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Decision Problem Structuring for Selection of Fixed Firefighting Systems

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DECISION PROBLEM STRUCTURING FOR SELECTION OF FIXED FIREFIGHTING SYSTEMS

By

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A dissertation thesis submitted in partial fulfilment of the requirements for the award of the degree Doctor of Engineering (EngD), at Loughborough University

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ABSTRACT

Active fire protection systems are an essential fire safety management tool, particularly in potentially high financial and risk consequence scenarios. In the UK and Europe over recent decades regulatory changes have been successful in creating an environment in which more innovation can take place. Increased numbers of fixed firefighting system types are now available to the user. However, not all systems offered are equal in terms of; suitability, cost, maturity of supporting knowledge, and overall performance or in-service reliability. Understanding of the systems' performance and its limitations and how to match this to the assessed fire risk is incomplete among users. Experts are observing increasing numbers of what they consider to be poor fixed firefighting system choices leading to weaker fire safety designs, which is a cause of concern.

Therefore the research aim is to verify that these concerns are founded and, that being the case, to develop a decision support system and related supporting resources to further this aspect of fire safety education and enable users to make better informed system selections. Thus, the focus of this research has been to develop a fixed firefighting system selection tool to complement existing legislation, which incorporates logic, rules and fire safety educational resources in a variety of formats to aid the fire safety design process. A variety of largely heuristic techniques have been used to aggregate data to form knowledge to underpin fixed firefighting system selection tool. In this form, the tool has been validated by experts as being a useful resource. The developed tool also provides ample opportunity for useful ongoing future development. The work recognises that cost and benefit are critical in the selection process. Supporting resources have been incorporated into the tool to assist users in evaluating the levels of reliability they might expect from a system in their circumstances.

This tool has now been exposed to a wider audience of experts as part of an evaluation process. Findings include: that the tool is an innovative approach to promoting good fire safety designs, the tool efficiently provides useful fire safety education to users and the developed supporting resources which consider firefighting system reliability are helpful. This thesis and reference papers summarise the key stages of this research and tool development. The thesis concludes by outlining the progress achieved by this work and recommendations arising.

KEY WORDS
Fire, suppression, firefighting, selection, decision support, expert system

PREFACE

The Engineering Doctorate (EngD) scheme is a PhD-equivalent research based education programme promoted by the Engineering and Physical Sciences Research Council (EPSRC). Students conduct research and undertake taught business and technical courses whilst working in partnership with an industrial sponsor, with focus on implementation of innovation.

The EngD final assessment is based upon a thesis (this work) and collection of published papers or technical reports (a minimum of three papers). This work includes three papers and two technical outputs, all with strong alignment and lending support to the work of the research.

USED ACRONYMS / ABBREVIATIONS

ABI	Association of British Insurers
AI	Artificial Intelligence
AR	Action Research
ARM	Availability, Reliability and Maintainability
BAFSA	British Automatic Fire Sprinkler Association
BIM	Building Information Modelling
BRE	Building Research Establishment
BS	Behavioural specification
BSI	British Standards Institution
CBA	Cost-Benefit Analysis
CEBR	Centre for Economics and Business Research
CEN	Comité Européen de Normalisation or in English translation European Committee for Standardisation
CICE	Centre for Innovative and Collaborative Construction
DCLG (or CLG)	Department for Communities and Local Government
DS	Decision Support
DSS	Decision Support Systems
EngD	Engineering Doctorate
EPSRC	Engineering and Physical Sciences Research Council
ES	Expert System
FDR	Fire Data Report
FFS	Fixed Firefighting System
FFSST	Fixed Firefighting System Selection Tool
FIA	Fire Industry Association

FPA	Fire Protection Association
GA	Genetic Algorithms
GIS	Geographic information systems
GUI	Graphical User Interface
HMSO	Her Majesty's Stationary Office
IRS	Incident Reporting System
IQ1	Insurer Questionnaire 1
KM	Knowledge Management
LP	Linear Programming
LPC	Loss Prevention Council
LPCB	Loss Prevention Certification Board
NFPA	Nation Fire Protection Association
PS	Product Specification
RAD	Rapid Application Development
REDEG	Risk Engineering Data Exchange Group
SFPE	Society of Fire Protection Engineers
SRD	Software Requirements Document

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LIST OF PAPERS

The following papers, included in the appendices, have been produced in partial fulfilment of the award requirements of the Engineering Doctorate during the course of the research.

PAPER 1 (SEE APPENDIX A)

S. N. Bird, N. M. Bouchlaghem, J. Glockling, S. G. Yeomans (2012).

Decision Problem Structuring Method for the Specification and Selection of Active Fire Protection Systems.

Proceedings of the 7th International conference on innovation in architecture, engineering and construction. 15th – 17th August 2012, The Brazilian British Centre, São Paulo, Brazil.

PAPER 2 (SEE APPENDIX B)

S. N. Bird, K. Ruikar, L. Bosher, N. M. Bouchlaghem, J. Glockling (2013).

Development of a Fixed Firefighting System Selection Tool for Improved Outcomes.

Journal of Information Technology in Construction, No. 18, pp. 353-371.

PAPER 3 (SEE APPENDIX C)

Bird, S. N., Ruikar, K., Bosher, L., Glockling, J. & Bouchlaghem, N. M (2014).

Decision Structuring Method for Selection of Fixed Firefighting Systems: development and lessons learned from case studies.

Proceedings of the 9th International Conference on Risk Analysis and Hazard Mitigation, 4th – 6th June 2014. New Forest, UK.

TECHNICAL OUTPUT 1 (SEE APPENDIX D)

Bird, S. N. (2014)

TB234 Protection of High Hazard Storage (HHS) configurations.

LPC Rules for Automatic Sprinkler Installations - Incorporating BS EN 12845. Moreton-in-Marsh, UK: The Fire Protection Association.

TECHNICAL OUTPUT 2 (SEE APPENDIX E)

Bird, S. N., Stephens, J. & J. Glockling. (2011).

IQ1: Water Mist Questionnaire: Building Protection.

The Fire Protection Association. Moreton in Marsh, Gloucestershire, UK,

1 BACKGROUND TO THE RESEARCH

This chapter introduces the research. It highlights the need for the research and describes the related background information. It also outlines the structure of the thesis.

1.1 THE GENERAL SUBJECT DOMAIN

Fire in the built and natural environment remains a destructive force and a significant vulnerability to mankind (Woodrow, 2011). It is the cause of numerous casualties, disruption to communities and economies, as illustrated in Figure 1.1and Figure 1.2. Preventable fires still significantly curtail productivity (CEBR, 2014). Fixed Firefighting Systems are one of the measures that can be used to mitigate fire hazard.

The majority of built or manufactured objects and buildings have *fire safety provisions* incorporated within them; Fire guards to protect from open household fires, over-current fuses protecting electrical appliances, use of non-combustible materials, thermal cut-out devices, gas safety shut-off valves, compartmentation in buildings, manual first aid (such as fire extinguishers, fire blankets, hose reels), fire service intervention, fixed firefighting systems such as fixed local systems, fixed building systems (Bird et al., 2012). These few examples vary in scale, complexity and approach. This project focuses on the challenge of selecting appropriate fixed firefighting systems.

In the built environment, as the density, complexity and scale of populations and activity within a building increase, then the potential sources of causes of fire will also increase dramatically in number. So too might the potential scale and consequence of a fire (Bird et al., 2013). Fixed firefighting systems tend to be specified as additional fire protection and resilience measures when various perceived risk and consequence thresholds are breached.

The work of BRE Global (2013) and CEBR (2014) confirm that fixed firefighting systems are a beneficial fire protection feature when the risk posed by fire is sufficiently great. They also confirm that the use of such systems is under exploited.

The term “fixed firefighting systems” is prominent in the title of several notable British and European Standards; BS EN 12259 series for “Components for sprinkler and water spray systems” (BSI, 1999), BS EN 12094 series “Components for gas extinguishing systems” (BSI, 2003a), BS EN 15004 series “Gas extinguishing systems - Design, installation and maintenance” (BSI, 2008c). The term is in fairly common use elsewhere (DCLGs Fire safety risk assessment guidance documents (DGCL, 2006), Mannan (2012) in “Lees' Loss Prevention in the Process Industries”. There are other variations upon this terminology. Sometimes “Firefighting” is written as “Fire Fighting”. Sometimes “Fixed Fire Protection Systems” appears to be preferred (BSI, 2011b). The terms “Fire Extinguishing Systems” (BSI, 2013) and “Fire Suppression System” (The Chartered Institution of Building Services Engineers, 2010) are also often encountered and sometimes used interchangeably, although arguably having different meanings (different firefighting objectives). It could be said they are subsets of the term “fixed firefighting system”. This term is therefore adopted for used as a generic descriptor for many types of fixed (installed and non-portable) firefighting (with *suppression* or *extinguishing* objective) systems. As the term is used frequently in this work it is often abbreviated to the acronym “FFS”.

FFS generally comprise a firefighting media (such as water, gas, powder or other chemical), a motive source (such as a pump, stored pressure or stored chemical energy), actuation device(s) and a delivery means (such as pipes and nozzles).

Field experience supported by BRE Global’s guide (BRE Global, 2009) tells us that FFSs are installed mostly; to meet legislative requirements, or to reduce risk(s) for business resilience purposes. The concern of this work is to investigate whether current FFS selection practice can be considered optimum and if not, to seek to develop a means by which improvements in selection practice might be affected.

Information Technology (IT) techniques; Knowledge Management, Decision Support or Expert Systems are identified as a potentially useful resource to this research. Proprietary development environments may now be sufficiently mature, easy to use and accessible that a non-IT expert user (but one with sufficient problem-domain knowledge, such as the Research Engineer) may be able to use such environments to help address the perceived selection problem.

1.2 THE INDUSTRIAL SPONSOR

The Fire Protection Association (FPA) is the UK's national fire safety organisation. Established in 1946, it has become recognised as an independent and authoritative source of information and advice relating to many aspects of fire safety, risk management and loss prevention. It offers independent and high quality research, consultancy, training, publications, risk surveying and auditing services (FPA, 2014a).

The FPA and several leading UK insurers who participate in its risk management work, have identified the requirement for assistance with the decision making process of analysing fire hazards and matching them to appropriate fixed firefighting systems. This is in order to make informed and impartial recommendations, with the intention to improve the outcome in the event of fire occurring in a fixed firefighting system protected scenario.

The FPA recognises that fire insurance (as a risk-sharing mechanism) is essential to the functioning of a developed economy. Fire insurance in high-risk, high-consequence scenarios typical of those where fixed firefighting systems must be properly specified, is one of the essential risk management tools used by the insurer to help manage the risk they take on for society collectively (Hanks, 2014).

