012) provides estimates of the cost of installing various measures, mainly in this case, sprinklers. It provides a cost per $m^2$ figure which allows an estimate for the cost of sprinklers being installed to be calculated based on the area of the building being considered. By providing the cost estimates of a sprinkler installation (installation of passive fire protection measures can also be calculated by changing the value for the cost of fire resistance) allows the tool to take this into account during the comparison of the basic building design and the more heavily protected fire protected solution to give an estimate on if the cost of installation is worth the cost of installing these additional fire protection measures.

### 6.2.2 Process

The process marked as statistical analysis in Figure 6.1 provides the main work for the proposed DSS. In this process, the data is statistically analysed, with the intention of three outcomes - calculating the cost of a fire (based on the estimated damaged), the cost of a fire had extra fire protection been installed (again, based on the estimated damage) and finally the cost of the extra fire protection. This statistical analysis is considered in this chapter. This analysis will take into account the various aspects of the building that could potentially affect the fire size and then putting these into a model, will output an estimated area damaged by a fire which can then be combined with the cost of fire data being drawn from the BCIS and FPA datasets. This process can then be repeated, changing the amount of fire protection installed on the building. By providing a comparison of the expected area damaged using one level of fire protection and the installation of additional fire protection, a cost benefit analysis can be undertaken to investigate if the additional fire protection is worth the higher initial cost to install. The tool would be able to provide estimates of the additional cost to install the extra measures and as it provides an expected cost of damage for both the lower and higher levels of protection, will allow the end user to immediately see if the levels of fire protection can be optimised further in regards to cost. Additional measures may also provide a benefit to life safety though this is not addressed within the tool and this research as it is already assumed that life safety is sufficient if the Building Regulations are being met.

### 6.2.3 Outputs

The main output of the model is to provide a basic cost benefit analysis report for the fire engineer using the DSS to support their work. This is done by estimating the damage that will arise should a fire occur to a property based on the occupancy type, the size of the building and the type of fire protection methods installed. With this data, an estimated fire damage is calculated for the building design and this is compared to the same design but with additional fire protection installed. A comparison of the the two outputs should give a difference in damage - the cost of which can be compared to the cost of the additional fire protection methods installed allowing a cost benefit comparison between the two solutions to be considered. Presenting this data in a format that is easy to read will allow the fire protection engineers to make the case to the client that additional fire protection measures are likely to save more money in the event of a fire and therefore the cost of this protection is beneficial over the lifetime of the building.

## 6.3 End Users

The end users of the model, originally envisioned to be fire engineers creating the fire engineered solutions for the final design of the building, will use the tool to create a report for the clients to decide on what method to proceed with. Yet, other stakeholders in the design process could make use of the framework of the DSS tool and therefore come to the same conclusions.

This section will explore how the different end users could make use of the tool.

### 6.3.1 Fire Engineers

In the initial stages of this research, questionnaires and interviews were carried out with various people within the Architecture, Engineering & Construction (AEC) industry and the fire engineering industry. These interviews indicated that fire engineers were the ones responsible for the creation of the fire safety strategies within buildings (see Section 4.2.2) and that they would make use of a cost benefit analysis tool for the fire safety measures being installed within the buildings they worked on (see Section 4.2.3).

Therefore the model was aimed at the fire engineers to allow them to conduct a cost benefit analysis on the proposed fire engineering solutions that they were proposing to allow them to see what effect the removal or addition of fire protection measures would have on the cost of a fire when/if the building has a fire (it is assumed for fire engineering purposes that a fire will always occur within the building (BSI, 2003a) and therefore the probability of a fire igniting is not considered within the model). Section 6.4, later in this chapter, details how a fire engineer would make use of the tool and the steps they would take to reach the final outcome.

As the fire engineers roles within the design process is to create the fire safety strategy for the building, the tool would not change their role. The tool would mean that the fire engineer has to create a second strategy to allow the cost benefit analysis to compare the potential fire losses that each strategy is likely to incur. This will perhaps add a slight additional workload onto the fire engineer but should hopefully be paid off in terms of the additional benefits offered to the client.

Outputs to the model for the fire engineers would be a cost benefit analysis that would allow them to approach the client with a range of fire strategies (or alternative fire strategies) that would let the client (or stakeholder) decide on which fire strategy he wanted to proceed with. This could be a simple case of estimated losses if a fire occurred though would more likely be a more detailed cost breakdown, such as a table detailing the likely cost of a fire strategy, the cost of additional protection and the losses that each strategy would entail. This would allow the fire engineer to broaden his services and allow the stakeholder of the design and build to decide on whether or not they wanted to install the additional fire protection. As the fire engineer always assumes that a fire will occur within the building, the stakeholder may require the probability of a fire occurring within their building but this currently isn't proposed for the DSS in its current design.

### 6.3.2 Architects

Whilst architects were not envisioned to be the main users of the cost benefit tool, if it were available as a Building Information Modelling (BIM) plugin or available to architects, they could potentially make use of the tool before the fire engineer is even brought into the project.

It is considered that the architect wouldn't make use of the full potential of the tool as it is unlikely that the architect would create two different fire strategies to conduct a cost benefit analysis. However, the tool could still prove beneficial to the architect to allow them to consider the cost of the initial layout they might have designed.

By allowing them to understand the potential costs of a design, they can potentially see an area that getting the fire engineer involved at an earlier stage might save more money for the client. Alternatively, by putting in the initial design into the cost analysis model, they can get an idea of the potential cost of damage and let the client know at an early stage, as the architects are involved very closely with the client and at an earlier stage of the design process (as seen in Table 4.2 in Chapter 4). This early contact with the clients could potentially lead to the ideas of spending more on fire protection, rather than less, being more readily accepted as the architect can help guide the design when it is more flexible, rather than when the fire engineer is involved at which point the design may be fairly fixed.

Whilst the fire engineer will report to the stakeholder of the building or the architect, the architect is likely to have a bit more of a role in the design and flexibility of the building and therefore the results of the DSS tool could potentially be acted on by the architect without involving the building stakeholder. However, the results will be the same as that for the fire engineer. The architect will be in the best position to change the design of the building to take into account the recommendations of the fire protection measures and can change the design to provide additional fire protection.

### 6.3.3 Insurers

The main benefit for insurers is that fire engineers would consider the costs of the fire protection measures they are installing and hopefully installing greater fire protection measures for the building than that required by the Building Regulations. Obviously, this would allow the insurers to hopefully see a a reduction in fires and fire damage.

By having access to the tool, the insurers can see the effects that the additional fire protection measures can have on the estimated damage levels. They can therefore make recommendations to the client that by having these additional measures installed at the design stage is likely to save them money in the long run.

Whilst this model is aimed at the design stage, unfortunately, insurers do not always get involved in the design stage, as seen in work by Wilkinson (Wilkinson, 2010). Without getting involved at the design stage, the insurers role with this DSS tool is unfortunately limited. If the tool is made available to them, they could perhaps make some recommendations to insurance brokers and to clients prior to any building work or design work taking place as purely advice but specific project work or benefits may prove to beyond the scope of the insurance role.

Whilst it is envisioned that the tool is a proactive design tool for the building designers and fire engineers, in the hands of the insurance industry, it unfortunately would come across more as a reactive tool. By putting the building design into the tool, the insurer could ask the designers why various design choices were made. They would also be able to see what the likely affect of the additional fire protection measures would achieve in the building - most insurers would ask for a reasonable level of fire protection to protect property if the costs were proportionate to that of the cost savings that they might entail. With this information, it would provide the underwriters an additional tool in calculating the premiums on the property in question.

### 6.3.4 Stakeholders

The stakeholders of the project are considered to be the clients or the end users of the building i.e. the company responsible for investing in the construction and design of the building in the first place.

Their role with the tool is a lot less involved than the rest of the roles discussed previously. It is considered that the stakeholders would not ever access the tool itself and would only ever be presented with the cost benefit analysis conducted by the fire engineer or to a lesser degree, an architect or insurer.

However, the stakeholder may want to see the tool in action or see the results for themselves and therefore the tool would mainly be used in a checking role by the stakeholders in instances where it is required on an individual basis.

The outcome of the tool, the cost benefit analysis, is considered to answer the questions of the stakeholders and to present to them in an easy format to view on how the fire protection measures affect the damage and therefore cost within the building. These results need to be easy to read and simple to allow the stakeholders to make an informed decision.

The building/design stakeholder is the group that would make the most of the tool - the results are tailored that regardless of who uses the tool, the stakeholder is faced with the choice of additional fire protection costs initially and a lower cost in regards to a fire occurring or the cost of meeting only the life safety requirements and potentially having a more costly fire in the future.

### 6.3.5 Overall

Usage by each group within the building design was discussed in the previous sections. In the Stakeholders section, the outcome is highlighted as needing to be simple - this applies across all usage scenarios as without having a clear and concise output, the stakeholder and the designers of the building cannot make any clear or concise decisions on the additional fire protection.

The usage scenario in the following section sets out the usage by a fire engineer for use in the design process to help them approach the design stakeholder and let them know of the potential cost savings.

## 6.4 Scenario for the use of Conceptual Fire Safety Model

The conceptual model being proposed in this thesis is for use by those involved in the fire engineering design of a building - this includes the specification and design of the fire safety systems, such as the level and grade of alarm system, the automatic fire detection systems along with the passive fire protection and compartmentation.

As discussed in Section 4.2.2, fire engineers were found to be the ones that were involved in this section of the building design and this is why the tool is aimed at this section of the AEC industry. Getting fire engineers involved at an early stage in the design process was discussed and in the views of the respondents, the stage of the involvement of the fire engineers would affect the costs of the final project. However, consideration isn't particularly given to how the fire protection measures specified will perform and reduce fire damage in case of a fire within a building - the main aim is Building Regulation compliance and therefore, by extension, life safety.

This was another of the conclusions that was drawn from the questionnaires sent to the UK AEC industry and by meeting the functional requirements of the Regulations (Crown Copyright, 2010), either by the use of the Approved Document, a Building Standard or by performing fire safety calculations. This is the minimum level of fire safety expected within the building. Where property protection is considered, additional measures, over and above that required by the Building Regulations will have to be installed. Insurance companies (through the FPA and RISCAuthority) have published a version of Approved Document B that incorporates the insurers recommendations for property protection (RISCAuthority, 2008). This is identical in layout to the original version of Approved Document B (ADB), as published by CLG. However, it also contains additional recommendations and notes, where appropriate, noting the additional measures recommended by the insurance companies for protection of the building structure and property contents in event of a fire. This allows the fire engineer to consider these requirements at the earliest possible stage to avoid a potentially costly redesign at a later stage in the building and design process. However, this only covers those buildings that are following the guidance in ADB and therefore alternative design solution, such as those within BS 9999 or BS 7974 are not covered and the engineer would have to use his or her expert judgement on what facilities are required to increase the property protection rating to the building and contents. Whilst the guidance with the Insurance Requirements ADB can be considered for an alternative, fire engineered solution, this proposed design tool methodology aims to provide additional assistance to the designer, regardless of the design guidance being used to complete the fire safety assessment of the building.

The DSS tool would allow the fire engineer, at this design stage, to input various parameters of the building into the tool to get an estimated cost of the installation of the protection measures that they are specifying. The tool will also output an estimation of area damaged and the equivalent loss in terms of cost that this design will likely to incur should a fire occur. It will assume that the data into the tool is for Building Regulations approval (and is therefore the minimum fire protection required for life safety and not property). Alongside the calculation, it will also calculate the predicted losses and costs should additional fire protection measures be installed, such as sprinklers or passive fire protection.

To illustrate how the conceptual tool would fit into the design process and help the fire engineer, the section below detail the tools use in two different scenarios where the tool could potentially be used.

### 6.4.1 Usage Scenario: Office Block

Office blocks are a common example of an occupancy type where fire engineering solutions are considered for the fire safety of the occupants. In an office environment, fire engineering solutions mean that stair cores can be removed and escape widths reduced, which increases the usable (and therefore the total area available to rent out) space for the buildings owner to make use of. This removal of stair cores and additional fire protection measures for escaping occupants is still considered safe (as it follows the engineering guides in the British Standards, such as BS 9999) but allows for the occupants to make fuller use of the building. Additionally, engineering analysis and Computational Fluid Dynamics (CFD) modelling can be undertaken to prove that this is the case. In terms of costs for the owners, the additional costs of hiring fire engineering experts to implement a fire strategy removing these features can be recouped through the additional rent they are able to collect from the occupant of the building by offering a large usable space for the occupant to make use of.

As mentioned in the previous section, in an effort to promote property protection within buildings, insurance companies have published a guidance document detailing the insurance companies requirements and advice for improving property protection from a fire incident (RISCAuthority, 2008). Whilst the Insurers Requirements indicate that additional passive fire protection should be installed (above that required to meet the life safety requirements of the Building Regulations - see Table A2, Page 137 of the guidance document), they do not indicate what the likely damage reduction (and therefore what cost saving is achieved). Therefore, the client employing the fire engineer only sees the additional cost of this passive protection and does not see the estimated benefits that this additional cost would provide to them, either in terms of insurance premium reductions or reduction in losses during a fire. Therefore, the insurance recommendations are often not considered and the building is considered using only the original ADB as published by CLG. It can be seen when this is the case that the property protection recommendations are not installed and therefore no additional benefit is provided to the building.

The proposed design tool in this instance would allow the fire engineer undertaking the design of the building to implement the additional fire protection requirements/advice of the RISCAuthoriy guidance and be able to show the results of that additional protection to the end user of the fire engineers work (the client of the fire engineer might not be the one providing the funding and making the decisions on the construction costs), allowing them to make a more informed decision on whether to proceed with only the Building Regulations required levels of fire protection for life safety or to install the additional fire protection levels to provide a level of additional property protection. The proposed design tool methodology would allow the additional fire protection levels to be taken into account - the estimated size of a fire for an office occupancy could be calculated using the different variables of the office size, type and protection measures in place (be they life or property protection) for both the life safety, code compliant solution and for the same scheme but with the additional fire protection measures installed. Using the cost data built into the model, a cost estimate can be attached to the loss of both scenarios.

This then allows a cost comparison to take place, looking at the cost effectiveness of the additional installation of fire protection measures on the loss.