1.3 THE CONTEXT OF THE RESEARCH

The United Kingdom (UK) along with the European Union (EU) has witnessed a recent proliferation of design approaches for potential fixed firefighting systems for the mitigation of fire risks in buildings and equipment (BSI, 1986) and (BSI, 2011a). This proliferation is reported in more detail in Paper 2, Appendix B (Bird et al., 2013). Accompanying this trend, there has been observed to be increasingly overlapping ambitions in terms of scope of application of some FFS types. Yet, this research has confirmed it is unreasonable to consider that competing fixed firefighting system technologies are unlikely to be equal in terms of the benefit they offer. This is reoccurring and central theme to this research and as such aspects of fixed firefighting system performance and optimum selection practice are discussed in several places in the thesis and the published papers (Paper 1 in Appendix A, Paper 2 in Appendix B, and Paper 3 in Appendix C). Particular attention should be drawn to section 4.2.6 of this thesis. This section finds that Availability, Reliability and Maintainability are likely to be the most significant determinants in overall fixed firefighting system performance. To put it another way, if Sprinkler Systems are 91% 'reliable' as determined by Hall (2010) and such systems are used to help protect and estimated £20 trillion pounds of insured assets, as revealed by insurance industry insider, Hanks (2014), even small fluctuations in 'reliability' will have a marked economic effect at a macro-scale. The work of CEBR (2014) makes it clear that appropriately specified fixed firefighting systems have a vital role to play in helping to optimise the developed economy. This work (CEBR, 2014) also reports identifying asymmetries of information in the warehousing protection sector, leading to a market failure resulting in the underutilisation of "AFSS" (automatic fire sprinkler systems). Although this work was confined to a study of cost-benefit of sprinkler protection in warehousing, the work highlights a problem with the fixed firefighting system supply chain in this area. Specifically that in the case of warehousing, decisions about the selection of fixed firefighting systems are often made by the builder without complete (or any) knowledge of the business of the ultimate occupier of the building, their business and the inherent risks of their operation. This is bound to have an impact upon the suitability of fixed firefighting system selections.

The promotion of a greater number of fixed firefighting system designs and supporting standards occurs at the same time as a move towards deregulation in relation to requirements invoking installation of fixed firefighting systems and the standards to which they are installed. The Fire Precautions Act (HMSO, 1971) generally followed a prescriptive regulatory model, whereas the Building Regulations (HMSO, 2010) and the Regulatory Reform (Fire Safety) Order (HMSO, 2005) provide a less prescriptive set of requirements. All Local Acts e.g. “London Building Acts” (HMSO, 1939), “Greater Manchester Act” (HMSO, 1981), “Berkshire Act” (HMSO, 1986) relating to requirements for buildings, some of which created the requirement to install fixed firefighting systems, were to be repealed on 9th January 2013 (DCLG, 2012) as part of the Government’s ‘Red tape challenge’. Some absolute regulatory requirements to install fixed firefighting systems in the form of sprinkler systems to BS EN 12845 (BSI, 2009a) have since been removed and are replaced with either a recommendation to install an unspecified type of fixed firefighting system (e.g. in the case of the “Domestic Fire Safety (Wales) Measure” (Welsh government, 2011)) or no such requirement at all.

There is now increased potential in the fixed firefighting system industry for adopting similar approaches to that recommended by the fire engineering community, where client teams can adopt a fire engineering approach to overcome novel design challenges (Wilkinson et al.

(2012), and/or reduce the costs of implementing fire protection (Sugden, 1998). However, the temptation to place too much emphasis on the latter is obvious and regulatory changes have paved the way to make this much more likely.

The use of Building Information Modelling (BIM) is increasingly prevalent in the design and specification of features of buildings. The UK government is mandating “fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016” (Cabinet Office, 2011). In using BIM, design teams may benefit from tools such as the fixed firefighting system selection tool developed by this work because it may increase the breadth and quality of information on fixed firefighting systems available to them.

At the inception of this research, it was noted that UK insurers were increasingly confronted with greater fire losses, particularly in their commercial portfolios. The Association of British Insurers (ABI) reported that the cost of fire damage in 2008 in the UK rose by 16% from 2007 to £1.3 billion (ABI, 2009). Figure 1.1 is extracted from the ABI (2009) report and illustrates the annual cost of fire insurance claim losses. It shows data spanning between 1988 and 2008 and is understood to be the most current study of this type available.

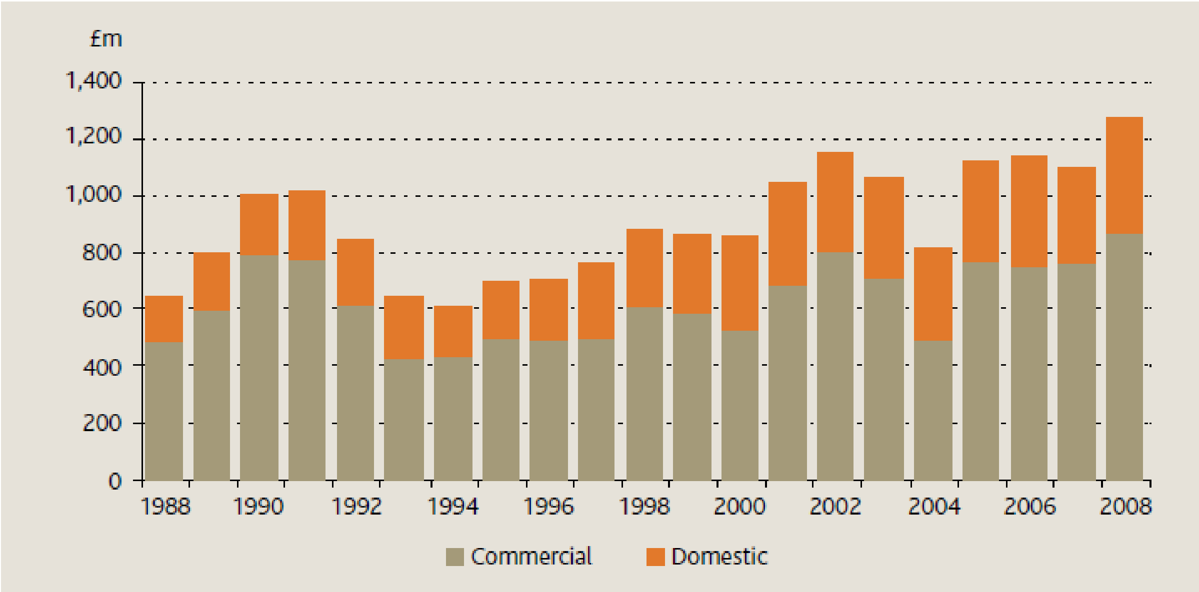


Figure 1.1: Annual cost of fire claims (ABI, 2009)

These increased losses are despite the absence of a trend of an increasing number of fires according to the statistics collected by the Department for Communities and Local Government (DCLG) (see 'Buildings' data in Figure 1.2 (DCLG, 2013)). These DCLG statistics are collated from data which is required to be returned by all UK Fire and Rescue Services. According to the data shown in Figure 1.2 (DCLG, 2013) there is a continuing trend of reducing number of fire instances. This should be considered to be a positive trend. However, when considering the decreasing number of fires shown in Figure 1.2 and comparing this to the increasing cost of fire shown in Figure 1.1, this presents a problematic picture for insurers. This is because considering these two trends, it seems likely to be indicative of increasing costs per fire event, which would have a negative impact upon both those directly affected by the fire and their insurers. If this were the case it is reasonable to believe anecdotally that the increase could be caused by a large number of factors to varying degrees, including but not limited to: increasing cost of insured items such as buildings and contents, increased business interruption costs, increased legal costs, greater areas of fire damage per fire, less effective interventions (e.g. weaker regulatory focus upon property protection as opposed to life safety, fire prevention measures, first aid firefighting, Fire and Rescue Service (F&RS), less effective fixed firefighting systems), and/or increased extent of insurance fraud.

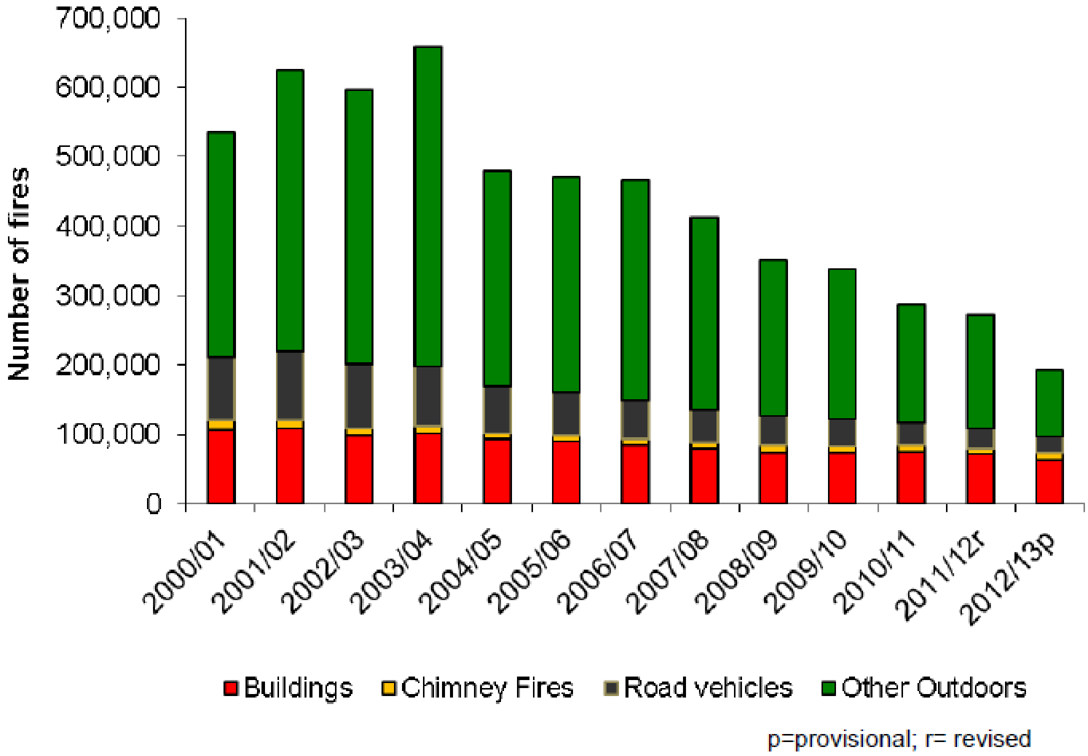


Figure 1.2: All fires by location group years 2000-2013 (DCLG, 2013)

It is against this background that the Fire Protection Association, who are often called upon to investigate aspects of the more exceptional fires have observed that in some cases, consequential losses from fire are certainly exacerbated by both the misspecification of fixed firefighting systems to the hazard and/or the misapplication of the correct fixed firefighting system to the hazard. Hazards can be difficult to describe and a great deal of knowledge is required to correctly identify all factors that may contribute to the risk that will be relevant to the performance of any given fixed firefighting system.

It is believed that these factors could be contributing to (although by no means the sole cause of) the apparently disproportionately deteriorating trend in the indicator: cost per fire incident. This research is to focus on investigating the role FFS selection might play in this phenomenon. If the concerns are found to have substance, it should then seek to affect improvements in the understanding and selection of fixed firefighting systems.

1.4 AIM AND OBJECTIVES

1.4.1 OVERARCHING AIM

The aim of this research is to verify that the concerns identified in the previous section (1.3) are founded and, that being the case, to develop a decision support system and related supporting resources, to further this aspect of fire safety education and enable users to make better informed system selections.

1.4.2 OBJECTIVES AND TASKS

In order to achieve the research aim, the work was broken down in to objectives and tasks. These objectives and tasks provided thematic structure to the conduct of the research and in effect form work streams which are reported in this thesis and supporting paper publications. The objectives and sub-tasks are as follows. To:

Objective 1: Review the use of FFS in the fire protection industry (particularly in the UK jurisdiction), to gain a detailed understanding of available knowledge and technologies:

- Task 1: Obtain evidence of the problem by reviewing standards, guides and practice. This is to help validate the need for the research and to focus the direction of the research and its outputs;
- Task 2: Determine scope of work;

- Task 3: Identify target FFS technologies and review existing available standards, guidance and practice, and;
- Task 4: Identify and address gaps in knowledge (underpinning and supporting). If necessary develop appropriate strategies and resources to overcome such gaps in the pursuit of advancing selection practice.

Objective 2: Assess current practice of selecting the most suitable FFS with a view to understanding the decision processes that lead to the selection of FFS:

- Task 5: Identify target users and explore their needs, and;
- Task 6: Consider, where multiple FFS solutions may exist, what constitutes the optimum solution in a variety of circumstances. Develop means(s) by which the comparative advantages and disadvantages of each FFS technology can be considered and thus incorporated as an influencing factor into the FFSST.

Objective 3: Develop and evaluate a tool to enable improved FFS selection:

- Task 7: Derive an environment conducive to developing selection processing and supporting resources;
- Task 8: Develop the tool to automate as far as reasonably possible the system selection decision making steps;
- Task 9: Address ‘systems maintenance and upkeep’ considerations, and;
- Task 10: Evaluate FFSST development and progress achieved.

Objective 4: Make recommendations for future developments.

Thus, expanding upon the original aim, the focus of this research became to develop a fixed firefighting system Selection Tool (FFSST) to complement existing legislation, which incorporates logic, rules and fire safety educational resources in a variety of formats to aid the fire safety design process. As the work progressed, gaps in required knowledge essential to underpin sound, well-informed selection practice were identified. For example, absence of detailed requirements for protection of very large warehouses and distributions centres, such as identified in Paper 1 in Appendix A and section 4.2.4 of this thesis. Optimum selection practice is discussed in section Papers 2 and 3 (Bird et al., 2013, Bird et al., 2014) and section 4.2.6 of this thesis. These became areas requiring attention to address gaps in order that the work on this project could continue to move forward.

The work has identified that cost and benefit are critical in the selection process (see section 4.2.6.2 of this thesis). Supporting resources have been developed, adapted and used for incorporation into the FFSST to assist users in evaluating the levels of reliability they might expect from a system in their circumstances.

1.5 NOVELTY OF THE RESEARCH

Few examples of literature or resources offering guidance upon the selection of fixed firefighting systems were identified. To the limited extent that it was identified (for example BS 5306-0 "Guide for the selection of installed systems and other fire equipment" (BSI, 2011a)) which, when reviewed critically, was found to offer considerable opportunity for improvement. Some examples of the problems with it: it makes several selection recommendations which would not be generally agreeable to experts, where there is overlap in the potential scope of application no comment is made upon the significance of this. It does not identify to users fundamental issues that should be considered when selecting a system; the advantages and disadvantages, what they might be and how to evaluate them to make properly informed decisions.

BS 7974 (and sub-parts) "Application of fire safety engineering principles to the design of buildings" (BSI, 2001a) is better in comparison in some respects in that in part 4 (BSI, 2003c) it does begin to outline a framework which could usefully be employed to start to explore advantages and disadvantages of various candidate FFSs. However, there are notable gaps in the approach outlined (for example no consideration of differing levels of system performance and reliability appears to be acknowledged). Further, this series of documents is only suitable for use by competent Fire Engineers rendering the knowledge and techniques within inaccessible to the majority of potential benefactors. This aspect is reported and the ideas developed further in Paper 2 (section "Factors influencing current selection practice") in Appendix B and section 4.2.6 of this thesis, in order to advance the techniques and understanding available to consider this aspect of FFS selection.

The selection problem, with increasing numbers of FFS choices being available only comparatively recently, is by virtue of these circumstances novel. As such it seems quite reasonable that only now has the problem achieved the attention of interested stakeholders to the extent where it has been considered necessary and worthwhile to try to seek to improve the situation.

In undertaking the research the following novel and innovative progress has been achieved (as reported in chapters 4 and 5 of this thesis):

- The fixed firefighting system selection problem domain has been further characterised;
- Challenges of optimally matching FFS solutions to circumstances have been explored and articulated. A deeper understanding of the optimum and sub-optimal process has been realised (see particularly section 4.2.6 of this thesis);

- Uptake of the outputs of this research has been recognised as key to the success or failure of the research in improving outcomes in the event of fire, where fixed firefighting systems are a feature. Efficient and widespread delivery of knowledge and information dissemination has been a guiding principle of the work; a variety of media types have been utilised to try and make communication efficient and maximise impact (see particularly section 4.2.5 of this thesis);

- Knowledge Management techniques have been reviewed in order to find suitable approached for this problem domain. The approach appearing most suitable selected as the basis for the tool (see particularly Papers 1 and 2 (Bird et al., 2012, Bird et al., 2013) and section 4.2.7 of this thesis);

- Logic and rules for use in the FFSST have been developed from sources of knowledge. These help to perform the decision making process and streamline the signposting of relevant informative and educational resources to the user (see particularly section 4.2.8 of this thesis);

- Both pre-existing and specifically developed informative and educational resources have been reviewed, evaluated found to be suitable and incorporated into the tool (see particularly section 4.2.10 of this thesis);

- Concepts key to the project (as above) have been documented, peer reviewed and published, contributing to the body of knowledge in the subject area and dissemination of this knowledge;

- It has been possible to disseminate some of the insights of this work via other forums such as British Standards Institution (BSI) and CEN (Comité Européen de

Normalisation (French language) or in English language translation European Committee for Standardisation) and private standards forums;

- A unique and novel interactive tool and supporting resources (the FFSST) has been developed for application in the field of fixed firefighting system selection. This is the first system of this type in the field of fixed firefighting system selection;
- Opportunities to further advance the body of knowledge in the subject area beyond this research have been identified.

1.6 STRUCTURE OF THESIS

This thesis is structured as follows:

Chapter 1 introduces the research, the general subject domain, industrial context, identifies the aim and objectives and justifies the need for and novelty of the research.

Chapter 2 summarises the findings of literature review activities.

Chapter 3 reviews the range of research methodologies used and considered in this research project.

Chapter 4 details the research undertaken to meet the project's aim and objectives.

Chapter 5 concludes by reporting the findings and implications of the research.

Appendix A Conference paper Decision problem structuring method for the specification and selection of active fire protection systems. This paper presents a summary, focusing on the demand for the research, development of the methodology and practical application of the emerging decision support system.

Appendix B Journal paper Development of a Fixed Firefighting System Selection Tool for Improved Outcomes. This paper reports seeks to provide a deeper understanding the problem, detailing the methods used to amass and structure the emerging knowledge base and progress towards developing a suitable knowledge management tool.

Appendix C Conference paper Decision Structuring Method for Selection of Fixed Firefighting Systems: development and lessons learned from case studies. This paper reports case studies illustrating aspects of fixed firefighting system selection practice and how this experience can contribute to the underpinning knowledge on which to base selection decisions. The paper concludes by considering the likely impact of the development of the fixed firefighting system selection tool.

Appendix D Technical paper TB234 Protection of High Hazard Storage (HHS) configurations. The research identified the need for more detailed requirements (or underpinning knowledge) in relation to the protection of High Hazard Storage (HHS) configurations. It contains much material which forms an ideal information/education/standard resource which has been signposted to in relevant circumstances from the fixed firefighting system selection tool.

Appendix E Technical paper Interactive Questionnaire 1: Water Mist Questionnaire: Building Protection. This questionnaire was developed to allow a more detailed audit and investigation of the suitability of proposed water mist fixed firefighting systems. It seeks to gather information on design, quality and anticipated performance of water mist systems. It was peer reviewed by a panel of insurance risk managers (subject matter experts) and has been published since 2011. It is now additionally made available as a resource for users from within the FFSST.

Appendix F to H contain other material prepared in the course of undertaking the research, including a final journal paper, currently under review with Automation in Construction Journal.

2 REVIEW OF RELATED LITERATURE

This chapter provides context to the research by exploring the available literature and its relationship to this work. In particular, it focuses on: drivers for fixed firefighting systems, evidence of the perceived selection problem, review of existing fixed firefighting system selection guidance, review of fixed firefighting system performance data and experience, knowledge management, decision support and expert systems, and sources of underpinning knowledge.