This data allows all the facts to be known by the client and fire engineer and the design can be changed accordingly. Additionally, it is considered that the Insurance Industry would be able to make use of the same tool to investigate the cost of fires - by seeing how much money can be saved through the installation of additional fire protection, premiums can be changed to represent the lower cost risk a property protected building provides to the insurance portfolio. Insurance companies could also use the tool to help provide incentives to building designers to install the additional protection. Currently, from experience, it is rare for the insurance companies to be consulted on a building design until the project nears completion. This means that the insurance companies often do not get to offer any recommendations on the fire protection methods until the fire engineering engineers have completed their work and appointment. Earlier involvement to get the insurance companies involved by the client could lead to better property protection systems being installed and considered.

As a worked example, the office of the multi disciplinary engineering company Hoare Lea is considered.

#### 6.4.1.1 Western Transit Shed

The Western Transit Shed is the location of the London office of the Mechanical and Electrical engineering consultancy firm, Hoare Lea. Forming part of the Kings Cross redevelopment in London, the building offers office and retail space to a number of different tenants over two floors and a mezzanine level.

The building a is classed as a new build under the Building Regulations and was completed in 2012 - it was designed to meet the life safety requirements set out in the Building Regulations 2010 (Crown Copyright, 2010). The office space takes up the entire top floor of the building and consists of the first floor office, with a mezzanine level. Figure 6.2 shows the layout of the office.

The image, taken from the mezzanine floor shows the open extent of the office. As an office occupancy, as denoted by the occupancy definitions within ADB, the office is allowed to consist of a single compartment of any size - there is no limit on compartment size within ADB for office type occupancies and it can be seen that the office makes full use of this regulation to create an open and inviting workspace.

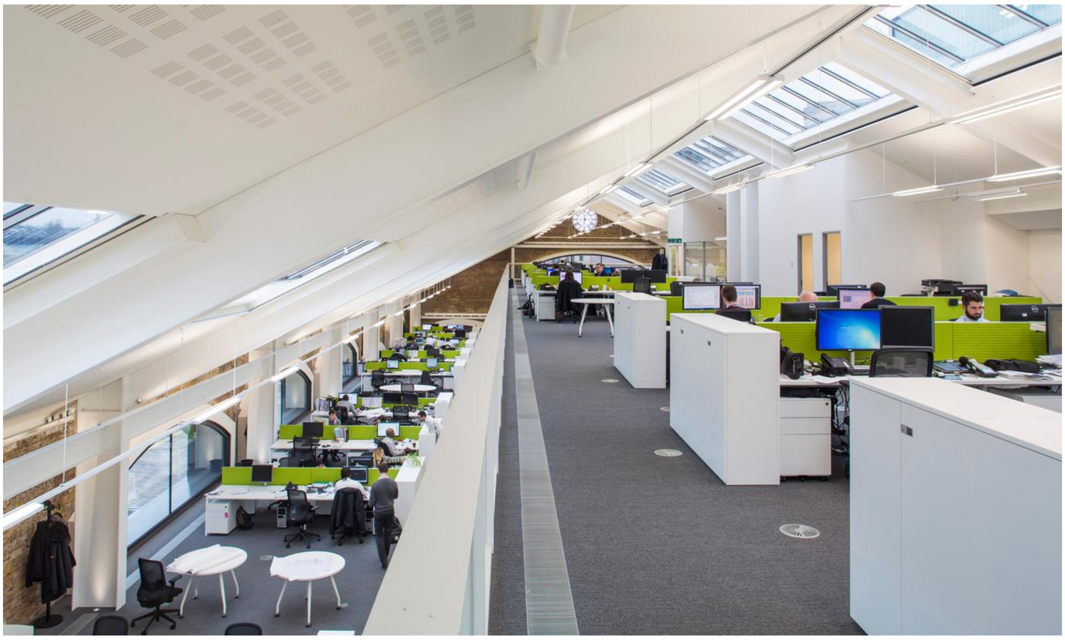


**Figure 6.2:** Hoare Lea Office

The Hoare Lea office is accessed via single stair case within a full height atrium, shown in Figure 6.3. This entrance lobby provides separation between the Hoare Lea offices (accessed on the left of the lobby) and the adjoining offices (accessed off the right of the lobby).

The proposed DSS tool would apply to the building as a whole, rather than each individual occupancy because as seen in Figure 6.2, the open office layout means that smoke is free to spread (and therefore damage) the entire Hoare Lea office. The proposed DSS tool would have been used at the design stage of the building by the company providing fire engineering advice and would be used to consider the fire protection levels to the entire building - if the damage within the individual offices wanted to be considered, then the installation of smaller compartments or sprinklers could help in this regard.

The fire separation between the offices of the different occupancies is required to be 60 minutes fire resisting construction per the requirements of ADB for an office building under 18m in height. Therefore, the building has been installed with this fire protection level. This level was specified either by the fire engineer or the project or the architect. The building was designed to meet the code requirements and property protection was not considered.

As mentioned above, the building is constructed to meet the Building Regulations and therefore the fire separation is 60 minutes - 60 minutes to structure and to the different occupancies. There is also no fixed fire fighting system such as a sprinkler system or mist

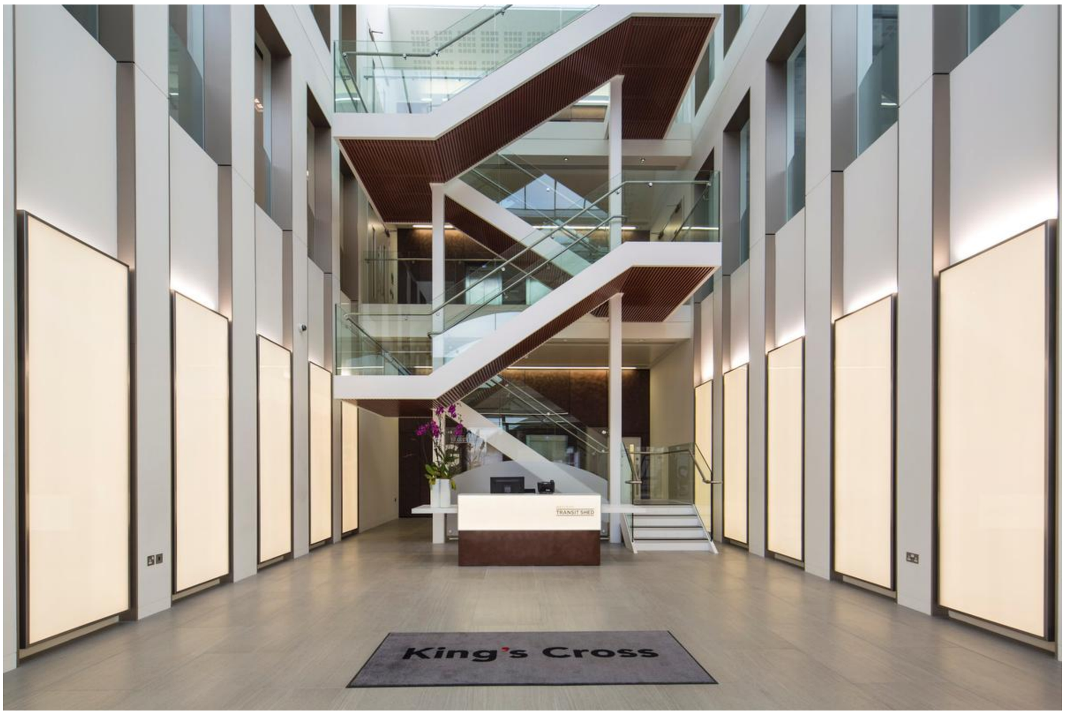



**Figure 6.3:** Hoare Lea Entrance Lobby

system, there is however, a normal level of alarm system for the type of building. This would be the base model for the scenario - the code compliant building. With the area of the building from the plans, the cost of the construction can be estimated using the BCIS database. The plans for the Hoare Lea office shows an area of 2390m², an estimate for the entire Western Transit Shed is therefore approximately 7170m² (only the plans for the Hoare Lea office is available for this research project). The estimated cost of building can then be estimated by looking at the cost values of office occupancy within the BCIS database which gives a value of £1,405 per m² (taken from Table 5.16) and therefore a cost of £10,073,850 for the Western Transit Shed. This is the cost of the code compliant solution to construct and forms the basis of the model.

With no additional costs in terms of extra fire protection systems, the cost of the building is £10,073,850. The rent of the building focuses on the usable area for the offices - therefore, if we consider that the common areas and staircases which are required by following the regulations in ADB are not usable space and are not rent-able, we can assume an area of 6438m² that provides the developer with income for the building. Therefore, if we can reduce the stair cores, the developer can utilise an additional 20m² per stair core of space to rent, providing additional income on the building. Consider this space - the cost of hiring a fire engineer to consider the plans and apply potential fire engineering to the building might cost between £4,000 - £6,000 for a Royal Institute of British Architects (RIBA) Stage D report, depending on the hours worked and the outcome required by the client and Building Control. Based on the 2010 rateable value (taken from the Valuation Office

Agency (VOA) website lookup for previous values - `http://www.2010.voa.gov.uk`) for the previous Hoare Lea office (Glenn House, Tottenham Court Road, W1T 7PL as the current office is not within the last database), the estimated rental value per m$^2$ is £400 (Valuation Office Agency, 2013) (in 2010 prices). Based on a life cycle of 25 years for the building, saving the area of 180m$^2$ from being used as staircase (three staircases with three floors served each) within Western Transit Shed could net the developer an additional £1,800,000 (£72,000 additional rent acquired a year). Assuming a stair core can be removed, this additional increase in rent easily shows that the employment of a fire engineer to remove the additional stair core is a cost effective. Building in the potential removal of a stair core into the to shows that fire engineering is a worthwhile investment but does not go as far to suggest how that would save money in regards to property protection.

Property protection is considered through the installation of extra fire protection measures, such as sprinklers and additional fire protection. The installation of sprinklers to the building would prevent the fire from spreading, reduce the heat and lower the amount of smoke produced. The installation of passive fire protection would mean that the fire (and fire related products, such as smoke) would take longer to flow around the building and therefore cause less damage from reduced fire spread. As discussed in Section 3.5.3.1, the Spon's Cost Guide (Davis Langdon, 2012) provides a value for calculating the cost of installing a sprinkler system within the property. Sprinklers are installed according to the hazard within the occupancy and this affects the cost of the sprinkler system (with higher hazards costing more). An office, according to BS EN 12845 (BSI, 2004), an office classes as an OH1 sprinkler system and therefore counts as an ordinary class hazard. The cost of installing sprinklers within Spon's guide (for an ordinary hazard) ranges from £16.90 per m$^2$ to £22.50 per m$^2$. Using a worst case scenario, the highest value of will be £22.50 per m$^2$. Taking into account the size of the building at 7170m$^2$, the installation of sprinklers will cost £161,325. Spons also place the cost of the installation of fire alarms at £6.25-£10.40 per m$^2$ - a basic alarm system was installed as part of the fit out of the Western Transit Shed as part of meeting the Building Regulations in ADB, therefore the most expensive price will be used for the cost of the alarm system. This gives a value of £74,568 for the additional fire alarm system.

These additional values for sprinklers and additional fire alarms gives a value of £235,893 total for additional protection to the building, over and above that required for life safety in ADB. Each compartment within the Western Transit Shed would cost £3,357,950 without the additional protection. The installation of the additional fire alarms is unlikely to make much difference in the fire spread within the compartment of the office where the fire occurs, due to the open nature of the office. However, the earlier warning, coupled with the sprinklers and increased passive fire protection would mean that the FRS would be hopefully be notified early and as the result, less damage occurs to the property. The data analysis shown in Section 5.4.3 shows that the the damage caused by fire is statistically less for fires where the FRS are notified and attend a fire before it spreads. The regression analysis indicated that the IGNTDISC category (the time taken from ignition of the fire until discovery) was a one of the key factors that strongly affected the area damaged by fire.

The statistical analysis performed within Section 5.2.1 gives the statistical probabilities of the fire alarms activating within the building. The analysis within Section 5.2.2 details the probability of the extinction systems operating. These values allow a probability tree to be constructed, allowing the output of the tool to reflect the probability of the money that will be saved. For example, the probability of the alarm operating is shown to be 74.1 percent in Section 5.2.1 and that of the sprinkler system operating is as low as 34 percent (considering all fires). This gives the probability tree in Figure 6.4.

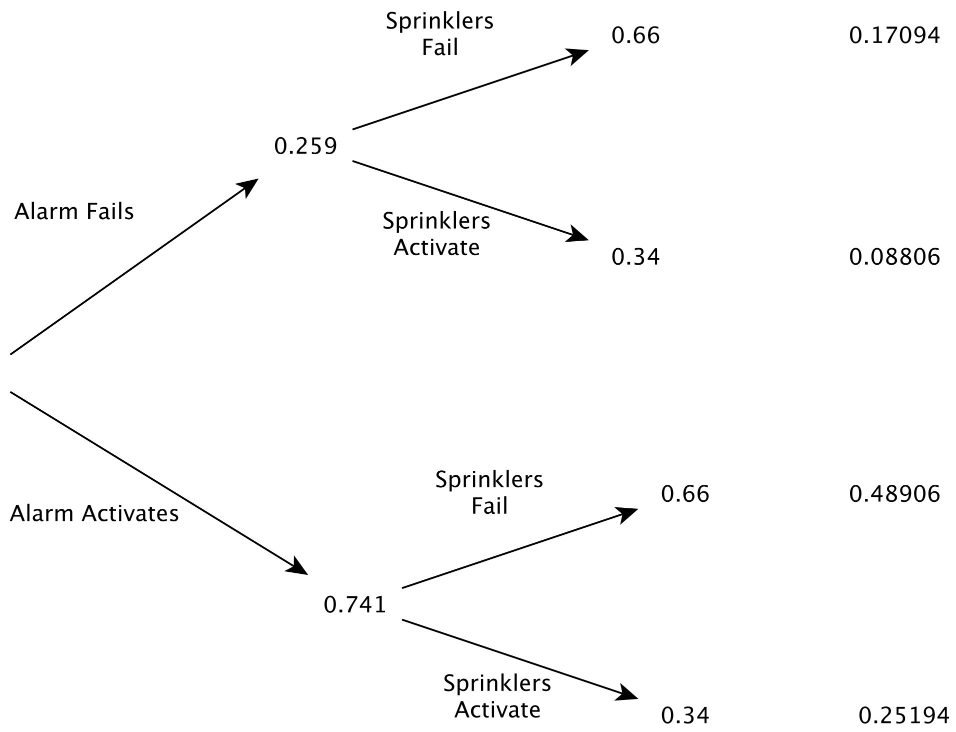



**Figure 6.4:** Probability Tree of Alarms and Sprinklers Activating

This allows the final savings to be calculated as a probability. Based on the probability tree, the most common outcome is that the fire alarm will activate but sprinklers will not activate (the value for sprinklers takes into account the instances that might not reach the size of fire that sprinklers activate - again, remember that sprinklers may activate and extinguish the fire, causing the buildings occupants/owners to not bother making a call to the FRS and therefore the incident wouldn't be recorded and will skew the data towards ineffective sprinklers). With the probabilities, the cost saving value of the protection systems can be considered.