2.1 DRIVERS FOR FIXED FIREFIGHTING SYSTEMS

In the UK, a framework of drivers, requirements and supporting resources for fixed firefighting systems exists in a number of documents. The drivers may be regulatory requirements or commercial risk control measures. Such documents setting out such requirements include, for example: regulations, “Approved Documents”, standards, codes of practice and supporting guidance documents. Review of these documents has determined that fire protection systems are specified or proposed as risk mitigation features in a number of situations. Notably, reference to (and requirement for) such systems occur in the following places, to identify a few:

- The Building Regulations (HMSO, 2010);
- Supply of Machinery (Safety) (Amendment) Regulations (HMSO, 2011);
- Approved Document B (Department for Communities and Local Government, 2007);
- LPC Design Guide (FPA, 1999);
- BS 9999 “Code of practice for fire safety in the design, management and use of buildings” (BSI, 2008a);

- BS 7974 "Application of fire safety engineering principles to the design of buildings" series (BSI, 2001a);
- Various locals acts (e.g. "London Building Acts" (HMSO, 1939), "Greater Manchester Act" (HMSO, 1981), "Berkshire Act" (HMSO, 1986)) (all of which were repealed during the course of this research), and;
- BS EN 13478 "Safety of machinery - Fire prevention and protection" (BSI, 2008b);

Considering a few of these sources in a little more detail, to understand the effect they may have upon the selection and specification of fixed firefighting systems, BS 9999 annex J.4 identifies the following as types of Suppression Systems (or fixed firefighting systems as this work prefers to call them): automatic sprinkler, gaseous, foam, powder, CO_2, water mist and directed water deluge systems (BSI, 2008a, p. 381. Annex J.4). Elsewhere and in the Introduction to BS 9999, provision of automatic fire suppression is identified as a factor in establishing the "package of fire protection measures" for a building. (BSI, 2008a, p. 2). Detailed guidance upon which system(s) are suitable for any specific circumstances is not given. However, BS 9999 section 6.5 does say "*Where it is proposed to modify the risk profile by using a fire suppression system other than a sprinkler system, it will need to be demonstrated that this system achieves the equivalent standard of fire protection and reliability. Sprinkler systems should be designed and installed in accordance with BS EN 12845, BS 5306-2 or BS 9251. However, where sprinklers are used to change the risk profile, only those installed in accordance with BS EN 12845 (new systems) or BS 5306-2 (existing systems) can be used to adjust the fire resistance periods*". No further guidance is given on other types of system mentioned elsewhere in BS 9999. The FFS design and selection challenge would then become one of establishing suitability at a fundamental level (see particularly section 4.2.6.1 of this thesis) and proving the *equivalent standard of fire protection* and *reliability* (see section 4.2.6 of this thesis).

Standard of fire protection evidence may be achieved by full scale fire performance testing (NFPA, 2010, BSI, 2009a, Bird et al., 2011a) and by mathematical modelling approaches (using computational fluid dynamics). An example of such modelling exercises include the work of Mawhinney et al. (2000). However although entirely justifiable and appropriate in many cases, full scale fire testing is often found to be prohibitively costly. Consequently such data is often not available to support sold systems, particularly innovative and/or bespoke systems when it should be. Achieving an <u>*Equivalent*</u> *standard of fire protection* and *reliability* would go beyond just fire testing (which, if successful would establish that a system was capable of suppressing/controlling or extinguishing a fire in laboratory controlled conditions). It should include a much broader range of considerations such as whole-life system availability, reliability and continued satisfactory performance. These aspects are reported in more detail in section 4.2.6.3 of this thesis.

Automatic fire sprinkler systems have the advantage that their design and performance has been the subject of many decades study, research and optimisation. The insurance industry and other sizable high value operations, which form an essential part of the developed economy were, and still are, dependent upon such systems to manage the high-risk ends of their portfolios. Such stakeholders had the motivation to undertake the research and development (which has been ongoing since the 19th century) necessary to mature sprinkler system design and performance to the high level it achieves today. Today, sprinkler systems are so well established and trusted that in the majority of applications their performance is not questioned. Sprinkler systems, with a few parametric variations are generally considered a universal firefighting solution. For other emerging technologies, this poses difficulties. It is unlikely they will have had the benefit of such a period of development and refinement, sponsored by such wealthy interests. They may be much more application-specific. Usually being promoted by a product manufacturer, much vital test data (which helps to mature the research and development process) is considered proprietary and not made available. Standards and specification documents supporting a number of the newer technologies do not enjoy the same levels of trust from experts across such broad application as those cited for Sprinkler Systems.

Having reviewed literature on reliability, such as BSI's "Guide to reliability and maintainability" (BSI, 2014) and US Department of Defence's "Guide for Achieving Reliability, Availability, and Maintainability" (US Department of Defence, 2005) it is clear that *reliability* may be achieved by : Good initial system design, certification (component level, system design level and system installation level), on-going surveillance of system performance, preventative and reactive maintenance, and iterative improvement feedback cycles (or pedigree). This topic is covered in more detail in sections 3.3.4, section 4.2.6.3 and papers (Bird et al., 2012, Bird et al., 2013) which can be seen in Appendix A and Appendix B.

PD 7974 part 4 gives sprinkler systems as an example of fire suppression systems (BSI, 2003c). It later defines a fire suppression system as "system designed to control, suppress or extinguish a fire, via the use of water, chemical or inerting gas, or other means".

BS EN 13478 "Safety of machinery - Fire prevention and protection" (BSI, 2008b) advocates a risk assessment and reduction approach to fire safety in connection with particular pieces of equipment. Several escalating risk reduction approaches are identified and they are to be applied until the subsequent risk assessment confirms that risk has been reduced to a suitable level. By following this process, it will be determined quite correctly that not all equipment does necessitate a fixed firefighting system to achieve a satisfactory state of being. However in the cases that do, it may well be this document that in effect creates the requirement to install FFS.

“The Loss Prevention Council Design Guide for the Fire Protection of Buildings” (FPA, 1999) enshrines much historical insurance industry custom and practice. Whilst the document does not give much detail on how current practice in relation to use of FFS was arrived at, it does testify to the use of FFS being an essential principle to insurers in certain circumstances. Insurers maintain proprietary ratings tables (confidential, as these intellectual property assets of considerable value to the insurers’ business model) which provide in great detail information upon the insurance premium discounts that may be offered per building type and occupancy if it is protected by a sprinkler system. These tables would reveal that in many instances the cost of obtaining insurance with and without FFS would be vastly different. It would not be unreasonable, in a developed economy, in some cases to expect this difference to be significant enough as to affect the financial viability of the concern in question. Without further technical measures, the cost to mitigate the risk against fire by insurance alone could be too great.

None of these sources of requirements for fixed firefighting systems address the proliferation of systems being promoted as potential solutions, or provide anything other than the briefest guidance on the considerations (see section 4.2.6 of this thesis) arising when faced with a choice of fixed firefighting system technologies purporting to fulfil the same function. This can be considered to be part of the origin of the selection problem.

2.2 EVIDENCE OF THE PROBLEM

Aligning with objective 1, a broad search was undertaken of literature documenting any aspect of FFS selection, underpinning knowledge and performance which could help to enrich understanding of practice and outcomes in situations where fixed firefighting systems are a feature. The findings of which are reported and drawn upon through this research and thesis, but particular attention is drawn to this chapter and Papers 1, 2 & 3 (Bird et al., 2012, Bird et al., 2013, Bird et al., 2014) where these findings are primarily reported.

The fire engineering approach promoted by BS / PD 7974 series (BSI, 2001a) to a large extent relies upon referenced design fires which feature no fixed firefighting system protection or sprinkler protection (as opposed to any other types of fixed firefighting system). Data relating to the performance of other fixed firefighting system technologies is not given. This presents a substantial obstacle in application of the fire engineering prescribed by the BS / PD 7974 series (BSI, 2001a) approach using FFS technologies other than sprinkler systems; the supporting data is not available. This is further acknowledged in Part 4 (p. ii., BSI, 2003c) “Historically, fire detection, alarm and suppression systems have been subject to product orientated prescriptive codes and standards. Research to calculate and predict fire growth and the performance of detection, suppression and smoke control systems is still on-going. There is much still to be done before the area becomes a mature science”. 11 years on and the statement still stands in that the same edition of PD 7974-4 remains the current edition and the data (in the form of prescriptive codes and standards) this paragraph eludes too is still not publically available.

PD 7974-4 (BSI, 2003c) considers different types of suppression system in more detail. Clause 9.2 addresses several of issues considered important in selecting a fixed firefighting system, but there are notable omissions. Figure 4 from PD 7974-4 (BSI, 2003c) intends to present key factors for consideration when selecting an appropriate fixed firefighting system. Figure 2.1 in this thesis is an adaptation of Figure 4 from PD 7974-4 (BSI, 2003c). It has been augmented by marks intended to show where requisite supporting data has been found to be scant or absent for fixed firefighting systems other than sprinkler and gaseous systems. Blue circles with solid line denote that no guidance was found to be available. Circles formed of dashed lines denote that only limited guidance was found to be available.

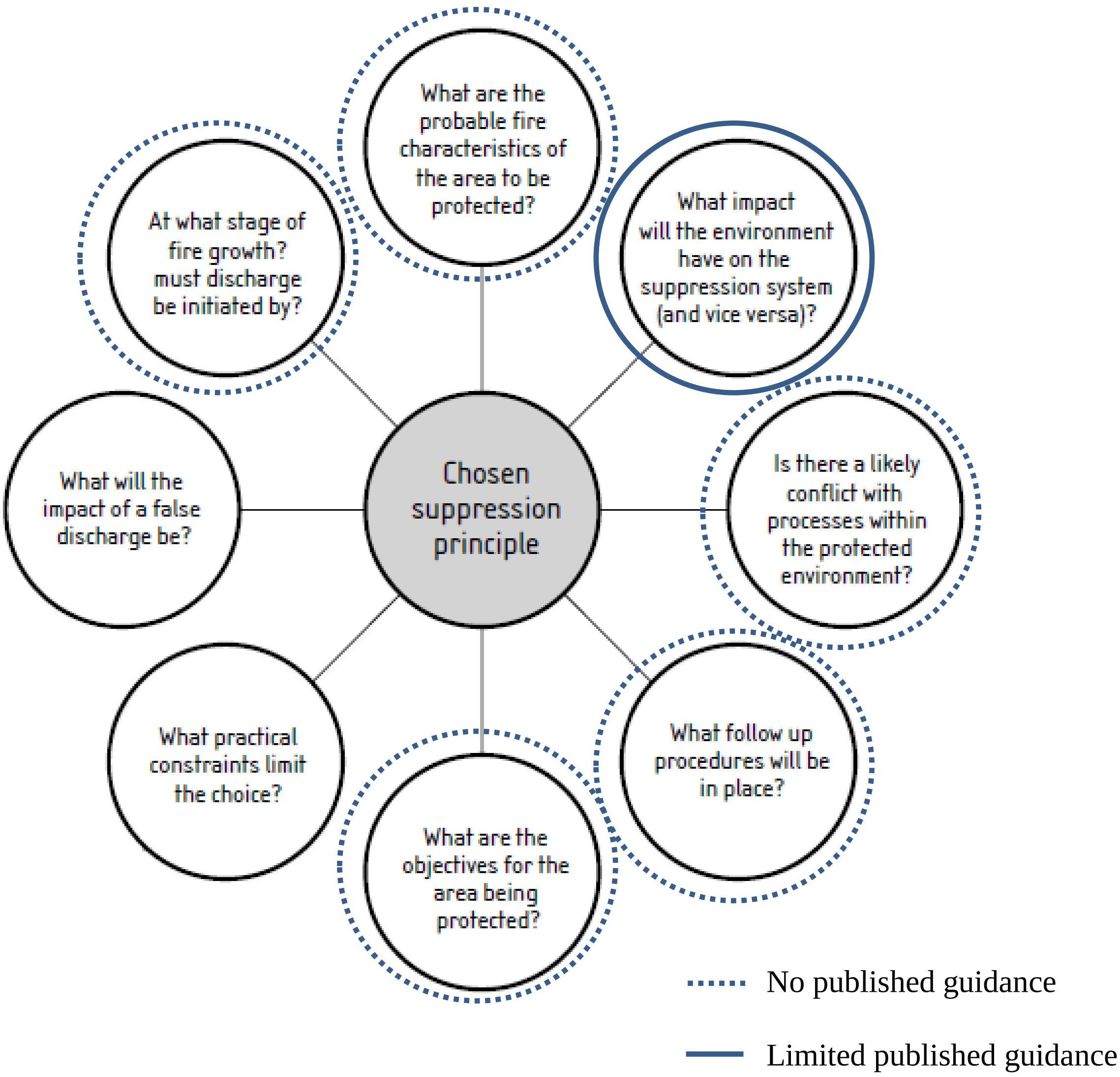


Figure 2.1: Fire suppression system choice matrix (adapted from (BSI, 2003c)).