The analysis of the FDR 1 dataset was to produce this final step of the cost tool - the regression analysis was aimed to find out the factors affecting how a fire reached a certain size. Unfortunately, as shown in Section 5.5, the regression analysis of the FDR 1 data was unable to provide this information so the key part of the tool, the estimate area damaged by fire, is missing. This step would allow all the above data to be added to the tool and the estimated area damaged calculated. The cost of the damaged is considered using the FPA dataset which gives an estimated cost of loss. Alternatively, the BCIS data can be used as an estimated cost of construction. In this instance, the model would use the cost of non residential buildings, which from the FPA dataset is £1,405 per $m^2$ and the BCIS database has as £1,452. Using a damage value of 2,390$m^2$ purely as an example (the entire compartment is lost due to fire damage), the cost of the fire would be £3,470,280 (using the BCIS cost).

Finally, the reduction in area damaged by the fire when these additional fire protection measures are installed is input into the model. If the data was available for the calculating the area damaged, the initial model (the code compliant or proposed model) could then be run against the same model but with the additional measures installed. This would give another area damaged, one that would hopefully be less than the initial run, as additional protection measures have been installed. The cost calculations are again performed. For the worked instance, it is assumed the sprinklers installed performed as expected and the damage is reduced by a quarter, due to less smoke and a smaller fire; as well as the earlier notification of the FRS with the additional, uprated alarm system. A damage of 1,792.5$m^2$ would give a cost of £2,764,035. Comparing this against the original fire damage shows a cost reduction of £706,245. The installation of the sprinklers additional sprinklers and fire alarms came to a total of £235,893, showing that the additional measures saved £470,352, making them cost effective. However, it should be noted that the cost savings do not take into account the potential reduction in insurance premiums that may incur due to the additional protection provided. The benefits do not also take into account the possible loss of human life and any monetary value that may be attached to a person. This tool focuses solely on the reduction of property damage.

This simple tool shows the designer the possible options open to him during the construction to help reduce property damage. Additional cost savings can be put into the tool, if the estimated cost savings from the insurance premiums were considered. This lack of data in regards to the insurance savings could be solved with the insurance industry getting involved at a much earlier design stage. Further work could be considered by investigating when insurance companies get involved in the insurance of a building and whether or not they can influence the design decisions at all.

This scenario also highlights the complex nature of using the tool - Hoare Lea had a role in designing and fitting out their own office but the site as a whole is owned, maintained and developed by Argent. At what point is the tool to be used and to what extent? This scenario assumes that it is used by the initial developers on a building to provide the best fire engineering solution is possible at the earliest possible opportunity, rather than at a later stage, such as during a fit out of the building.

## 6.5 Decision Support Tool Layout

Whilst this thesis does not consider the actual programming of the DSS tool itself, a brief overview of the process and potential methods are covered in this section.
In the Literature Review, the potential computing languages the model could be developed in were briefly covered, in Section 2.6. This mentioned the two potential alternative solutions for programming a tool that were quick and would allow a good use model to be developed. Whilst these two solutions would allow quick tools to be created, they are by no means exhaustive and with the rise of "apps" for smartphones and tablets, the potential exists that this tool could be programmed for on the move devices such as these.

Based on the comparison of either Microsoft Excel or the use of Visual Basic, it was concluded that the use of Visual Basic would allow the DSS tool to be constructed quickly, accurately and would be able to fulfil the requirements of a Graphical User Interface (GUI) program, as discussed in Section 2.5.1. Whilst each language had strengths and weaknesses, it was felt that the ability to be run anywhere and the ease of use of a custom designed program using Visual Basic would mean that it was better suited than trying to program a Microsoft Excel spreadsheet to achieve the same results. The ability to run on any system and offer the program for free without relying on additional software is a good incentive to use Visual Studio for the design and development.

The software design methodology of the tool potentially isn't that relevant to the project. The tool can potentially be built by a single developer and thus the teamwork aspects of each methodology are defeated. The use of either a sequential or iterative approach could be used for the design and construction, however it is suggested that the best approach to take in the programming of the DSS tool would be an iterative approach, using the feedback from the fire engineers along the development path to help in creating a software that they'd use.

## 6.6 Summary

This chapter discussed how the previous chapters work on the data analysis of the FDR 1 and FPA data could be combined into a DSS tool and the actual process that a fire engineer would use the model for with a worked example.

The start of the chapter looked at the structure of the tool, identified the inputs and the process the data underwent within the tool and then the outcomes of the tool.

The tool was initially aimed at the fire engineers who, according to the questionnaire performed for this research, and discussed in Section 4.2, were the ones responsible for the fire safety design of the building. However, the tool could prove of use to others within the building design phase and therefore a section detailing how each end user might get the benefits of the tool was discussed.

Finally, a usage example of the tool itself was constructed so that an example of the use of the tool can be seen.

# Chapter 7

# Discussion and Conclusion

## 7.1 Introduction

This chapter discusses the findings of this research, what this means for the fire engineering community, recommendations for stakeholders of the project and what potential further work exists going forward from this research. A summary of the findings are presented in this chapter, detailing the findings of the questionnaire, aimed at finding out the views and practises of the UK Fire Engineering industry and the analysis of the FDR 1 and Fire Protection Association (FPA) fire incident databases. It also summarises and details the findings of the cost analysis of the Building Cost Information Service (BCIS) and FPA data.

## 7.2 Findings

The findings from this research can be split into three different areas:

- Fire incident data
- Statistical analysis of the data
- Costs of fires

These will be discussed individually below.

### 7.2.1 Fire Incident Data

The fire incident data from the FDR 1 forms provided the basis for this research, with supporting information taken from the FPA fire incident database. This research highlights some of the issues with these two databases.

The FDR 1 data, which was used primarily for the statistical analysis, was found to be missing large sections of information, especially in areas concerning the break down of damage. Throughout the research, the value for total area damaged (AREATOT) was used for analysis. However, it would have been preferred to use the areas for smoke damage or fire damage though it was apparent that the majority of incidents within the database did not have this information. Missing fields was not restricted to the different areas of damage, there were also values missing in all other areas investigated in this research, though to a lesser degree than the area damaged. This meant that the data was limited to the records that were completed. This finding shows that the data collection methods are not the best - whether this is due to the method of data collection and then transcription (paper form completed at the scene of an incident and then computerised at a later date by someone not present at the incident) or due to a lack of understanding of the fire fighters on how important the information actually is. It should be hoped that the introduction of the Incident Reporting System (IRS) (an electronically collected form) will allow all fields to be completed before moving on and therefore leading to a more complete database, ready for analysis.

The second major finding of analysis databases is that the collection methods lead to a lot of binary or coded data. Whilst this allows for quick and easy collection, it makes statistical analysis of the results at a later stage to be difficult. The question should be raised as to how and why the data is being collected. It is stated that the FDR 1 data is collected to help inform Government policy, Department of Communities and Local Government (CLG) funding and fire fighting funding. However, if the database cannot be analysed accurately or with any degree of enhanced statistical analysis, the question remains why should the data be collected? The simplistic collection of data allows for simplistic results such as how many fires happened in a year, how many people were injured or killed and how large was the damage. However, these questions can be answered by a much shorter FDR 1 form than the one that was filled in by the attending Fire and Rescue Service (FRS) and therefore the question is why is the form so much longer than the collection of these simplistic values would require? This unnecessarily wastes time the attending fire fighters could potentially be better spent and the collection and storage of data adds additional costs for no additional statistical benefit.

The data analysed also forms the basis of analysis for the Fire Service Emergency Cover (FSEC) toolkit which informs fire fighting policy. Based on the findings of the statistical analysis of this research, the FSEC toolkit could be improved by using better data than is currently available than the FDR 1 form. The IRS database will suffer from a number of the same limitations of the FDR 1 database if the recommendations of this research is not considered.The limitations of the databases are discussed later in Section 7.3.1.

The FPA data appears to provide some areas of overlap with the FDR 1 data and appears to offer a much more complete dataset. It was immediately apparent that the data in each record was far more complete than that of the FDR 1 data. However, the number of records was far smaller. This was due to method of collection and the fact that collection and entry into the FPA database meant that participation was less widespread in comparison to the compulsory completion of the FDR 1 form by the FRS. Whilst more complete, due to the size of the database in comparison to the FDR 1 data, it was felt that the analysis of the data would suffer from individual incident bias and therefore the data could not be used for statistical analysis on the factors affecting a fire. Additionally, due to the method of data collection, statistical analysis of just this database could lead to some heavily biassed figures, especially in regards to cost of damage and sprinkler activation due to the exclusion of results that did meet the FPA collection criteria.

### 7.2.2 Statistical Analysis of Data

The statistical analysis of the data found that the format of recording and storing the FDR 1 data did not allow deep statistical analysis of the data, due to the collection format. The binary nature of the work meant that regression analysis struggled to differentiate between the different incident records that were being analysed and the regression analysis was not fully able to indicate the factors that affected the final fire damage.

The regression analysis was initially proposed to find the factors that would affect the fire damage and give an estimate on the damage likely to be caused by the fire. However, due to the binary nature of the data, the initial multiple regression analysis was replaced with logistic regression analysis which would consider the factors affecting the fire reaching and exceeding 200$m^2$ and give a probability of the fire reaching and exceeding this value, rather than giving an estimated damage size that a multiple regression model would be able to achieve.

Use of logistic regression to identify the factors that affected the fire reaching and exceeding 200$m^2$ found that the presence of dangerous substances and the time from ignition to discovery were statistically the most influential factors. However, the regression model did not provide a good fit for the data and so whilst these two factors were identified as the biggest factors, it cannot be stated with certainty that these are the only factors that would affect the fire growing to cause over 200$m^2$ of damage or even if these are the factors that affect a fire reaching an area greater than 200$m^2$.

The data analysis of the FDR 1 has allowed the calculation of a number of different probabilities, based on fires within the UK. For example, the analysis of the alarm activations within the dataset has allowed the real world probability of an alarm activating to be calculated and statistical analysis shows that an alarm system installed within a building and activating, will mean that, statistically, the size of the fire is likely to be less than in a building without a working fire alarm. This can be perhaps be related to the findings that the time to ignition to discovery plays a role in the fire reaching 200$m^2$ or greater as by the alarm being raised is discovery of the fire and can potentially reduce the time before the FRS reach the scene of the fire (by earlier notification).

### 7.2.3 Costs of Fire

Two methods of calculating fire costs were analysed to see how they compared and to see if loss adjustor's estimates of fire costs compared to that of new build structures within the

UK. The statistical analysis of the BCIS and FPA showed that either database provided statistically similar results when it came to calculating the costs of fires, assuming that the cost of fire can reasonably be assumed to be the same as the cost of a new build. It was considered that this was a reasonable assumption to make, as replacement of parts of a property will still require the same materials as a new build structure but potentially a difference in the cost of labour (replacement may require more work than a new build). However, due to a lack of cost data in the UK regarding fires, it was considered that this analyse of the two available databases would allow a benchmark figure to be calculated and considered for future research.

This analysis of the two databases found that the data collected from the insurance loss adjustor's in the FPA database was not statistically different from the data collected by quantity surveyors for the BCIS database stored by the Royal Institute of British Architects (RIBA) and Royal Institution of Chartered Surveyors (RICS). This therefore indicates that the cost of fires as estimated by the loss adjustor's is statistically similar to that collected at the completion of a building project. It can therefore be considered that in the future calculation of cost of fires, that the BCIS database can provide a reasonable assumption to the cost of the loss of building materials.

It is seen that the cost of the of loss in the FPA database in the instances of Industrial Premises and Warehousing is higher than the cost of the same building occupancy types within the BCIS database. It is assumed that in these two cases, the cost of the building itself is only a fraction of the cost of the fire losses - the cost to replace the specialised industrial equipment in use in industrial premises and the cost of the items being kept in the warehouses consist of a significant proportion of the insurance claims - based on the figures in this research, in warehouse fires, approximately fifty percent of the insurance claim is from the materials stored and in industrial fires, the cost of the equipment and materials lost are equal approximately six to seven times the cost of the a new build industrial unit. However, further work would enable this link to be considered fully and better understood.

## 7.3 Limitations

All research suffers from some degree of limitations, either due to time constraints, methods of data collection or statistical analysis. This research is no different. This section describes the limitations that the research has and what can be done in the future to negate this limitations.

### 7.3.1 Data Limitations

The majority of the data used in this work was collected by external sources. To collect the amount and depth of data used in this project for this work, would have proven to be impractical, due to the time scales and the sheer amount of data collected. The FDR 1 data, whilst only the year of 2005 was used, stretches over 10 years worth of data, which would have been impossible to collect in a 3 year PhD project.

Without the support of the FPA and CLG this project would not have access to the databases that they had spent significant time and effort in collecting and collating.