A notable omission from BSIs original figure is any direct mention of 'whole-life expected performance of fixed firefighting system technology' or an expression of similar intent. The identified gaps in documented knowledge are further exacerbated when considering *bespoke* or *innovative* solutions (as are often required to suit local object protection scenarios), as case specific data was found to be even scarcer. This research presented the opportunity to report (in very light detail to preserve anonymity) two such case studies which touch upon these issues (reported in Paper 3 in Appendix C).

The opportunity is taken by this research to seek to improve awareness and information available in this area. The progress achieved is reported in section 4.2.6 of this thesis. The remainder of this sub-section goes on to consider the other specific sources of evidence of the problem identified.

2.2.1 EXISTING FFS SELECTION GUIDANCE RESOURCES

Aside from the example given in the previous section relating to BS / PD 7974 series (BSI, 2001a) requirements for and guidance upon the selection of fixed firefighting system resides in several other places in documents such as regulations (e.g. the Building Regulations (HMSO, 2010)), guides and standards (e.g. BSI's selection guide (BSI, 2011a)). Many more of these sources are identified in previous work (Bird et al., 2012, Bird et al., 2013, Bird et al., 2014). These have been found mostly to concern themselves with broad regulatory matters (encompassing many aspects of a building; not just fire safety) or intended to deal with one specific FFS technology only (the exception being BS 5306-0 (BSI, 2011a), which has already been discussed in section 1.5 of this thesis as being of limited use). From these types of documents, some information on broadly how and when they should be used (useful when considering this selection problem) is often found in the 'Scope' section of documents, where the intended application of a technology is given. As a simple example, the scope section of BS EN 12845 "Fixed firefighting systems - Automatic sprinkler systems - Design, installation and maintenance" (BSI, 2009a) tells the reader that it "*gives requirements for the design, installation and maintenance of fixed fire sprinkler systems in buildings and industrial plant*". It later states that "*The requirements are not valid for automatic sprinkler systems on ships, in aircraft, on vehicles and mobile fire appliances or for below ground systems in the mining* *industry*”. Thus the reader would know that (subject to being able to comply with the rest of the applicable parts of the document) this would appear to be a suitable fixed firefighting system for where the risk to be protected is a building or some industrial plant, but not a ship, aircraft or other stated exclusion.

Other limitations of application of various fixed firefighting system technologies can be found peppered throughout some of the documents. Referring again to BS EN 12845 “Fixed firefighting systems - Automatic sprinkler systems - Design, installation and maintenance” (BSI, 2009a) for an example, clause 5.1.2 “Necessary exceptions” provides a more detailed list of scenarios when a sprinkler system would not be considered a suitable fixed firefighting system.

None of these sources of guidance deal in sufficient detail with the issue of selecting fixed firefighting where a choice of types is available. A more extensive and systematic review of the relevant sources of selection guidance was undertaken as part of this research. This can be considered to be the knowledge elicitation phase in support of the development of the fixed firefighting system selection tool. The methods used are reported in Chapter 3 and the findings are reported in sections 4.2.3, 4.2.6.1 and 4.2.8.

2.2.2 UK GOVERNMENT DATA

It was considered that evidence of the fixed firefighting system selection problem might be apparent in statistical data kept by various agencies upon fires. If this were the case, it could be helpful in identifying the problem and improving the position. The most notable UK fire statistics datasets are derived from the Fire Data Report templates (FDR1) (Home Office, 1979) that were used from 1978 until a phased change over to the newer Incident Reporting System (IRS) (Home Office, 1994). The IRS system was improved over its predecessor in that it attempts to seek some basic information relating to the presence and performance of active fire protection systems. However, this approach is neither sufficiently comprehensive nor backed by sufficient skills and training at the practitioner (data collection) level to ever be likely to yield data of similar quality to that available in the US through the NFPA "U.S. Experience with sprinklers" (Hall, 2013) and their Fire Service reporting channels.

Only one attempt at analysing and reporting UK FFS performance data "Automatic Sprinkler Suppression Systems Data" (Firkins, 2012) from this source has been identified (which was understood to be limited to sprinkler systems only). The data is sourced from the IRS and has required (considerable) further analysis and interpretation even to achieve the limited data and conclusions presented. This work is not considered suitable to support this research; whilst it does offer some insight in to adverse (and favourable) outcomes where sprinkler systems were present, the dataset is small, it offers no comparison between different the performance of different fixed firefighting system types, detail on whether outcomes were 'adverse' is lacking, what would constitute an 'adverse' outcome is subjective to name a few of the problems. In summary, UK government data, aside from providing high-level background information (e.g. Figure 1.2 in section 1.3) is of very limited use to this research.

2.2.3 OTHER INTERNATIONAL DATA

Having determined that UK data was of limited use to this research, the search was broadened to include international sources. Work by NFPA (National Fire Protection Association, US), (Hall, 2010, Hall, 2013) was found to contain reliability and effectiveness figures for sprinkler systems. However, of more use to this research is slightly older work (Hall, 2008) which also reported reliability estimates for chemical and CO_2 system types in addition to sprinkler systems, thus allowing some comparison to be made. This study states that the available data set for other types of system beyond sprinkler, chemical and CO_2 systems (see Table 4.1 for details of all fixed firefighting system types incorporated in this research) is too small to support any estimates of reliability and effectiveness. This appears consistent with general historical experience of prevalence and numbers of system types installed in practice. In Hall (2008) the following reliability figures are given;

- all sprinkler systems 90%.

This figure is further broken down in to two system sub-types;

- wet-pipe (most common) sprinklers 91% reliable and;
- dry-pipe (less common) sprinklers 83%.

The leading reason for sprinkler systems not operating was stated to be that the water supply was turned off prior to the fire starting (typically due to maintenance or inspection). Other leading reasons are stated to be (Hall, 2008):

- lack of maintenance, or;
- incorrect intervention measures at the time of the fire, or;
- inappropriate system for the type of fire.

For comparison, reliability figures are given for dry powder and CO_2 systems of 49% and 90% respectively. Naturally, to read these statistics a definition of 'reliability' is required and Hall does develop one in his work (Hall, 2008). Section 4.2.6.3 of this thesis also considers what constitutes 'reliability' in the context of this research.

These quoted figures as reported by in Hall (2008) are based upon 2002 to 2004 US fire department statistics. No such equivalent dataset exists which is directly relevant to the UK experience.

2.2.4 FIXED FIREFIGHTING SYSTEM SELECTION CASE STUDIES

Case studies or “Lessons learned” activities are recognised (Paranagamage et al., 2012) as being potentially very useful in improving practices and outcomes. In order that this research might benefit from such an approach, academic journals, trade journal archives, the internet and institutional repositories were searched for documented case studies focusing on fixed firefighting system selection and surrounding issues. No previously published lessons-learned or experience based case studies relevant to this work were identified. In the course of undertaking this research it has become apparent that it is hard to obtain such data. It is probably reasonable to conclude that this is because: only a few organisations have much interest in collecting such data, and; invariably exacerbated fire losses (where a fixed firefighting system has underperformed and there are lessons to be learned) are either considered commercially sensitive and/or professionally embarrassing. The outcome is that detail which reaches the public domain is very limited.

As part of this research, cases studies from the experience of the research engineer and industrial sponsoring organisation were considered, written up and published (see Paper 3 in Appendix C). Detail was limited to help to preserve anonymity as already observed, such cases can be quite commercially sensitive and/or sources of professional embarrassment. These case studies (see Paper 3 in Appendix C) intend to highlight some aspects of practice recently observed which are considered to be indicative of the perceived selection problem:

- Incorrect identification and understanding of the protection objectives contributing to a poor choice of FFS technology;
- An example of generation and dissemination of trade literature believed to be intended to create a sense of pedigree and maturity to promote the uptake of certain technology types. This literature was considered to be biased and misleading;

- Poor quality supporting guidance available to suppliers and users. Problems and complexities associated with the bespoke nature of many (particularly object protection) scenarios.

The key lessons learned from these case studies were translated in to implications for the conduct of this work (see Paper 3 in Appendix C). In summary:

- The need for the tool to both elicit information and educate the user on their firefighting objective(s). Reported further in sections 4.2.3 to 4.2.8;
- Affirmation of the need for a source of independent and unbiased information across technologies, which may be competing with one and other. Reported further in sections 4.2.3 to 4.2.8;
- Recognition of the gaps in documented knowledge in the subject domain in certain areas. Where possible to contribute to an improvement in knowledge, by for example: filling knowledge gaps, identifying the knowledge gaps or signposting on to other appropriate resources. Reported further in section 4.2.4.2.

This paper can be seen at Appendix C.

2.2.5 LEGAL CASES

Some of the lessons that might otherwise have appeared as published case studies, if it were not for the difficulty in producing such material (as discussed in section 2.2.4), does occasionally surface to some extent in the form of legal proceedings. This is particularly the case where there is a large financial claim arising from the fire loss. Whilst such legal cases rarely (although one is reported below) comment upon the detailed technical role that fixed firefighting systems have played in the events, in seeking to establish the financial significance of the function or malfunction (or presence or absence) of a fixed firefighting system, they do sometimes contain comparative financial information. This provides some evidence which helps one to gauge the financial order of magnitude which can be dependent upon protection by fixed firefighting systems. This is the sort of information that would be required to support a cost-benefit approach as discussed in section 4.2.6.2 of this thesis.