However, by using these external databases, the data cannot be verified as accurate or correct and the results within the database have to be taken at face value. This is because at no point was this research involved with the collection or collating of the results and so the documentation and word of the associations responsible for the data collection is all the evidence there is for this research that the data has been collected as stated. It is assumed that the associations responsible for the data collection have some form of data cleaning system in place to allow erroneous results to be excluded from entry into the database but in some rare cases, errors may still slip through. Additionally, in the case of the FDR 1 data, the paper forms were computerised by human data entry - therefore additional errors may have been introduced by the conversion process. There have been no studies found by this research on the accuracy of the FDR 1 database and how accurate the data is to the actual fire incident that the FDR 1 record represents. In completing this research and presenting the findings throughout the PhD, concerns have been raised by various members of the FRS on the use of FDR 1 data. In the views of these individuals, the collection of the FDR 1 data by the FRS itself is flawed and some of the data is either missing (which was found to be the case in the analysis of the data, described in Chapter 5) or is made up by the fire fighter or officer completing the form. This means that the data must be viewed with a degree of scepticism because it might not be a representative of the fire incidents that the data is supposed to represent. However, the large number of collections (and the combined nature of the data from different FRS regions who will have different practises on collecting the data) should mean that these errors are minimised. However without knowing the error rate with the database collection, it makes it difficult to estimate the error level in this research.

Both databases were cleaned before this research was allowed access to them - this was to fulfil the UK data protection act and the data removed was data that would allow the incident to be traced back to the incident of origin. Other personal data was also removed - for example, in the FPA database, the names of the insurance companies that submitted the claim were also removed. This anonymised data meant that no verification checks could be undertaken on the data to see if the data was correct and represented a true figure of the fire incident. Likewise, because both database had the locations of the incident removed, a merge between the two databases (which may have proven beneficial) could not be completed. In hindsight, this would not have been possible due to the fact that the FDR 1 data studied was only that for the year 2005 whilst the FPA database only covers fires from the later half of 2008 onwards.

One of the limitations of the FDR 1 database was the method of sampling and weighting employed by the CLG statisticians. All years (except 2005) were sampled and only a certain percentage of data was converted from the paper based FDR 1 forms into the electronic FDR 1 database. Had the data only been sampled in this method, then the results from the database could have been extrapolated and the entire ten year database could have been used. However, the data in the databases has also been weighted according to a formula, that CLG publish in each release of the UK fire statistics. However, this weighting formula is not clear and even with statistical help from the university statistic support centre and the employed statistical help on project that this research was conducted alongside were unable to provide a method for successfully extrapolating the data back into a complete dataset. The various methods put forward for doing this would provide an estimate of the dataset but was warned that due to the sampling and the weighting factor, the error factors in doing so could potentially outweigh the benefits of doing so. Therefore, the decision was made to only focus on the 2005 data as this was entered into the database unweighted and unsampled meaning that no extrapolation was needed and this year represented a full years worth of fire incidents.

The main drawback from the FPA database was the entry requirements for an incident to be recorded. These limitations are shown in the list below.

- Material damage for all interested parties estimated at £100,000 or more *and/or*
- Business interruption damage estimated at £100,000 or more *and/or*
- A fatality *and/or*
- Sprinkler actuation occurred *and/or*
- Where the combined figure for material damage and business interruption is expected to exceed £100,000

These entry requirements are meant to focus the database on only large losses in the UK, though it can be seen that it will also include data on fires where fatalities occurred or sprinklers were activated. It has been seen in the data analysis that the number of fires in the UK are heavily skewed towards the smaller fires - that is, there are a larger number of fires with a small amount of damage than fires with large amounts of damage. Therefore the number of incidents in the FPA database are restricted by removing most of these smaller fires from being entered. The FPA database has also been collecting data for a lot less time than the FDR 1 database and therefore the number of incidents are also lower due to the time of the database data capture. With time, the number of incidents will increase. Lastly, entry of data into the FPA database is voluntary. The FDR 1 form was required to be completed by an FRS attending a fire incident and submission to CLG was also compulsory - this means that the FDR 1 database, every fire the FRS attended where a fire had occurred, a fire incident report had to be filed for that event. The FPA database is collected by insurance companies and whilst it is in their best interests to allow the data to be collated by the FPA for statistical analysis, it is not currently required to do so and therefore all fires that meet the entry requirements for entry into the FPA database may not actually be entered as there is no obligation for the incident to be logged. It cannot, therefore, be used to calculate the number of fires happening in a year (because they might not all be logged) and it cannot be used to calculate the probabilities of fire occurring (or other probabilities) as it is not know what percentage of the incidents are actually being logged. Should the FPA ask the insurance companies for an estimate of how many (or what percentage) of incidents are actually being logged, then getting an estimate might be feasible but in it's current form, the FPA database does not allow these to be calculated to any degree of certainty.

Even with the large number of records available from the beginning, with the filtering of the data to only focus on the data that was required for the project (detailed in Section 3.5.1.1.2)

## 7.3.2 Analysis Limitations

Initially, analysis was hampered by the large FDR 1 dataset provided by CLG. The large database would crash most of the programs that it was opened with and made analysis difficult. However, once the data had been broken down into years to make the database more manageable (in terms of size and computational power needed), this no longer proved to be a limiting factor. This was achieved through the use of scripted, non GUI programs, to separate the data (examples of which are shown in Appendix C).

As stated within 5, the method of data collection (binary data sets) meant that the initial method for analysing the data was unable to discern differences between the different factors affecting the fire size and therefore was unsuitable for working with the data. This meant that logistic regression modelling had to be used instead which would provide a lower level of accuracy for the tool and would only be able to give the probability of a fire reaching a size greater than 200m$^2$ rather than being able to calculate an estimated fire size as originally intended.

## 7.4 Recommendations

Based on the findings of this research, the following points can be considered as recommendations. It should be noted that these are recommendations and do not take into account the cost or ability to be implemented - this would be for an additional study or body to decide. The reasoning behind the current data collection methods can be seen and it is understood why this method has been chosen. It is viewed that the methods of data collection has been reasonable for the methods and mains of collection but this collection provides insufficient and potentially inaccurate data for the statistical analysis of building fires in the UK. However, a few changes to the data collection process and storage of data may enable better statistical analysis at a later date when additional data is collected. Additionally, the move to the IRS data collection system instead of the FDR 1 data collection means that some of these recommendations may have already been met, but as the IRS data was studied as part of this work, this has not been assessed.

1. Make the weighting system easier to understand
2. Remove the sampling and weighting system for future data collection
3. Improve the data collection techniques to prevent missing values
4. Store actual areas of damage, rather than in groups
5. If data cannot be measured, then estimated area damages rather than groups would be preferable
6. Make the variables in the FDR 1 database clearer
7. Update the FDR 1 key book
8. Include an estimate (or allow the building location to be known) so that an estimate of the loss ratio can be calculated
9. Reduce the number of occupancy types
10. Potentially work with other data collection agencies to build a combined database (or make it easier to combine datasets)

11. Allow the computerised data to be exported in a format suitable for statistical analysis in a range of academic and statistical programs

These recommendations are discussed in detail below.

### 7.4.1 Weighting System

The FDR 1 data is collected by the FRS on attendance to a fire. This form is then finished and stored by the FRS who completed the form, be it at the station or at the brigade headquarters. This form is then requested by CLG for entry into the computerised FDR 1 database. These forms were then sampled using a sampling factor, discussed in Table 3.5 in Section 3.5.1.1.1. These sampled records are also entered into the electronic database with a weighting factor. Whilst CLG publish how the weighting factor is applied in the fire statistics publications published each year (Department for Communities and Local Government, 2010, 2011a), the explanation was found to be inadequate for estimating or completely "reverse engineering" the figures back to the pre weighting values. This was attempted with help from the University Statistics Support unit and additional statistical help attached to the Integrated Risk Management Plan (IRMP) project at Loughborough. Neither of these professional, qualified and experienced statistical avenues were enough to calculate the original values and therefore it is recommended that the weighted factor is removed from the dataset - this would have immediately allowed more data to be analysed for this project - all data, except the data for 2005, was discarded because it was unable to be "reverse engineered" back to the full, unweighted, unsampled data and therefore could not be used for analysis accurately without skewing the data analysis.

It is understood that the sampling of the data has been removed from the new dataset by the application and use of the IRS dataset where all records are entered into the electronic database as all data is entered electronically from the start. This then allows the entire IRS database to represent every real incident (i.e. not a false alarm) that the FRS attend in the UK and this will therefore allow future data analysis of the UK fire incident record to use the entire database, making the data analysis more accurate.

### 7.4.2 Data Collection

The data collection of the FDR 1 one data is not analysed to see how accurate the data is, though from speaking to people during the course of this research and the data analysis itself, it was found that the FDR 1 data could be improved in a number of different ways.

It was immediately apparent during the analysis that a lot of the data in the FDR 1 records were blank and missing. This affected the research in what data was able to be analysed

- this research had to make use of the data field for the total area damaged in the FDR 1 form, rather than the total area damaged by fire that was the initial method. Additionally, records were missing in other sections of the FDR 1 data, though to a lesser extent, which did not affect the analysis of the data. However, this data does mean that the full number of records could not be used for the data analysis.

The move to the IRS data will have reduced the likelihood of errors entering the dataset by changing the format from paper to the electronic database and it also allows the data being entered to undergo a form of validation whilst being entered into the database, meaning that an incident cannot be entered until all data entry fields are completed within the database. It also allows the database to be validated against specific rules, for example, if the cause of a fire is a specific incident, contradictory data cannot be entered at a later point in the data entry point - this would allow for a more accurate data entry method.

The analysis of the FDR 1 data was also hindered by the format of the data that had been collected. In a number of instances, the data had been collected and grouped together within the database. For example, the areas used in the different area damaged in the fire was made up of a grouping, based on arbitrary figures decided when the form was designed (and obviously focuses on the smaller fires as these are the most common as the data clearly shows). However, this grouping of the data like this meant that the database becomes a lot harder to statistically analyse and means that the data patterns are not as clear because data is grouped and categorised before the data analysis has even begun. This could be changed by improving the data collection so that each incident is given the actual area damaged. Ideally, the area damaged (or cases where the data is entered via a group like this) would be measured and stored as a complete, accurate record. The FPA database does this. However, it is understood that the FPA data is from a much lower frequency of incidents and therefore the person making the record will have the time to accurately measure the area damaged (it's also in the insurance companies interest to ensure that the damage is recorded correctly for the claims on the property) and that the FRS recording the data would not have the time to accurately record the data. However, as the current method of data collection is based on the estimate, it is not assumed that the use of a stored estimated value would change the accuracy of the results in this instance - post processing by computers would be able to filter the results into groups, rather than store the data in it's initial form as a grouped variable. This change in recording would make one of the biggest changes to the accuracy of this research and future work being carried out with the fire incident records.

### 7.4.3 Variables

The variables within the FDR 1 database were felt to be sufficient for the calculation of the data for this research. However, a number of recommendations can be made on the variables. In a few instances, the variables might require some clarification (or if they cannot be clarified, removed from the collection process to streamline it).

Various different damages are collected in the FDR 1 form. These include area damaged by fire, smoke, water and the total. It is not clear in the FDR 1 form that if a record has entries for all four records, that the total value should obviously be the greatest value. It is also not stated whether or not what the different damages equate to - i.e. in the case of water damage, is this only areas of the building that contain water damage, but no damage from smoke or direct burning? Likewise with the are damaged by direct burning and smoke damage, the direct burning may only affect the room of fire origin but the smoke might have damaged the entire rest of the property - is this stored separately and the combined in the case of the total area damaged? This does not appear to be the case. This could therefore be considered an argument for the abolishment of the different damage figures and the reliance on the total area damaged value. It is clearly seen that this is the figure that the FRS's complete, rather than fill in the additional damages. After all, the argument can be made in almost all cases that the damage as a *result* of a fire is of the same importance as the damage caused by the fire itself. As stated earlier in this thesis, the argument can be made that all the damage as a result of the fire occurring will need to be repaired and therefore this all has a cost. This applies to the building occupancy types studied in this research as well as residential occupancies (which were not included in this research).

The FDR 1 form contains a large range of occupancy types. Whilst this allows statistics to be collected for a range of different buildings, it has a number of inherent problems for the statistical analysis of the data. Whilst it appears initially to be a good idea to be able to record every different occupancy type possible, it becomes apparent in the statistics that the the number of fires in the non-residential properties is far less than the number of dwelling fires (in 2011, there were 45,000 dwelling fires and 25,000 other building fires (Department for Communities and Local Government, 2011a)). This number seems high, but due to the large number of occupancy types, some of those will have a small number of fires a year, if any fires occur at all. This means that statistical analysis of these small incident cases are inaccurate and cannot be done without one case potentially skewing the results. Therefore, by combining the occupancy types into a smaller range of values (such as those in the FPA database, detailed in Table 5.13), then a larger dataset is provided to allow these buildings to be better studied. This allows cuts down on the list of occupancies that the FRS attending the fire would have to work their way through to find the correct occupancy for recording in the FDR 1 database. Ramachandran states in his paper (1980) (Ramachandran, 1980) that at least twenty fire records need to be present to allow a sufficient data analysis method to be carried out. Though this research looked at extreme value theory and the use of large loss statistics in the UK, the same statistical principles can apply to this, and future, research.

### 7.4.4 Additional Comments

Additionally to the recommendations above, a number of other recommendations can be made. These can be seen as additional factors that would improve the range and value of statistics that the data would offer.

Recording the total area of the building at the same time as recording the area damaged by the fire would allow the loss ratio of the building to be calculated. This would be beneficial in the analysis of the cost of the loss to the building, allowing comparisons between large and small damaging fires and would allow the relationship between the cost of the fire and the extent of the damage to be explored.

Whilst the data was in a format that allowed further data analysis within this research, care should be taken to ensure that the data from the FDR 1 and the IRS dataset are available in a format that will allow further research to be carried out. The IRS data was provided to Loughborough University for the IRMP project but at a stage where the data could not be useful to the project due to the time scales. This was brief investigated and it was found that the storage method of the data meant that the data would have needed considerable pre-processing time to allow meaningful data analysis to take place.

Whilst the IRS and FDR 1 dataset are collected by the FRS and stored by CLG, it is worth considering the possibility of combing, or allowing third parties to add additional data to these records, perhaps in a combined UK Fire Incident database. For example, the FPA data collected by the insurance companies is stored separately to the FDR 1 and IRS incident records. As this contains similar information as well as *additional* information, it is probably worth considering storing the two databases together to allow a fuller picture of a fire incident to be analysed by both parties. Alternatively, a third party could compile those results and others from different companies or organisations (English Heritage keep a database of fire incidents occurring in buildings they own for example). Additionally, this could use additional statistics from sprinkler companies and detection firms (if they collect data on the operation of their systems) and allow all data to be compared to each other.

The insurance companies should provide the driving force for change within the UK Architecture, Engineering & Construction (AEC). The cost of fires to the UK economy has been rising, as their own research has shown (Association of British Insurers, 2009). However, the driving force for change needs to originate with the insurance they provide. Current practise, especially within the period of recession and austerity is to save as much money as possible on all costs - this includes not providing additional fire protection measures as this increases construction costs. Yet the insurance companies still provide insurance for basic life safety requirements. They have a number of options:

1. Don't provide insurance for those buildings not meeting a property protection standard - Understandably, this is a difficult position to take as if a company does not provide insurance, a competitor can step in to provide the service.

2. Encourage the use of additional protection - Getting the insurance companies provided and making clients aware of the benefits of additional protection and potential for reduced insurance costs.

3. Educating on the use of additional protection - Clients can have misguided views of fire protection systems, a common example of sprinkler systems where Hollywood has enforced the public perception that a sprinkler activation involves an entire floor, rather than only the area where the fire occurs. Changing the perception of this would potentially sway some building designers to the benefits of these additional systems.

4. Make clear cost savings - the biggest incentive for building designers and owners is the cost. Increasing profit from either increasing rental values or rentalable space from engineering design or reducing running costs would provide the biggest incentive to the building designers that the additional fees of fire engineering and additional protection is worthwhile.

Regardless of which option (or mixture of options are chosen), the onus of improving the property protection levels of the new UK building stock should be on the insurance companies - they stand to gain in reduced numbers and values of claims should the property protection be improved, perhaps more so than building owners who would probably only lose out on the building insurance premium fees and excess. Therefore, it is recommended that the UK insurance industry investigate and enact, the best method of encouraging the UK AEC to adopt additional property protection measures.

## 7.5 Further Work

This research has a number of possible avenues for future work. These are discussed here.

### 7.5.1 Accuracy of Data

The accuracy of the data itself within the FDR 1 forms is unknown. No studies were found, either by CLG or a third party on the accuracy of the data that was stored within the FDR 1 database and how this tallied with the data collected at the fire incident by fire fighters.

This research was conducted with the knowledge that the incident data collected may not be the most accurate data (as the accuracy of the data was not known) but that by providing a methodology for the analysis, that in the future, the research could be switched to using a dataset where the accuracy of the values were known.

It is therefore recommended that a study of the collection of IRS data is conducted to prove the accuracy of the data values being collected. It would prove to be beneficial to the future analysis of any IRS data analysed and would allow inaccuracies to be picked up and more robust statistical analysis (when the margin of error is known).

### 7.5.2 Costs of Fires

Two available databases were found within the UK that would allow the cost of fire across an industry to be calculated. These two databases, the BCIS and FPA databases were analysed to compare the costs in each database. However, the work assumed that the losses in a fire would be equal or similar to that of a new design and construction. No prior research had been found to either confirm or reject his assumption, and therefore it was assumed that this was case, based on the fact that the insurance industry (and the Xactware software) based the cost calculations of a fire on the cost of a new build.

Further research into the area of fire costs could therefore investigate the effect of the cost on the repair of a fire, compared to the cost of a new build. Consideration would have to be taken in which costs were considered, as for example, the cost of replacement and repair might not consider the cost of loss of heritage or business that may occur in a fire. Research in this area would allow future cost estimations by the insurance industry or any research investigating the costs of fire to more accurately predict or consider the costs of fire, something that is currently not available.

For this research it was assumed that the fires detailed within the incidents followed the $t^2$ fire growth rates, set out by Heskestad **??** and it was assumed that the cost of a fire increased in proportion with the size of a fire. This was assumed because no data was found describing a relationship between the costs of a fire as the damage increased. More research into this area would allow the costs of a fire to be better understood.

### 7.5.3 Building Information Modelling

Building Information Modelling (or BIM), is a new method of designing and constructing buildings (Eastman *et al.*, 2011). The principle is that a computerised 3D model of the building is built with all aspects of the building design being undertaken on a single model. This allows each team involved in the design of the building to view the effect they have on the final building design and allows for greater teamwork and less wastage as the model will highlight clashes between different services effecting the design and allows this to be sorted before the building proceeds to site for construction.

The main benefit in how the model is created, is that each component of the model is linked to a database in the background of the model which means that information can be stored on the component, such as its make and manufacturer, amongst other metadata, such as cost. Research is already underway on creating cost tools using BIM models (Redmond *et al.*, 2011) and this research could be used alongside a BIM cost plugin.

As each object is added to the BIM model, metadata is added to the database on the cost of that object. A report could then be run on the database, showing the total cost of the building. With this cost calculation already being undertaken by other research, the Decision Support System (DSS) tool could just add the additional statistics and cost benefit analysis to the BIM model to allow the building stakeholders to view what affect the additional fire protection would have on the cost of a fire and potential losses within the building in event of a fire.

## 7.6 Conclusions

The conclusions to this research can be considered by seeing how the research has met the original aims and objectives, set out in Section 1.5. By comparing the outcome of the work to these objectives, the research can be judged on how well it has met it's objectives.

The objectives for the research were as follows:

1. To investigate the current practise within the fire engineering industry through questionnaires and interviews;
2. Analyse questionnaires and interviews to consider if a cost benefit tool is needed;
3. Review of fire protection measures and their applications;
4. Identify the different aspects that will affect the costs of a final design;

5. Statistically analyse data collected by CLG and FPA;
6. Identify data within the FPA and FDR 1 datasets that can identify building protection systems and measure and how effective they are;
7. Identify costs of building materials and estimated costs should a building fire occur;
8. Use the FPA and CLG data as an evidence base, develop a cost benefit tool framework.

Looking at each measure individually will demonstrate whether or not this objective was met.

### 7.6.1 Investigate Current Practise

This objective set out to investigate the practise of fire engineering within the UK AEC industry and how the process of fire engineering took place within the UK. It was found that fire engineering was mainly conducted by specific fire engineers, who would be brought onto projects when specific fire safety knowledge was required by the architect or designer. Engineers were brought in at different stages of the design process (as specified by the RIBA stages of work) and it was felt that the stage of the involvement of the fire engineer was reasonable for each project. Fire engineers would make use of codes, regulations and first principles of fire science to justify departures from the recommendations in Approved Document B (ADB) and this was validated or verified through prior research from the academic community, Computational Fluid Dynamics (CFD) modelling and the incorporation of this prior research into fire safety publications, such as the SFPE Handbook of Fire Protection Engineering (SFPE) Handbook (Society of Fire Protection Engineers, 2002).

### 7.6.2 Cost Benefit Tool

In the questionnaire and interviews, respondents were asked if they considered the costs of the fire protection measures that they specified in the design of the fire safety systems within the buildings. They were also asked if that there was a cost benefit tool available to them to help them specify the fire safety measures within the design of the fire safety plan. It was clear that during the course of the questionnaire and interviews that no such tool existed (however, during the progress of this PhD, it should be noted that National Institute of Standards and Technology (NIST) released a cost benefit tool for the installation of sprinklers in a building which can be found on their website `http://ws680.nist.gov/firesprinkler/default.aspx`). Whilst a tool did not currently exist, it was clearly stated that the respondents of the survey would welcome the addition of a cost DSS to their day to day work flow and would make use of such a tool, should one be created. Therefore it can be seen that this objective was met by finding that the UK fire engineers would use a cost benefit tool and that therefore the outcome of this research could be the creation of a DSS methodology for the tool.

### 7.6.3 Review of Fire Protection Measures

To consider the costs of the fire protection and design, the application of the different methods of fire protection had to be considered and investigated as to how each fulfilled the role within the fire safety design of the building. This was achieved within the literature review where fire engineering aspects were covered in the review, such as active fire protection measures like sprinklers systems and passive protection measures, such as fire resistant materials. By considering what materials are used within the fire engineering design, these could be incorporated into the DSS tool. It was found that cost effectiveness studies had been undertaken on sprinkler installation but in regards to the cost of passive fire protection, studies hadn't considered these or studies on other countries fire data had found statistics to be inadequate for the calculating the cost benefits. These previous studies were focussed on specific areas of the building industry and didn't consider the UK building industry as a whole.

### 7.6.4 Identify Aspects Affecting the Costs of the Final Design

The literature review highlighted areas of the fire design that would affect the costs of the building design and along with review of the statistics, it was able to narrow down these factors. The literature review initially showed areas of investigation where other researchers had identified cost critical aspects of a building and these were taken into the analysis of the FDR 1 data. With the values identified through literature and through investigation of what data was contained with the FDR 1 data, the factors that could potentially affect the cost of fire were identified and were investigated further with statistical analysis to see if they did affect the cost of fire damage.

### 7.6.5 Statistically Analyse Data

One of the main objectives of the research was to statistically analyse the UK fire incident data to achieve a statistical evidence base for the cost DSS. The data was statistically analysed to see how this could be achieved. A number of different statistical tests were performed to investigate what factors would statistically effect the size of the fire damage. This analysis showed that the time between ignition of the fire until the discovery and the presence of dangerous substances were the biggest factors statistically on whether or not the fire would be greater than $200m^2$. Unfortunately, due to the data collection method and storage of the collected data, advanced statistical analysis was inconclusive, due to the binary nature of the data. The statistical tests had difficulty separating out the factors that had an effect on the fire damage within the fire incident. This means that whilst statistical analysis was completed to the best of the ability of the data, the data restricted the results that could be achieved with the data itself and therefore restricted the creation of a cost benefit tool.

### 7.6.6 Identify Data

Data within the FDR 1 and FPA datasets were analysed and investigated to see what data could be used to identify the building protection systems and how effective these systems performed in actual fire incidents. The FDR 1 dataset contained a data on both alarm systems and sprinkler installations. Both of these were analysed to see how effective each one proved to be in real world conditions. It was noted that in both cases, that only the incidents where the FRS attended, were these entered into the FDR 1 database. If an alarm or sprinkler system activated and the fire was extinguished (though the sprinkler activation or via first aid fire fighting) and the FRS did not attend the scene, then the data would not be recorded and therefore this data would not be available to affect the results. Therefore it was seen that alarm systems were effective in almost seventy five percent of cases. This meant that seventy five percent of the time that where an alarm system is within a building, it will activate and raise the alarm. It was found that the activation of an alarm system would mean that the fire was more likely to be smaller than if no alarm system was fitted (or the alarm system failed to operate).

In regards to the sprinklers systems operating, it was found that the operation of sprinklers did not coincide with the figures that have been published by previous research. Previous research stated that sprinklers were ninety five percent effective, but statistical analysis of the FDR 1 and FPA records give a much lower figure than that. Recent research in New Zealand, using New Zealand fire statistic shows similar figures (Frank *et al.*, 2012).

One of the initial aims of the project was to investigate the construction materials and the design of the building and see how this affected the fire damage. However, it was clear that the FDR 1 data did not contain any data that would have allowed this value to be used. The FPA dataset did contain some records where areas of special construction materials were used (such as timber framed building or buildings using Structural Insulated Panels (SIPs) - buildings that the insurance companies don't have much data on and therefore struggle to provide accurate risk estimations and as a consequence, struggle to insure). However the amount of data within the FPA database was to low to properly statistically analyse due to the low number of incidents of properties with these construction materials within the database. As the FPA database continues to collect data, the database would be able to provide meaningful data and therefore at a later stage, it may be worth re-visiting the database to carry out this analysis.

### 7.6.7 Identify Costs

A number of different methods were identified for calculating the costs of the fires occurring within the UK. Two were discarded for being either to low and therefore not a good representation of the UK building fire costs and the other one offered an incredibly accurate method of estimating the costs of a single fire but could not be used to calculate the cost of fire as a whole to an individual sector.

In the end, the two methods of calculating costs were by using the estimations of loss adjustor's in the FPA database (it should be noted that the Xactaware tool is aimed at the insurance industry and therefore if the loss adjustor's are using this tool, the figures quoted in the FPA database should be considered fairly accurate representations of the actual costs) and then BCIS database, which considers the cost of new build buildings within the UK.

The BCIS data was combined to match the occupancy types of the FPA dataset and statistical analysis was conducted to see if there was any statistical difference between the two datasets. Statistically there was no difference and therefore either dataset could provide a cost estimation of a fire within the UK. The values of bother databases are broken into a cost per $m^2$ value and therefore if the estimated damage is calculated, a cost estimate of the fire can be calculated.

### 7.6.8 Develop a Cost Benefit Framework

The aim of this research was to construct a cost benefit DSS tool to support those in the UK fire engineering industry to make decisions regarding the cost of fire protection in the buildings they were designing the fire safety systems and evacuation strategy for. It was hoped that this cost benefit tool would allow them to offer the option to install additional fire protection measures at the design stage that would later benefit the building stakeholders (the building owner, the building's insurance company and the UK public as it is within their interest to minimise the costs of fire) should a fire occur within the building during its lifecycle. The addition of this extra protection would be to provide an additional protection and therefore reduce the amount of damage the building suffers in a fire.

Due to the method of data collection within the FDR 1 data, this statistical analysis did not provide the evidence base that was required for this tool. A framework of what would be needed was however drawn up and should the data collection process change, it would be possible to use this framework to create the cost benefit tool.

The statistical analysis of the data does raise some questions regarding the data collection, such as is it worth collecting this data if it isn't possible to make use of the data? However, the analysis of the dataset also raised questions regarding the effectiveness of sprinkler installations, alarm systems and other aspects of the fire fighting process. Therefore, whilst the data could not provide an evidence base, it did allow for statistical analysis to take place on items of the database for other considerations.

## 7.7 Contribution to Knowledge

This thesis and research provides an original contribution to knowledge. This contribution is the analysis of the FDR 1, FPA and BCIS databases to construct a cost loss model and cost benefit analysis, decision support tool that will allow fire engineers (and those involved with fire engineering as part of the UK AEC industry) to see the effects of the fire prevention measures that they are specifying for a building (or even the effect the removal of the protection system is likely to have on a building if it were to be removed under a fire engineered design).

A through literature review at the beginning of this research indicated that this had not been previously attempted and therefore this research provides an original contribution to knowledge for both the academic requirements of the award of Doctor of Philosophy and for the fire engineering industry.