A number of legal cases with some relevance to the work are identified in Paper 1 in Appendix A. Generally two types of case were identified; those where the non-operation of a FFS was found to have had a significant adverse impact (magnitude of the extent of damage and financial loss) upon events. The other type being one other case (The Honourable Mr. Justice Coulson in Cadbury v ADT EWHC 1936, 2011) which was found to go further and in addition to issues surrounding the magnitude of loss, considered aspects of FFS design and its suitability for the protected risk. The transcripts of these cases provide a detailed narrative of the events in question. These cases serve to highlight:

- The comparative differences to the scale of financial loss in fires with and without FFS (different in each case, but ranging from millions to hundreds of millions of pounds sterling)
- The criticality of systems being maintained in an operational state
- The suitability of FFS design for the nature of the risk to be protected

The cases are cited in Paper 1 in Appendix A as evidence in support of the criticality of the role that FFS plays and thus the potential severity of poor selection choices.

2.3 KNOWLEDGE MANAGEMENT, DECISION SUPPORT AND EXPERT SYSTEMS

In order to pursue the project aim; to develop a decision support system and related supporting resources, a search was undertaken to explore the domains of Knowledge Management (KM), Expert Systems (ES) and Decision Support (DS). Information was sought on background and contemporary techniques used to solve problems with similarities to the aim of this work. This work is reported in Paper 1 in Appendix A. Literature review findings are summarised here in this section and application to this research is reported in section 4.2.7 of this thesis.

Work by Wilson and Welsh (1986) and Giarratano (1998) reports that (at that time), many fortune 500 companies were seeking ways to exploit the capability of so-called Expert Systems (ES) because they believed “there is substantial commercial value in using machines to emulate portions of human behaviour”. Burstein and Holsapple (2008) report that organisational need for intelligent decision support gave rise to the development of expert systems, deigned to encapsulate the knowledge of experts and the apply it to solving well-structured problems. The literature review found that the terms such as Decision Support and Expert System are generally used interchangeably. However it is probably more correct to say that Decision Support may be provided by an Expert System.

As highlighted in the work of Duan (2005), the time of subject domain experts (such as those providing advice on fixed firefighting system specification and selection) is sought after, scarce and expensive. The field of fixed firefighting system selection is no exception. Thus an Expert System which successfully captures knowledge and automates part of the expert decision making process is potentially of considerable value in improving access to expensive expertise. Such systems improve the chances of expert knowledge being available to and reaching those who need it. Inspired by the work of Nilsson (1998, p. 281.) and Giarratano (1998, p. 3.) a simple, adapted graphical representation of the main elements and interactions with a typical expert system can be seen at Figure 2.2. This model is further adapter later in this work to form Figure 4.4 in chapter 4.

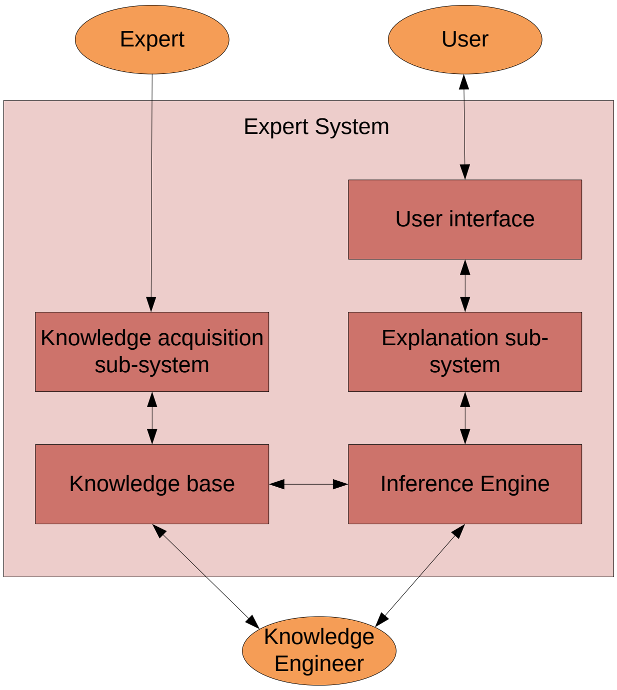


Figure 2.2: Main elements and interaction with a typical expert system (adapted from Nilsson (1998) and Giarratano (1998)

Expert Systems may be feared as making the expert (or decision makers) redundant. However, this view is countered with the opinion that in reality this will seldom be the case as these systems often will not replace the need for experts and may simply result in the expert being available to address other decision making problems (Pomykalski et al., 2001).

Liabilities associated with Expert Systems are considered in the paper by Gemignani (1991), particularly: liability for malfunction of an ES, recovery for injuries stemming from and ES, and negligence (injury or breach of duty). This highlights the need in this research to ensure that potential liabilities be managed to an acceptable level. Such measures might include taking steps to ensure the accuracy of input/output data. Use of appropriate disclaimers and warnings has been adopted in the development of the fixed firefighting system selection tool to advise users upon the limits of the capability of the tool. For example, the first screen the user encounters aims to make clear the limitations of the capability of the tool. Also, where uncertainty is identified as arising as a result of responses from the user, this uncertainty is identified and either requires the user to take further actions or is declared in the report presented to them upon conclusion of their passage through the tool. Note 5 under the heading "LPC Rules sprinkler system" in Figure 4.8 (chapter 4) is an example of this.

2.4 SOURCES OF UNDERPINNING KNOWLEDGE

In seeking to develop a decision support system and related supporting resources, underpinning knowledge is required upon which to base both the logic and rules of the system (see for example the 'knowledge base' and 'inference engine' as depicted in Figure 2.2) and the supporting resources. Whilst the main drivers for FFS are cited in section 1.1 of this thesis and papers (Bird et al., 2012, Bird et al., 2013, Bird et al., 2014), these requirements are supported by a number of other documents (see Table 4.1, chapter 4) which tend to focus more on the detail of the design of particular systems. These other documents (see Table 4.1, chapter 4) were found to contain and record much of the subject area knowledge amassed to-date. As such there are many standards, guides and documents intended to fulfil this role and assist users in designing FFSs. These documents are potentially rich sources of knowledge for this work. However, they are of varying age, relevance, scope, quality and suitability. Some are written for national or international standards bodies by committees and independent bodies whilst others are written by trade associations, certification bodies or commercial organisations such as user groups or system suppliers. Mostly, each document is written to support one particular technology type and not with a view to performing or supporting some overarching selection function, such as the purpose of this research. The notable exception to this ambition is BSIs BS 5306-0 “Guide for the selection of installed systems and other fire equipment” (BSI, 2011a) which, when reviewed critically (as reported in section 1.5) can only be considered partially successful (as reported in section 1.5) in achieving the documents aim. The stated aims being: “*This part of BS 5306 gives guidance on the selection, use and application of automatic water sprinkler, water spray, watermist, gaseous, foam and powder fire-fighting systems and hypoxic air fire-prevention systems.”* (p. 1, BSI, 2011a).

The systematic process of identifying and reviewing sources of heuristic knowledge (to derive underpinning rules and logic of the FFSST) is considered to be a substantial part of this research. The method used is reported in sections 3.1.1 and 3.3.1. The findings are reported in section 4.2.3.

3 ADOPTED METHODOLOGY

This chapter discusses the methodologies selected and applied to this research.

3.1 REVIEW OF METHODS

It is essential when conducting research that suitable methodologies are employed. Correct selection and use of methods is important in ensuring identification of relevant variables, their mechanisms and impact (Fellows and Liu, 2008). In order to undertake this research, a review of the suitability to the task of various research methods was undertaken. The main methods used in this research are summarised and critically reviewed in following sub-sections.

3.1.1 LITERATURE REVIEW

Literature review is a fundamental to most research. Considerable emphasis was placed upon literature review at the inception of research, in determining the scope of the research, focus of investigation and the current state of knowledge. Literature review must be kept up to date, otherwise the field may advance unknown to the research. Ongoing literature review also served to inform subsequent stages of the research, in keeping abreast of new developments and as tangential areas for enquiry emerged.

3.1.2 QUANTITATIVE AND QUALITATIVE

Quantitative methods may be defined as those which gather evidence which is measureable and quantifiable, being characterised by having adopted "scientific method" (Calado et al., 2009). Quantitative methods, by their nature may be more readily verifiable and therefore easier to trust when compared to qualitative methods. However they may not be suitable where supporting data is unavailable or limited.

Qualitative methods are said to be more suited to in depth study of opinions, origins of opinions and associated consequences (Easterby-Smith et al., 2002) being ‘subjective’ in nature emphasising meanings, experiences and descriptions. Analysis of qualitative data may be more difficult than quantitative data as it often requires filtering, manipulation and sorting (Fellows and Liu, 2008). Whilst this introduces additional scope for variability to creep in to research, applied with care and diligence meaningful progress is possible.

3.1.3 CASE STUDIES AND FIELD EXPERIENCE

Case studies are one means suitable for exploring the “how” and “why” of phenomena, without controlling behavioural events, but whilst focusing on contemporary events Yin (2009). This is a method of investigation that may accompany other methods. In this research, as quantitative sources of data and knowledge were relatively scarce, case studies were considered a means by which to enrich and evidence the work; the object being to capture knowledge and lessons learned from experience. This approach was used to explore in a little more depth the selection process, fire loss experience, FFS promotion and marketing issues related legal cases and the industrial sponsoring organisations experience. Case study information made a contribution to all of the objectives of this research.

3.1.4 ACTION RESEARCH

Action Research (AR) is defined by Stringer (2007) as “a systematic approach to investigation that enables people to find effective solutions to problems they confront in their everyday lives”. Stringer (2007) proposes a model to represent research progress; iterative spirals augmented by the annotations “look”, “think” and “act”. The action research model was applied throughout this research. Its use is particularly evident in pursuit of objective three.

3.1.5 Rapid Application Development

The Rapid Application Development (RAD) approach is often used when a degree of incremental development is acceptable (or desirable i.e. where requirements change often) rather than an approach whereby whole new systems are developed each time there is a change (Avison and Fitzgerald, 2003). This technique has the potential to facilitate iterative system developments (in this research, objective three) with more efficient resource usage and allowing a solution to be incrementally developed and improved with the experience gained of practical application of the preceding version of the development.

3.2 METHODOLOGICAL DEVELOPMENT/REFINEMENT

Section 3.1 of this thesis identifies the principle methodologies used in this research. This section explains how the methods were adapted to suit the nature of this research problem.

A review of literature remained ongoing through the various stages of the research. This was to ensure the research remained current and to adapt to emerging issues. Fellows and Liu (2008) highlight a potential pit-fall; that the research may never be finished if and end-point is not assigned. Thus, the majority of literature review effort was constrained to the “look” and “think” stages of action research (Stringer, 2007) spirals. The literature reviewed and findings of the literature review can be found in Chapter 2 and cross-referenced parts.