## 7.8 Summary

In summary, the project set out to analyse the UK fire incident data, collected from both the FPA and UK FRS's. This was then to be formed into an evidence base for a cost benefit DSS tool for the UK fire engineers. Based on the objectives, the main aims of the PhD were met though the collection of questionnaire and interview data from the UK AEC industry, the analysis of the FDR 1 and FPA data to find and finally to layout the framework of a cost benefit DSS for the UK fire engineers. Whilst the analysis of the data did not provide the evidence base that was initially considered, the results of the analysis indicate shortcomings in the data collection methods and storage of fire incident data within the UK and also the potential shortcomings of sprinkler and alarm systems. The main factors affecting the size of the fire damage was found from the statistical analysis of the FDR 1 data.

Overall, it can be seen that this research has achieved the aims and objectives that were set out at the start of this research. Overall, the contribution to knowledge can be summed up as the analysis of the UK FDR 1 and FPA data to provide statistical evidence of what affects the amount of fire damage within UK properties and the analysis of various cost databases to indicate the costs that a fire is likely to cause within the UK, based on the occupancy of the building type.

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# Appendix A

# Questionnaires

## A.1 Pilot Questions

**Personal Questions**

1. How many years have you spent in the fire engineering trade?
2. What is your relation to the fire engineering trade?

**Design Phase**

1. Do you spend time risk assessing the property?
2. If you do a risk assessment, how do you carry out or identify the hazards?
3. At what stage are you normally brought onto the project?
4. When is a more suitable time to be brought onto the project?
5. Do you believe that not being brought onto a project early can affect the costs of the final project?
6. Do your designs only focus on life safety?
7. Are the majority of your designs mainly code compliant with a few “trade offs” for non code compliant areas?
8. Do you build in any form of redundancy into your designs?
9. Would you say your designs are inherently safe?

**Costs**

1. In your design decisions, is cost the critical design factor?
2. Do you consider the costs of protection measures you specify?

**Fire Protection**

1. Do you have to validate/verify your non code compliant designs?
2. Is there any guidance on what should be validated or verified?
3. How do you prove that a design you are proposing is equivalent to that specified in the codes?
4. How does the approvals process work?
5. Do you believe that Building Control reject your plans due to a lack of understanding in Fire Engineering?
6. Buildings are relying more on good design and less on active systems for ventilation and the like. Can you see fire engineering following this trend?
7. Do you specify extra passive fire protection rather than that just described in the codes?
8. If a certain protection method lowered costs for insurance for a building, would you specifiy that protection measure?
9. On a scale of 1-5, how essential do you think passive fire protection is?
10. On a scale of 1-5, how effective do you think passive fire protection is?

**BS 9999**

1. How often do you use BS 9999 over other current codes?
2. Has BS 9999 changed your methods of design work?
3. Part of BS 9999 focuses on building management and the management of the building after completion. Do you provide the management plans?
4. Do you believe that BS 9999 reduces the scope for fire engineering?
5. Do you believe that BS 9999 offers a more cost effective method of design?
6. Does a design using BS 9999 take less time to complete a design, on average, than with previous design codes?
7. How have other project stakeholders taken to BS9999?
8. Do you believe that BS 9999 will help building owners comply with The Regulatory Reform Order?

9. Do you believe that the addition of sprinklers to reduce a risk profile is cost effective?

10. Do you still design non code compliant areas within buildings?

11. Do you think BS 9999 will have a positive effect on the management of the building's passive fire protection measures?

12. Considering the building is tailored to a specific risk profile, how severe can you see a change of risk profile being in the future?

## A.2 Final Questionnaire

### Current Practice, Design Process and BS 9999 Survey

This questionnaire is part of a study at Loughborough University.

It aims to:-

1. Investigate current practices in fire engineering.
2. Establish how BS 9999 is used and how it can be improved.
3. Collect professional's views on fire engineering.

**1. What is your expertise in fire safety?**

☐ Fire Safety/Risk Management ☐ Fire Engineering ☐ Fire Service Personnel
☐ Architect ☐ End User/Client ☐ Building Controller

**2. How many years have you been involved in your profession?**

☐ 1-2 Years ☐ 3-5 Years ☐ 5-10 Years ☐ 10+ Years

**3. What is your job title?**

☐ Architect ☐ Consultant ☐ Building Control Officer ☐ Fire Officer

☐ Other (Please State)______

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### *Design Process*

This section aims to find out more about the design process, when fire engineers get involved in the project and about validation of building designs.

**1. Do you conduct fire risk assessments?**

☐ Yes ☐ No ☐ N/A

**2. If you do a fire risk assessment, what methods or procedure do you follow?**

**3. When do you normally get involved in a project?**

☐ Preparation ☐ Design ☐ Pre Construction ☐ Construction

☐ Operation/Use

**4. When would be a more suitable time to get involved?**

☐ Preparation ☐ Design ☐ Pre Construction ☐ Construction

☐ Operation/Use

5. **Do you believe that the stage of the involvement of fire safety experts can affect the costs of the final project?**

☐Yes ☐No

6. **Do the fire safety considerations in buildings only focus on life safety?**

☐Yes ☐No ☐Don't Know

7. **If no, what other aspects are considered?**

8. **Are the majority of the buildings you manage/design/work on mainly code compliant with a few non code compliant areas within the building?**

☐Yes ☐No

9. **Do the non code compliant buildings or areas in buildings have to be validated or verified?**

☐Yes ☐No

10. **If so, how do you validate them?**

11. **Is there any guidance on what should be validated or verified?**

☐Yes ☐No

12. **How do you prove that a building is equivalent to that specified in the code?**

13. **Do you believe that Building Control or an Approved Inspector can REJECT plans due to a lack of understanding of fire engineering?**

☐Yes ☐No

14. **Do you believe that Building Control or an Approved Inspector can APPROVE plans due to a lack of understanding of fire engineering?**

☐Yes ☐No

## *Cost*

This section focuses on the costs involved within the project.

1. **In your fire safety decisions, is cost a critical factor?**

☐Yes ☐No

2. **Do you consider the cost of the protection and prevention measures specified?**

☐Yes ☐No

3. **Would you be more likely to choose a cost effective solution for a problem, if there was data available on various solutions cost effectiveness?**

☐Yes ☐No

4. **Would you use extra passive fire protection if it meant reductions in insurance premiums for the client?**

☐Yes ☐No

5. **Do you believe the addition of sprinklers to reduce risk is cost effective over the lifetime of the building?**

☐Yes ☐No

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## *Fire Protection*

This section focuses on the fire protection systems specified for a design.

1. **Do you build any form of fire safety redundancy into your buildings so if a system fails, another can compensate?**

☐Yes ☐No

2. **Do you consider inherent safety in your buildings?**

☐Yes ☐No

3. **Are extra protection measures installed over what is required in the codes?**

☐Yes ☐No

4. **On a scale of 1-5, how ESSENTIAL do you think that passive fire protection is?**

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Not Essential | ☐ | ☐ | ☐ | ☐ | ☐ | Essential |

5. **On a scale of 1-5, how EFFECTIVE do you think that passive fire protection is?**

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Not Effective | ☐ | ☐ | ☐ | ☐ | ☐ | Effective |

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## *BS 9999*

This final section focuses on British Standard 9999 and how it is used within the fire safety environment.

1. **How often do you use BS 9999 over other current design codes?**

   ☐ More Often ☐ About the same ☐ Less Often ☐ Don't Use It

2. **Has BS 9999 changed your methods of work?**

   ☐ Yes ☐ No

3. **If yes, how?**

4. **Do you think that BS 9999 is too complicated?**

   ☐ Yes ☐ No

5. **Are non code compliant areas still designed into buildings that use BS 9999?**

   ☐ Yes ☐ No

6. **Do you believe that BS 9999 reduces the scope for fire engineering?**

   ☐ Yes ☐ No

7. **Does BS 9999 offer a more cost effective method of design over Approved Document B or the old BS 5588?**

   ☐ Yes ☐ No

8. **Does the use of BS 9999 affect the design time compared to previous codes?**

   ☐ Increases design time ☐ Decreases design time ☐ No difference

9. **How is BS 9999 received by other project stakeholders?**

   ☐ Like it ☐ Dislike it ☐ No difference

10. **Part of BS 9999 focuses on building management and the management of the building after completion. Does the fire engineer supply this?**

    ☐ Yes ☐ No

11. **If not, who does?**

12. **Do you believe that a building designed to BS 9999 standards can help building owners and operators comply more easily with the Regulatory Reform (Fire Safety) Order?**

☐Yes ☐No

## Thank you

Thank you for finishing the questionnaire, your responses are much appreciated.

**If you don't mind being contacted to discuss your answers further, please leave a contact email.**

Privacy will be respected and you details will not be passed onto anyone else.

**Email:**

# Appendix B

# Data Conversion Tables

## B.1 FDR 1 Filtered Occupancies

**Table B.1:** FDR 1 TOP Data

| FDR 1 Code | FDR1 Description |
|---|---|
| 9 | Public administration and defence building other than elsewhere. codable e.g. office |
| 109 | Other building for public assembly, entertainment, recreation (not elsewhere specified) |
| 113 | Amusement Arcades |
| 121 | Dance Halls |
| 122 | Exhibition Halls |
| 123 | Sports Stadia |
| 129 | Other Sports Facilities |
| 131 | Building Of Worship |
| 133 | Church Halls |
| 141 | Social Clubs |
| 142 | Sports Clubs, Clubs for Recreational and Other Cultural Entertainment |
| 144 | Casino |
| 146 | Youth Clubs |
| 151 | Libraries |
| 152 | Museums, Art Galleries |
| 161 | Restaurant (Cafes Take Away Food Shops) |
| 162 | Night-Clubs |
| 163 | Public Houses |
| 174 | Railway Station Building, Tracks at Surface Level |
| 175 | Railway Station Building, Tracks Sub-Surface Level |

FDR 1 TOP Data

| FDR 1 Code | FDR1 Description |
|---|---|
| 176 | Railway Station Building, Tracks Above-Surface Level |
| 179 | Passenger Terminals (Not Railway) |
| 181 | Theatre (Live) |
| 182 | Concert Halls |
| 183 | Cinema |
| 185 | Radio/TV Studio |
| 186 | Film Studio |
| 189 | Other Theatres/Studios |
| 219 | Schools Etc |
| 249 | Further Education Establishment (Non Residential) |
| 261 | Conference Centres |
| 309 | Other type of welfare or charitable establishment |
| 311 | Old Persons Rest Home |
| 322 | Children’s Home |
| 331 | Hospital - Psychiatric Or Mentally Handicapped |
| 332 | Hospital - Other |
| 341 | Prison and Remand Centres |
| 345 | Police Stations |
| 359 | Home for physically handicapped or disabled (other than children) |
| 369 | Home for mentally handicapped or disabled (other than children) |
| 409 | Other establishment providing accommodation (excluding penal Establishments) |
| 449 | Hotel, Boarding House or Guest Hose |
| 469 | Block accommodation for occupational, religious, national etc groups |
| 489 | Establishment providing short-stay accommodation for recreational purposes |
| 509 | Single Shop |
| 511 | Supermarket |
| 581 | Department Store |
| 585 | Shopping Mall/Centre/Indoor Market |
| 591 | Offices - permanent stand alone structure |
| 593 | Other Medical or Dental Establishments |
| 596 | Offices - Temporary |
| 615 | Other Electricity Equipment |
| 616 | Gas Works Plant (Structure) |
| 648 | Sewage Works (Structure) |

FDR 1 TOP Data

| FDR 1 Code | FDR1 Description |
|---|---|
| 659 | Agricultural Buildings |
| 700 | Industrial Premises |
| 761 | Chemical Plant (Structure) |
| 815 | Zoo |
| 882 | Car Park Building (Separate From Other Building) |
| 888 | Fire Stations |
| 891 | Warehouse |
| 901 | Public Lavatories |
| 959 | Railway Building Other Than Station |
| 982 | Oil Refinery and Oil Rigs (Structure) |
| 985 | Kiln, Furnace, Other Heating Structure |

## B.2 FDR 1 to FPA Occupancy Type Conversion

**Table B.2:** FDR 1 to FPA Conversion Table

| FDR 1 Code | FDR1 Description | FPA Occupancy |
|---|---|---|
| 9 | Public administration and defence building other than elsewhere. codable e.g. office | Non Residential |
| 109 | Other building for public assembly, entertainment, recreation etc (not elsewhere specified, Sports and social clubs) | Non Residential |
| 113 | Amusement Arcades | Entertainment and Culture |
| 121 | Dance Halls | Entertainment and Culture |
| 122 | Exhibition Halls | Entertainment and Culture |
| 123 | Sports Stadia | Sport |
| 129 | Other Sports Facilities | Sport |
| 131 | Building Of Worship | Religion |
| 133 | Church Halls | Religion |
| 141 | Social Clubs | Entertainment and Culture |
| 142 | Sports Clubs, Clubs for Recreational and Other Cultural Entertainment | Sport |
| 144 | Casino | Entertainment and Culture |
| 146 | Youth Clubs | Entertainment and Culture |
| 151 | Libraries | Education |
| 152 | Museums, Art Galleries | Education |
| 161 | Restaurant (Cafes Take Away Food Shops) | Food and Drink |
| 162 | Night-Clubs | Food and Drink |
| 163 | Public Houses | Food and Drink |
| 174 | Railway Station Building, Tracks at Surface Level | Transport |
| 175 | Railway Station Building, Tracks Sub-Surface Level | Transport |
| 176 | Railway Station Building, Tracks Above-Surface Level | Transport |
| 178 | Railway station, otherwise not specified or unknown | Transport |
| 179 | Passenger Terminals (Not Railway) | Transport |
| 181 | Theatre (Live) | Entertainment and Culture |

FDR 1 TOP Data

| FDR 1 Code | FDR1 Description | FPA Occupancy |
|---|---|---|
| 182 | Concert Halls | Entertainment and Culture |
| 183 | Cinema | Entertainment and Culture |
| 185 | Radio/TV Studio | Entertainment and Culture |
| 186 | Film Studio | Entertainment and Culture |
| 189 | Other Theatres/Studios | Entertainment and Culture |
| 219 | Schools Etc | Education |
| 249 | Further Education Establishment (Non Residential - Else See 469) | Education |
| 261 | Conference Centres | Education |
| 309 | Other type of welfare or charitable establishment | Non Residential |
| 311 | Old Persons Rest Home | Medical |
| 322 | Childrens Home | Medical |
| 331 | Hospital Psychiatric Or Mentally Handicapped | Medical |
| 332 | Hospital Other | Medical |
| 341 | Prison and Remand Centres | Public Utilities |
| 345 | Police Stations | Public Utilities |
| 359 | Home for physically handicapped or disabled (other than children) | Medical |
| 369 | Home for mentally handicapped or disabled (other than children) | Medical |
| 409 | Other establishment providing accommodation (excluding penal Establishments) | Other Residential |
| 449 | Hotel, Boarding House or Guest Hose | Other Residential |
| 469 | Block accommodation for occupational, religious, national etc groups | Other Residential |
| 489 | Establishment providing short-stay accommodation for recreational purposes | Other Residential |
| 509 | Single Shop | Retail |
| 511 | Supermarket | Retail |
| 581 | Department Store | Retail |
| 585 | Shopping Mall/Centre/Indoor Market | Retail |
| 591 | Offices permanent stand alone structure | Non Residential |
| 593 | Other Medical or Dental Establishments | Medical |
| 597 | Offices Temporary | Non Residential |

FDR 1 TOP Data

| FDR 1 Code | FDR1 Description | FPA Occupancy |
|---|---|---|
| 615 | Other Electricity Equipment | Public Utilities |
| 616 | Gas Works Plant (Structure) | Public Utilities |
| 648 | Sewage Works (Structure) | Public Utilities |
| 659 | Agricultural Buildings | Permanent Agricultural |
| 700 | Industrial Premises | Industrial Processing |
| 761 | Chemical Plant (Structure) | Industrial Processing |
| 815 | Zoo | Public Utilities |
| 881 | Private Garage | Car Parks |
| 882 | Car Park Building (Separate From Other Building) | Car Parks |
| 888 | Fire Stations | Public Utilities |
| 891 | Warehouse | Warehouses |
| 901 | Public Lavatories | Public Utilities |
| 904 | Other private non-residential building | Non Residential |
| 926 | Private shed or greenhouse | Non Residential |
| 959 | Railway Building Other Than Station | Transport |
| 982 | Oil Refinery and Oil Rigs (Structure) | Industrial Processing |
| 985 | Kiln, Furnace, Other Heating Structure | Industrial Processing |

## B.3 BCIS to FPA Occupancy Type Conversion

**Table B.3:** BCIS Data Combined with FPA Data

| Building Function | FPA Group |
|---|---|
| Railway stations | Transport |
| Railway lineside buildings | Transport |
| Railway signal boxes | Transport |
| Railway relay buildings/substations | Transport |
| Railway lineside staff accommodation | Transport |
| Rail vehicle storage/repair buildings | Transport |
| Coach and bus stations | Transport |
| Car parks (Multi-storey) | Car Parks |
| Car parks (Underground) | Car Parks |
| Petrol stations | Transport |
| Traffic control buildings | Transport |
| Road vehicle storage/repair buildings (incl car showrooms) | Transport |
| Garages | Transport |
| Domestic scale garages | Transport |
| Vehicle storage buildings | Transport |
| Coach and bus depots | Transport |
| Vehicle showrooms | Retail |
| Vehicle showrooms with workshops, garages, etc | Retail |
| Vehicle showrooms with workshops, garages, etc | Retail |
| Vehicle showrooms with workshops, garages, etc | Retail |
| Vehicle showrooms with workshops, garages, etc | Retail |
| Vehicle showrooms without workshops, garages, etc | Retail |
| Vehicle showrooms without workshops, garages, etc | Retail |
| Vehicle showrooms without workshops, garages, etc | Retail |
| Vehicle showrooms without workshops, garages, etc | Retail |
| Vehicle repair and maintenance buildings | Transport |
| Vehicle repair and maintenance buildings | Transport |
| Vehicle repair and maintenance buildings | Transport |
| Vehicle repair and maintenance buildings | Transport |
| Car wash buildings | Transport |
| Port and harbour buildings | Transport |
| Boat control buildings | Transport |
| Air transport terminals | Transport |
| Air traffic control buildings | Transport |

BCIS to FPA Conversion Table

| Building Function | FPA Group |
|---|---|
| Aircraft storage/repair buildings | Transport |
| Radio buildings | Entertainment and Culture |
| Recording studios | Entertainment and Culture |
| Television buildings | Entertainment and Culture |
| Television studios | Entertainment and Culture |
| Close circuit television control buildings | Public Utilities |
| Telephone exchanges | Public Utilities |
| Telephone engineering centres, TSCVs | Public Utilities |
| Transmitting/receiving stations | Public Utilities |
| Post Offices | Public Utilities |
| Sorting Offices | Public Utilities |
| Generator houses, power stations, etc | Public Utilities |
| Sub-stations (electricity transmission) | Public Utilities |
| Battery buildings (electricity storage) | Public Utilities |
| Water supply, treatment, storage and distribution buildings | Public Utilities |
| Refuse depots | Public Utilities |
| Incinerators | Public Utilities |
| Mortuaries, morgues | Public Utilities |
| Bulk goods storage facilities | Warehouses |
| Fish farms, fisheries | Permanent Agricultural |
| Nurseries (horticulture), greenhouses, etc | Permanent Agricultural |
| Livestock buildings - farms(pig pens, milking parlours, etc) | Permanent Agricultural |
| Stud farms, stables and the like | Permanent Agricultural |
| Agricultural storage buildings | Permanent Agricultural |
| Agricultural storage with non thrust resistant walls | Permanent Agricultural |
| Food/drink/tobacco factories | Industrial Processing |
| Breweries | Industrial Processing |
| Factories for chemical and allied industries | Industrial Processing |
| Factories for metals | Industrial Processing |
| Factories for mechanical engineering | Industrial Processing |
| Factories for instrument engineering | Industrial Processing |
| Factories for electrical engineering | Industrial Processing |
| Factories for electronics, computers, or the like | Industrial Processing |
| Factories for vehicles | Industrial Processing |
| Factories for textiles | Industrial Processing |
| Factories for leather, leather goods and fur | Industrial Processing |

BCIS to FPA Conversion Table

| Building Function | FPA Group |
|---|---|
| Factories for clothes, footwear | Industrial Processing |
| Factories for bricks, pottery, glass, cement | Industrial Processing |
| Factories for timber, furniture | Industrial Processing |
| Factories for paper, printing and publishing | Industrial Processing |
| Builders yards, Local Authority maintenance depots | Industrial Processing |
| Factories | Industrial Processing |
| Factories | Industrial Processing |
| Factories | Industrial Processing |
| Factories | Industrial Processing |
| Advance factories | Industrial Processing |
| Advance factories | Industrial Processing |
| Advance factories | Industrial Processing |
| Advance factories | Industrial Processing |
| Advance Factories/Offices - mixed facilities (class B1) | Industrial Processing |
| Advance Factories/Offices - mixed facilities (class B1) | Industrial Processing |
| Advance Factories/Offices - mixed facilities (class B1) | Industrial Processing |
| Advance Factories/Offices - mixed facilities (class B1) | Industrial Processing |
| Purpose built factories | Industrial Processing |
| Purpose built factories | Industrial Processing |
| Purpose built factories | Industrial Processing |
| Purpose built factories | Industrial Processing |
| Purpose built factories/Offices - mixed facilities | Industrial Processing |
| Warehouses/stores | Warehouses |
| Warehouses/stores | Warehouses |
| Warehouses/stores | Warehouses |
| Warehouses/stores | Warehouses |
| Advance warehouses/stores | Warehouses |
| Purpose built warehouses/stores | Warehouses |
| Purpose built warehouses/stores | Warehouses |
| Purpose built warehouses/stores | Warehouses |
| Purpose built warehouses/stores | Warehouses |
| Cold stores/Refrigerated stores | Warehouses |
| County, City, Town halls | Public Utilities |
| Local admin buildings | Public Utilities |
| Law courts | Public Utilities |
| Offices | Non Residential |

BCIS to FPA Conversion Table

| Building Function | FPA Group |
|---|---|
| Offices | Non Residential |
| Offices | Non Residential |
| Offices | Non Residential |
| Offices | Non Residential |
| Offices | Non Residential |
| Offices | Non Residential |
| Offices | Non Residential |
| Offices | Non Residential |
| Offices with shops, banks, flats, etc | Non Residential |
| Offices with shops, banks, flats, etc | Non Residential |
| Offices with shops, banks, flats, etc | Non Residential |
| Offices with shops, banks, flats, etc | Non Residential |
| Artist's studios | Non Residential |
| Banks/Building Society branches | Retail |
| Mixed commercial developments | Retail |
| Wholesale trading building/auction rooms | Retail |
| Retail warehouses | Warehouses |
| Retail warehouses | Warehouses |
| Retail warehouses | Warehouses |
| Retail warehouses | Warehouses |
| Retail warehouses | Warehouses |
| Market building providing accommodation for pens stalls etc | Retail |
| Shopping centres | Retail |
| Department stores | Retail |
| Hypermarkets, supermarkets | Retail |
| Hypermarkets, supermarkets | Retail |
| Hypermarkets, supermarkets | Retail |
| Hypermarkets, supermarkets | Retail |
| Hypermarkets, supermarkets | Retail |
| Shops | Retail |
| Shops | Retail |
| Shops | Retail |
| Shops with domestic, office accommodation | Retail |
| Service shops | Retail |
| Undertakers | Public Utilities |

BCIS to FPA Conversion Table

| Building Function | FPA Group |
|---|---|
| Mountain and cave rescue stations | Public Utilities |
| Fire stations | Public Utilities |
| Fire stations | Public Utilities |
| Fire stations | Public Utilities |
| Fire stations | Public Utilities |
| Fire service admin/control buildings | Public Utilities |
| Fire stations with rescue and other emergency services | Public Utilities |
| Fire training towers | Public Utilities |
| Fire training buildings | Public Utilities |
| Ambulance stations | Public Utilities |
| Ambulance admin/control buildings | Public Utilities |
| Police stations | Public Utilities |
| Police admin/control buildings | Public Utilities |
| Military buildings | Public Utilities |
| Air Force facilities, operations building | Public Utilities |
| Army facilities, operations buildings | Public Utilities |
| Territorial Army Centres | Public Utilities |
| Civil defence facilities | Public Utilities |
| Camps, depots, bases, ranges | Other outdoors (including land) |
| Open prisons | Public Utilities |
| Closed prisons | Public Utilities |
| Reformatories,borstals,secure residential units for children | Public Utilities |
| Cells and custody blocks | Public Utilities |
| Specialist facilities within prison complex | Public Utilities |
| Teaching hospitals | Medical |
| Hospital teaching centres | Medical |
| General hospitals, GP hospitals, cottage hospitals | Medical |
| General hospitals, GP hospitals, cottage hospitals | Medical |
| General hospitals, GP hospitals, cottage hospitals | Medical |
| General hospitals, GP hospitals, cottage hospitals | Medical |
| General hospitals, GP hospitals, cottage hospitals | Medical |
| Hospital - mixed specialist facilities | Medical |
| Mental, psychiatric hospital facilities | Medical |
| Psychiatric units | Medical |
| Psycho-geriatric units | Medical |

BCIS to FPA Conversion Table

| Building Function | FPA Group |
|---|---|
| Mental handicapped units | Medical |
| Ear, nose and throat units | Medical |
| Eye hospitals | Medical |
| Dental units (hospital facilities) | Medical |
| Cardiac units | Medical |
| Spinal injuries units | Medical |
| Chiropody units | Medical |
| Dermatology units | Medical |
| Hospital facilities for treatment of parts of the body | Medical |
| Maternity, gynaecological hospital facilities | Medical |
| Genito-urinary facilities | Medical |
| Paediatric, geriatric hospital facilities | Medical |
| Paediatric units, children’s hospitals | Medical |
| Geriatric units | Medical |
| Diagnosis excluding radiography (x-ray) | Medical |
| Radiography (x-ray) units | Medical |
| Surgery including operating theatres | Medical |
| Hospital laboratories | Medical |
| Pathology laboratories | Medical |
| Occupational therapy, physiotherapy, hydrotherapy | Medical |
| Palliative units | Medical |
| Chemotherapy including pharmacies, dispensaries | Medical |
| Pharmacies | Medical |
| Chemotherapy units | Medical |
| Radiotherapy units (incl linear accelerators) | Medical |
| Specialised facilities | Medical |
| Ward blocks | Medical |
| Outpatients/casualty units | Medical |
| Day hospitals | Medical |
| Intensive care/Acute wards | Medical |
| Sterile stores, sterilisation units | Medical |
| Health Centres, clinics, group practice surgeries | Medical |
| Health Centres, clinics, group practice surgeries | Medical |
| Health Centres, clinics, group practice surgeries | Medical |
| Dentists surgeries | Medical |
| Welfare consultation centres | Medical |

BCIS to FPA Conversion Table

| Building Function | FPA Group |
|---|---|
| First aid posts | Medical |
| Medical research facilities | Medical |
| Blood transfusion facilities | Medical |
| Observation and assessment centres | Medical |
| Nursing homes, convalescent homes, short stay medical homes | Medical |
| Hospices - Homes for chronic invalids, addicts, etc | Medical |
| Homes for mentally handicapped/deficient | Medical |
| Homes for mentally handicapped/deficient | Medical |
| Homes for mentally handicapped/deficient | Medical |
| Homes for mentally handicapped/deficient | Medical |
| Homes for physically handicapped | Medical |
| Childrens homes | Medical |
| Homes for children with special needs | Medical |
| Old people's home | Medical |
| Old people's home | Medical |
| Old people's home | Medical |
| Old people's home | Medical |
| Day centres | Medical |
| Veterinary hospitals | Permanent Agricultural |
| Animal clinics | Permanent Agricultural |
| Animal rearing and living facilities: research, domestic etc | Permanent Agricultural |
| Kennels and catteries | Permanent Agricultural |
| Canteens, refectories | Food and Drink |
| Restaurants | Food and Drink |
| Cafes, snack bars, coffee bars, milk bars | Food and Drink |
| Motorway services buildings - mixed facilities | Food and Drink |
| Public houses, licensed premises | Food and Drink |
| Public houses, licensed premises | Food and Drink |
| Public houses, licensed premises | Food and Drink |
| Function rooms, banqueting rooms, meeting rooms, etc | Entertainment and Culture |
| Dance halls, ballrooms, discotheques | Entertainment and Culture |
| Concert halls | Entertainment and Culture |
| Opera houses | Entertainment and Culture |
| Theatres | Entertainment and Culture |
| Drama ancillary buildings | Entertainment and Culture |