Quantitative, semi-quantitative (parametric or “triangulated studies” (Fellows and Liu, 2008)) and qualitative research methods have been used to elicit heuristic knowledge by review of regulations: The Regulatory Reform (Fire Safety) Order (HMSO, 2005), The Building

Regulations (HMSO, 2010). Standards (national, international and sector specific fixed firefighting design, installation and components standards; for sprinkler systems (BSI, 1999, BSI, 2009a, FPA, 2014b), water mist systems (BRE Global, 2012, BSI, 2011b, BSI, 2010b), foam-based systems (BSI, 2009b), gaseous systems (LPCB, 2005, BSI, 2003a, BSI, 2008c), oxygen reduction systems (BSI, 2011g) and aerosol systems (BSI, 2009c) to name a few) and guides and practice documents (BRE Global, 2009, BSI, 1986, BSI, 2011a, FPA, 1999, Williams, 2009).

Denzin and Lincoln (2003) sought to develop the idea of Action Research further. They introduce the word “participatory” to form the concept of “participatory action research”. In essence they argue special acknowledgement should be given to action research where a high degree of stakeholder input is to be expected or necessary. It was anticipated that this would be the case with this research, given the level of commercial vested interest in the fire protection industry, disparity in maturity of development of FFS technologies, disparate stakeholders e.g. owners, specifiers, users/benefactors, regulators and insurers (or asymmetries of information as CEBR (2014) term it), and the value of the assets dependant on being protected by such technology.

The evolution of the research is depicted in Figure 3.1. Tasks 1 to 6 (as detailed in section 1.4.2) generally formed the foundations of the work. Tasks 7 to 10 (as detailed in section 1.4.2) were founded upon this work and can be considered to follow a model akin to an adapted “action research interacting spiral” (Stringer, 2007). See section 3.1.4.

Tasks 2,4 and 6 to 10 also used some of the principles of Rapid Application development (RAD). See section 3.1.5.

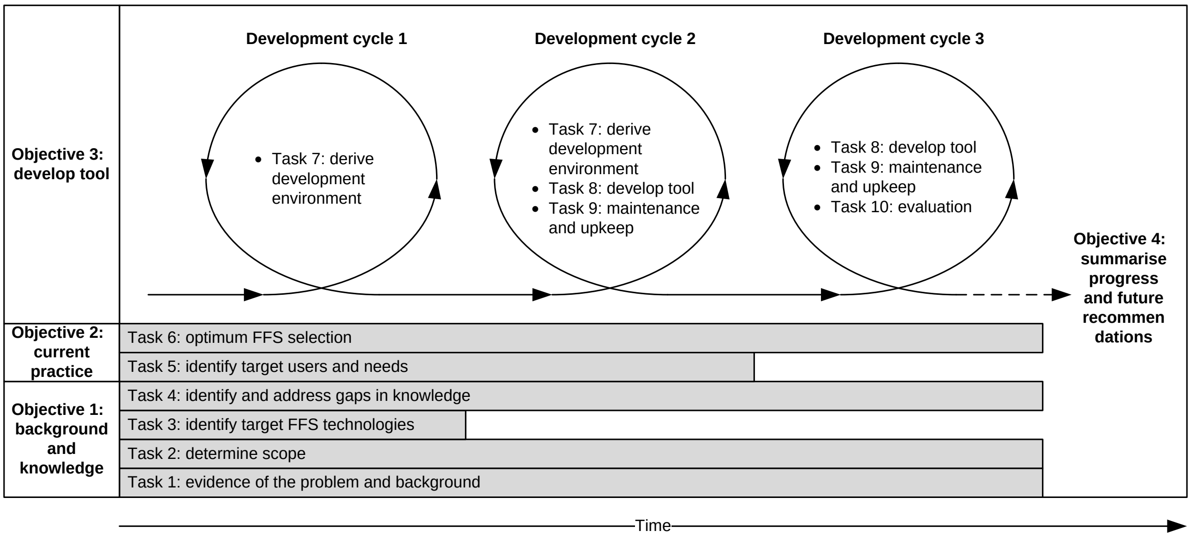


Figure 3.1: Derived approach to the research, incorporating an adaptation of "Action Research interacting spiral" (Stringer, 2007)

3.3 SUMMARY OF METHODS AND TECHNIQUES USED

The research has employed a range of methodologies and techniques at different stages of the project. Table 3.1 summarises the research methods and techniques used to pursue each objective and task, along with the key research outputs. The sub-sections that follow provide explanation on the application of each of the methodologies and techniques adopted.

Table 3.1: Research matrix

Objective	Task	Method and technique used	Key contribution to the research
1. Use of FFS	1. Evidence of the problem, justification for the research	-Literature review -Participatory consultation -Study of loss data -Case studies	-The problem exists -Background and contextual information -Scenarios where FFS is a feature are likely to be potentially high consequence fires
	2. Determine scope of work	-Ongoing refinement: -Literature review -Participatory consultation -Study of loss data -Case studies	-Continuous refinement of aim and objectives
	3. Identify target FFS technologies	-Literature review / systematic review of documents	-Table 4.1 -Underpinning knowledge -Basis for heuristic rules
	4. Identify and address gaps in knowledge (underpinning and supporting)	-Ongoing refinement: -Literature review -Study of loss data -Case studies	-Tool help text -Tool external resources created -Tool external resource referenced -Basis for heuristic rules
2. Current practice	5. Identify target users and explore needs	-Participatory consultation -Literature review	-Knowledge of users/stakeholders -Multi-media presentation
	6. Optimum FFS selection	-Literature review -systematic review of scopes -CBA -Reliability -Case studies	-Approach to developing optimal selection criteria -Basis for heuristic rules -Tool external resources created
3. Develop tool	7. Derive an environment conducive to developing selection processes and supporting resources.	-Proof of concept / prototype -Rapid application development	-Proof of concept / prototype -Improved understanding of available development environments and input knowledge requirements
	8. Develop tool	-Use of derived development environment -Rapid application development -Case studies	-Developed Tool
	9. Address 'systems maintenance and upkeep' considerations.	-Literature review -Rapid application development	-Ongoing maintenance required -Developed Tool
	10. Evaluate research findings and progress achieved	-Validation -Participatory consultation	-Refinements to the tool -Confidence in the progress achieved
4. Recommendations for future developments			-Chapter 5

3.3.1 PARTICIPATORY CONSULTATION

In this research considerable gaps in documented knowledge have been identified in undertaking the literature review. Notably, gaps exist in underpinning knowledge required within the FFSST and the supporting educational and informative resources to be made available to users, as required by objectives one, two and three. As a result, participatory activity is seen as an important technique to be used to augment literature review findings. The value of such activities can be improved if techniques are used in combination. For example, questionnaires can yield broad but generally shallow information. Questionnaire findings can sometimes be improved upon by follow-up interviews which can deepen and validate findings. Such activities provided a means by which as yet undocumented experience was captured and incorporated in to this research. Examples of such methods used include: questionnaire (see section 4.2.10.2), active review (see section 4.2.10.5), collaborative development by committee (see sections 4.2.10.3 and 4.2.10.4), which report the progress of developing substantial supporting resources Technical Output 1 (Appendix D) and Technical Output 2 (Appendix E) and ongoing dialogues with experts.

3.3.1.1 Questionnaire

One of the means chosen to elicit information required to support the research was a survey questionnaire. Moser (1967, p. 2) broadly defines the purpose of undertaking surveys to be “simply to provide someone with information”. He then goes on to describe the three broad methodological problems of surveys: who to collect information from, what methods to use and how to analyse and interpret the data. Questionnaires are generally considered to yield quite shallow data, which can be augmented by further more in depth enquiries, such as interviews. Wengraf (2001, p. 61) illustrates a possible relationship between levels of interview structure to phases in development of a theory. This figure is reproduced at Figure 3.2.

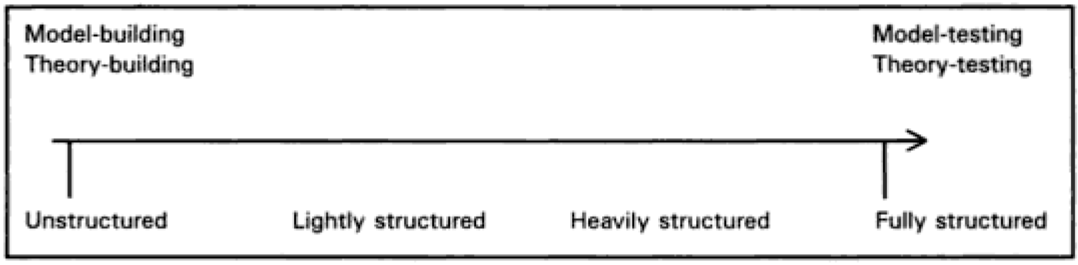


Figure 3.2: Possible relationship; interview structure to development of a theory

A questionnaire was selected as a means to engage with a larger number of parties with interest and experience relevant to the research project. The questionnaire was designed to include a mix of both open and closed questions (Xiong and Seligman, 2011, Sánchez-Vera et al., 2012). The closed questions were intended to elicit opinion in specific areas and more open questions were intended to draw out information, opinions or views that might have otherwise been missed (O'Cathain and Thomas, 2004).

A questionnaire survey was undertaken (see Appendix G) early in the research to gather views in a range of areas related to the research. 64 responses were received. Analysis of the questionnaire findings was generally qualitative. Key questionnaire findings are reported in sections 4.2.1, 4.2.5 and particularly 4.2.10.2, where participants and findings are discussed. The questionnaire and results in full can be seen at Appendix G.

3.3.1.2 Correspondence

Throughout the course of the research, on occasion correspondence was used to seek the views of experts and involved parties.

3.3.2 CASE STUDIES AND FIELD EXPERIENCE

Experience from case studies made a contribution to all of the four objectives of this research. As discussed in section 2.2 of this thesis and Paper 1 in Appendix A, case study and fire protection industry field experience was found to be available from other sources; FPAs experience, FPAs large loss database, UK government fire statistics and FFS reliability studies. All of which were identified for review and analysis to see if they contained data relevant to the project and whether they could contribute to the research. The findings and implications are reported primarily in sections 2.2 and 4.2.1 and cross-referenced parts.

3.3.3 COST-BENEFIT ANALYSIS

Cost-Benefit Analysis (CBA) as a systematic technique, with relevance to all of the objectives in this research and especially objective three. It is used to consider in detail the desirability of a particular project or programme (Mishan and Quah, 2007). It allows the comparison of the values of cost and benefit. CBA is a widely recognised as a technique the principles of which can be applied to any problem (Layard et al., 1994). The general principles of CBA have been observed in two key ways in this research; in a simplistic way as a part of the development environment software down-selection process (reported in section 4.2.7) and as a guiding principle when considering issues surrounding current and optimum FFS selection. Particular attention in this regard is drawn to section 4.2.6 (particularly 4.2.6.2) of this thesis, where the issue of cost and benefit in relation to a fixed firefighting system selection is considered in more detail.