BCIS to FPA Conversion Table

| Building Function | FPA Group |
|---|---|
| Cinemas | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
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| Community Centres | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
| Community Centres | Entertainment and Culture |
| General purpose halls | Entertainment and Culture |
| General purpose halls | Entertainment and Culture |
| General purpose halls | Entertainment and Culture |
| General purpose halls | Entertainment and Culture |
| Visitors' centres | Entertainment and Culture |
| Clubs, youth clubs, students unions, etc | Entertainment and Culture |
| Mixed recreation buildings, holiday camps, caravan sites,etc | Entertainment and Culture |
| Covered swimming pools | Sport |
| Covered swimming pools | Sport |
| Covered swimming pools | Sport |
| Covered swimming pools | Sport |
| Small swimming pools | Sport |
| 25 metre swimming pools | Sport |
| 50 metre swimming pools | Sport |
| Leisure pools | Sport |
| Diving pools, special pools | Sport |
| Boat houses (private and recreational) | Sport |
| Sports centres/recreational centres | Sport |

BCIS to FPA Conversion Table

| Building Function | FPA Group |
|---|---|
| Sports centres/recreational centres | Sport |
| Sports centres/recreational centres | Sport |
| Sports centres/recreational centres | Sport |
| Sports centre/recreation centres inc swimming pools | Sport |
| Sports centre/recreation centres inc swimming pools | Sport |
| Sports centre/recreation centres inc swimming pools | Sport |
| Sports centre/recreation centres inc swimming pools | Sport |
| Gymnasia/sports halls | Sport |
| Gymnasia/sports halls | Sport |
| Gymnasia/sports halls | Sport |
| Gymnasia/sports halls | Sport |
| Indoor athletics training centres | Sport |
| Indoor athletics training centres | Sport |
| Indoor athletics training centres | Sport |
| Gymnasia, fitness centres, etc | Sport |
| Gymnasia, fitness centres including swimming pools | Sport |
| Squash courts | Sport |
| Tennis courts (indoor) | Sport |
| Table tennis centres | Sport |
| Indoor cricket centres | Sport |
| Indoor football training centres | Sport |
| Bowling alleys (tenpin bowling alleys) | Sport |
| Indoor bowling greens | Sport |
| Stadia, sports grounds | Sport |
| Stadia, sports grounds | Sport |
| Stadia, sports grounds | Sport |
| Stadia, sports grounds | Sport |
| Indoor sports arenas | Sport |
| Indoor motor sports centres | Sport |
| Riding schools | Sport |
| Rifle ranges | Sport |
| Golf driving ranges | Sport |
| Covered ice rinks | Sport |
| Sports pavilions, club houses and changing rooms | Sport |
| Sports pavilions, club houses and changing rooms | Sport |
| Sports pavilions, club houses and changing rooms | Sport |

BCIS to FPA Conversion Table

| **Building Function** | **FPA Group** |
|---|---|
| Sports pavilions, club houses and changing rooms | Sport |
| Sports pavilions, club houses and changing rooms | Sport |
| Sports changing rooms | Sport |
| Sports changing rooms | Sport |
| Sports changing rooms | Sport |
| Sports changing rooms | Sport |
| Sports pavilions and club houses | Sport |
| Sports pavilions and club houses | Sport |
| Sports pavilions and club houses | Sport |
| Sports pavilions and club houses | Sport |
| Sports pavilions and club houses | Sport |
| Golf club houses | Sport |
| Golf club houses | Sport |
| Golf club houses | Sport |
| Golf club houses | Sport |
| Casinos | Entertainment and Culture |
| Churches, chapels | Religious |
| Mission halls, meeting houses | Religious |
| Temples, mosques, synagogues | Religious |
| Convents | Religious |
| Crematoria | Religious |
| Schools | Education |
| Schools | Education |
| Schools | Education |
| Nursery schools/creches | Education |
| Nursery schools/creches | Education |
| Nursery schools/creches | Education |
| Nursery schools/creches | Education |
| Primary schools | Education |
| Primary schools | Education |
| Primary schools | Education |
| Primary schools | Education |
| Middle schools | Education |
| Primary/middle schools - specialised teaching blocks | Education |
| Primary Schools - mixed facilities | Education |
| Secondary schools (high schools) | Education |

BCIS to FPA Conversion Table

| Building Function | FPA Group |
|---|---|
| Secondary schools - specialised teaching blocks | Education |
| Secondary Schools - mixed facilities | Education |
| Sixth form/tertiary colleges | Education |
| Sixth form specialised teaching blocks | Education |
| Sixth form - mixed facilities | Education |
| Special schools | Education |
| Schools for the mentally handicapped | Education |
| Schools for the physically handicapped | Education |
| Boarding schools - mixed teaching/residential buildings only | Education |
| Playcare centres, out of school clubs | Education |
| Universities | Education |
| University - specialised teaching blocks | Education |
| University - mixed facilities | Education |
| Colleges | Education |
| Colleges | Education |
| Colleges | Education |
| Colleges | Education |
| Colleges - specialised teaching blocks | Education |
| Colleges - mixed facilities | Education |
| Adult education facilities | Education |
| Adult education facilities for the mentally handicapped | Education |
| Adult education facilities for the physically handicapped | Education |
| Lecture theatres | Education |
| Research facilities | Education |
| Laboratories | Education |
| Observatories, recording stations | Education |
| Botanical gardens, herbaria, zoos | Education |
| Aviaries | Education |
| Aquaria | Education |
| Museums, planetaria | Education |
| Art galleries, facilities for special displays | Education |
| Exhibition buildings | Education |
| Libraries | Education |
| Libraries | Education |
| Libraries | Education |

BCIS to FPA Conversion Table

| **Building Function** | **FPA Group** |
|---|---|
| Libraries | Education |
| Public Libraries | Education |
| School/College/University Libraries | Education |
| Special libraries | Education |
| Computer buildings | Education |
| Computer buildings | Education |
| Computer buildings | Education |
| Record offices, archives, patent offices | Public Utilities |
| Gate houses etc | Non Residential |
| Waiting rooms | Non Residential |
| Links, corridors, etc | Non Residential |
| Stair towers, lift towers, etc | Non Residential |
| Conference centres | Education |
| Staff rooms, common rooms, rest rooms, etc | Non Residential |
| Kitchens | Food and Drink |
| Kitchens with dining facilities | Food and Drink |
| Public conveniences | Public Utilities |
| Toilet blocks - private facilities | Public Utilities |
| Utility blocks (washing and toilet facilities) | Public Utilities |
| Dressing, changing rooms | Public Utilities |
| Laundries | Retail |
| Boiler houses | Public Utilities |
| Boiler houses, including boiler plant | Public Utilities |
| Boiler houses, excluding boiler plant | Public Utilities |
| Pier buildings | Public Utilities |

# Appendix C

# Source Code

## C.1 FDR 1 Occupancy (TOP) Data Filter

**Listing C.1:** FDR 1 Filtering Code

```
:: Data Seperation Script for FDR 1 Data

:: Change Drive
E:

:: Change Path
cd "E:\Documents\IRMP Data\DATA ANALYSIS\FDR1 DATA"

:: Print top line of file to output file (contains dat
   headings)
sed -n 1p Lboro_9908.csv > Filtered_Buildings.csv

:: Find data and append to output file
awk -F , "$14=="9" {print}" Lboro_9908.csv >>
   Filtered_Buildings.csv
awk -F , "$14=="109" {print}" Lboro_9908.csv >>
   Filtered_Buildings.csv
awk -F , "$14=="113" {print}" Lboro_9908.csv >>
   Filtered_Buildings.csv
awk -F , "$14=="121" {print}" Lboro_9908.csv >>
   Filtered_Buildings.csv
awk -F , "$14=="122" {print}" Lboro_9908.csv >>
   Filtered_Buildings.csv
```

```
awk -F , "$14=="123" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="129" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="131" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="133" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="141" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="142" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="144" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="146" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="151" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="152" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="161" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="162" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="163" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="174" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="175" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="176" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="178" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="179" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="181" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
```

```
awk -F , "$14=="182" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="183" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="185" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="186" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="189" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="219" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="249" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="261" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="309" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="311" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="322" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="331" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="332" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="341" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="345" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="359" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="369" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="409" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="449" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
```

```
awk -F , "$14=="469" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="489" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="509" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="511" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="581" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="585" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="591" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="593" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="597" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="659" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="700" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="815" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="881" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="882" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="888" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="891" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="900" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="901" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="904" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
```

```
awk -F , "$14=="909" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="926" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="953" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
awk -F , "$14=="959" {print}" Lboro_9908.csv >>
    Filtered_Buildings.csv
```

## C.2 FPA Occupancy Data Filter

**Listing C.2:** FPA Data Separation Bash Script

```
#!/bin/bash

# Variables
# ~~~~~~~~~
Original="./
   FPA_Fires_Non_Residential_Only_Empties_Removed_Cost_Per_SQM
   .csv"

# Explanation
# ~~~~~~~~~~~
# sed -n 1p $Original > File.csv
# Sed command takes first line of file and adds to new file
    - these are the variable headers.

# grep "Variable" $Original >> File.csv
# Grep returns only lines which include the variable search
    term and appends them to the new file.

# Code
# ~~~~~~~~~~~

# Industrial Processing Separation
sed -n 1p $Original > Industrial_Processing.csv
grep "Industrial Processing" $Original >>
   Industrial_Processing.csv

# Non Residential -Misc Separation
sed -n 1p $Original > Non_Residential-Misc.csv
grep "Non Residential -Misc" $Original >> Non_Residential-
   Misc.csv

# Food and Drink Separation
sed -n 1p $Original > Food_and_Drink.csv
grep "Food and Drink" $Original >> Food_and_Drink.csv
```

```
# Retail Separation
sed -n 1p $Original > Retail.csv
grep "Retail" $Original >> Retail.csv

# Warehouses Separation
sed -n 1p $Original > Warehouses.csv
grep "Warehouses" $Original >> Warehouses.csv

# Permanent Agricultural Separation
sed -n 1p $Original > Permanent_Agricultural.csv
grep "Permanent Agricultural" $Original >>
    Permanent_Agricultural.csv

# Education Separation
sed -n 1p $Original > Education.csv
grep "Education" $Original >> Education.csv

# Entertainment and Culture Separation
sed -n 1p $Original > Entertainment_and_Culture.csv
grep "Entertainment and Culture" $Original >>
    Entertainment_and_Culture.csv

# Religious Separation
sed -n 1p $Original > Religious.csv
grep "Religious" $Original >> Religious.csv

# Sport Separation
sed -n 1p $Original > Sport.csv
grep "Sport" $Original >> Sport.csv

# Medical Separation
sed -n 1p $Original > Medical.csv
grep "Medical" $Original >> Medical.csv

# Validation Step
# ~~~~~~~~~~~~~~~

# Counts the number of lines in each file
# Should be +1 to the number of records found in SPSS
```

```
# +1 value due to counting of variable names

wc -l *.csv
```

## C.3 FDR 1 Fire Time Filter

**Algorithm 4** Filter 0 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF (IGNTDISC = 1 AND DISCCALL = 1).
EXECUTE.
```

**Algorithm 5** Filter 2.5 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF ((IGNTDISC = 2 AND DISCCALL = 1) OR (IGNTDISC = 1
    AND DISCCALL = 2)).
EXECUTE.
```

**Algorithm 6** Filter 5 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF (IGNTDISC = 2 AND DISCCALL = 2).
EXECUTE.
```

**Algorithm 7** Filter 17.5 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF ((IGNTDISC = 3 AND DISCCALL = 1) OR (IGNTDISC = 1
    AND DISCCALL = 3)).
EXECUTE.
```

**Algorithm 8** Filter 20 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF ((IGNTDISC = 3 AND DISCCALL = 2) OR (IGNTDISC = 2
    AND DISCCALL = 3)).
EXECUTE.
```

**Algorithm 9** Filter 35 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF (IGNTDISC = 3 AND DISCCALL = 3).
EXECUTE.
```

**Algorithm 10** Filter 75 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF ((IGNTDISC = 4 AND DISCCALL = 1) OR (IGNTDISC = 1
    AND DISCCALL = 4)).
EXECUTE.
```

**Algorithm 11** Filter 77.5 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF ((IGNTDISC = 4 AND DISCCALL = 2) OR (IGNTDISC = 2
    AND DISCCALL = 4)).
EXECUTE.
```

**Algorithm 12** Filter 92.5 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF ((IGNTDISC = 4 AND DISCCALL = 3) OR (IGNTDISC = 3
    AND DISCCALL = 4)).
EXECUTE.
```

**Algorithm 13** Filter 120 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF ((IGNTDISC = 5 AND DISCCALL = 1) OR (IGNTDISC = 1
    AND DISCCALL = 5)).
EXECUTE.
```

**Algorithm 14** Filter 122.5 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF ((IGNTDISC = 5 AND DISCCALL = 2) OR (IGNTDISC = 2
    AND DISCCALL = 5)).
EXECUTE.
```

**Algorithm 15** Filter 137.5 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF ((IGNTDISC = 5 AND DISCCALL = 3) OR (IGNTDISC = 3
    AND DISCCALL = 5)).
EXECUTE.
```

**Algorithm 16** Filter 150 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF (IGNTDISC = 4 AND DISCCALL = 4).
EXECUTE.
```

**Algorithm 17** Filter 195 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF ((IGNTDISC = 5 AND DISCCALL = 4) OR (IGNTDISC = 4
    AND DISCCALL = 5)).
EXECUTE.
```

**Algorithm 18** Filter 240 Minute Records

```
FILTER OFF.
USE ALL.
SELECT IF (IGNTDISC = 5 AND DISCCALL = 5).
EXECUTE.
```