3.3.4 RELIABILITY EVALUATION

Data upon the potentially different levels of reliability of FFS was sought. In the absence of such data being available (except for some data of limited applicability in relation to a limited number of system types), pre-existing methods of predicting likely levels of performance were sought. The research undertaken and subsequent method derived is presented in section 4.2.6.3.

3.3.5 SOFTWARE SPECIFICATION

Consideration was given to identifying potentially suitable commercially available software development environments or techniques, which could be used to develop the fixed firefighting system selection tool. However, this exercise highlighted that no suitable (readily commercially available) solutions could be identified by merely reviewing existing tools and the research or industrial literature. The decision was therefore taken by the project team to seek external expertise on the software development side of the project.

Frappier et al. (2010, p. preface) suggest that “A specification method is a sequence of activities leading to the development of a produce called a specification“. They then go on to state that typically several system characteristics may be specified; Functional requirements (input-output behaviours), efficiency requirements (addressing execution time considerations) and implementation requirements (programming language to use, targeted hardware and software platforms). Alagar and Periyasamy (2011) refers to the concept of a Software Requirements Document (SRD) as an essential tool in taking an abstract idea for a piece of software through to development. The route through various stages of software development is proposed in Figure 3.3.

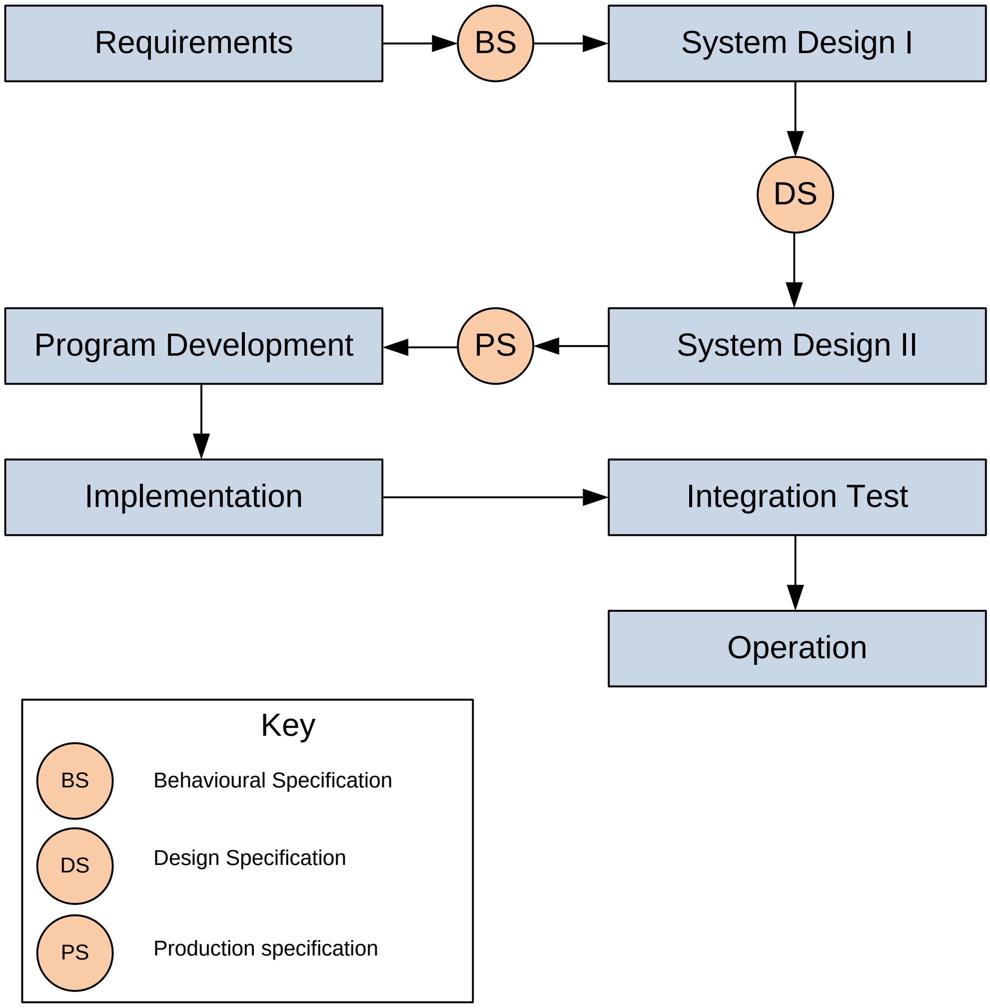


Figure 3.3: A simple life-cycle model with specification phases (Alagar and Periyasamy, 2011)

Three levels of specification are shown; ‘BS’ Behavioural specification, ‘DS’ Design Specification (note that in this instance ‘DS’ should not be confused with DS meaning Decision Support) and ‘PS’ Production specification. The idea being that an incremental approach is used to improve and add to the specification at each level. Whilst this model (Figure 3.3) bares some close resemblance to the steps followed in this research, some of the general principals were observed (such as developing a behavioural specification and partial development of a design specification) in order to obtain some of the benefits (suitability of end product, efficient use of resource) of utilising a specification approach. The progress achieved and a summary of the software specification produced is reported in section 4.2.7 and Figure 4.4 which depicts the overview of the desired FFSST architecture.

3.3.6 OUTSOURCING

Two areas of the research required expertise beyond that reasonably within reach of the research team;

- selection of a suitable DS development environment (see section 4.2.7, which details the software specification method used to communicate the key requirements to the external consultants), and;
- conversion of output data from the developed FFSST into an archival and portable electronic document format.

In the latter case, a sample report, along with sufficient description of the required functionality and identification of the source software 'variable' names (to allow automatic population of reports) was produced to enable the software programmer to fulfil this task.

3.3.7 SOFTWARE DOWN-SELECTION

In order to choose between the potential development environments identified by the research team and the external consultants (see section 3.3.5) employed to assist with the task, a simple ad-hoc comparative method was devised. Key attributes of the sought software were identified (such as: cost, functionality, end user interface and ease of use for the knowledge engineer). Some criteria were pass/fail (such as: functionality and end user interface) and others were weighted (cost, and ease of use). The research undertaken to ultimately derive and develop the adopted development environment is reported further in section 4.2.7.

3.3.8 VALIDATION

Evaluation of research is an important step in support of demonstrating the validity and reliability or “the confidence which someone may have in the findings” (p. 263. Fellows and Liu, 2008). Wong (2006) lists some of the problems that can occur as a result of defective software (such as the FFSST under development as part of this research) including: undesirable outcomes, reduced customer (or user in this case) satisfaction, increased maintenance costs and/or decreased productivity (or usefulness in this case) and profits (or societal benefit in this case). Evaluation is therefore identified as being a critic step in concluding the research in terms of helping to impart rigor and as a quality assurance step.

Evaluation of the research progress was performed on an ongoing basis in the research. Methods used include scrutiny against the findings of: Literature review, participatory consultation and case studies and field experience. In order to conclude the development cycle (see Figure 3.1), final evaluation steps were undertaken. This research poses some challenges in terms of evaluation as the scope of works is considered by the researchers to be considerably broader than it has been reasonably possible to action in the time available. As a result it was anticipated that much feedback will (quite reasonably and correctly) identify the plethora of opportunities to further the research. Whilst such feedback is useful, constructive and valuable it is expected it will also highlight the considerable areas where further work could usefully be undertaken. The strategy proposed to manage this situation was that findings from the feedback and evaluation process be divided in to two categories; actions which it was reasonable to act upon in the remaining time available within the EngD programme (a finite period of funded research time) and those which must be deferred into potential future phases of work which FPA (the industrial sponsor) may choose to support. When designing, undertaking and reviewing the evaluation steps it was considered necessary to keep these circumstances in mind. In order to evaluate the research progress, the techniques used are described as follows. Exploratory data analysis in the form of open ended questions. This technique may be suitable when numerous and varied responses are expected (Naoum, 2007). Such responses were considered to be likely in the case of this research, given the breadth of scope of the work and necessarily limited extent to which development has been pursued. Although this technique can certainly yield useful feedback, analysis of the responses to questions can be rather complicated and it is noted that "it also requires a great skill to accurately report the information" (p. 86. Naoum, 2007). Naoum (2007) then goes on to propose an example method to structure questions and code example responses to such questions. However even this methodology is considered too structured and inflexible given the expected unstructured nature of feedback anticipated. Instead, because of the breadth of scope of the work and necessarily limited extent to which development has been pursued, it is considered in this case that the only practical means of capturing information to support the final evaluation will be to use open questions and accept that laborious analysis of the comments by suitable informed persons will be the only method which can be applied.

Developing further the method, Active Design Review (Parnas and Weiss, 1985) is an approach that would appear to lend itself to the circumstances. Wong (2006) explains the background to the approach is sympathetic to contemporary working life in that reviewers may be overloaded, may not be intimately familiar with the objective and intricacies of the software (the FFSST) design and often do not achieve much progress when expected to work as large review groups. Wong goes on to outline the three steps of the active review process: 1) the author presents an overview of the artefact (the Tool), 2) Defect detection is facilitated by means of open ended questions 3) the final step is defect collection where more in depth review meetings focus on one specific identified problem area at a time. Further, it is noted that reviewers are to be selected based upon their expertise (being appropriate for the task). It is therefore expected that this staged approach will allow reviewers to focus on making improvements in small areas with reduced risk of them becoming overloaded. It follows that small improvements can be appropriately re-combined the results can be significant overall progress towards improvement and will also yield information upon the validity of the FFSST.

4 THE RESEARCH UNDERTAKEN

This chapter summarises the research undertaken in pursuit of the project objectives.

4.1 ONTOLOGICIAL CONSIDERATIONS

Whilst this research does not delve deeply in to the field of ontology, it is considered worthwhile to acknowledge the importance of the area in the field of knowledge engineering, where words may assume parametric-like qualities. This is exemplified by the knowledge derivation process outlined in Table 4.4 in section 4.2.8, which is underpinned by the research reported in Paper 1 in Appendix A.

An ontological assignment may be thought of as an agreement to use specified vocabulary and terminology in a way that is consistent (Gruber, 1993). The purpose of such assignments is to standardise important concepts and terms in order to improve clarity of understanding and effectiveness of knowledge sharing. A simple example of where such considerations became significant in this work was found at a fundamental level; the title “Active Fire Suppression System Selection Tool” (as used in earlier work (Bird et al., 2012)) was considered to no longer be the most appropriate way to title the project. Feedback received indicated that this title could be taken to mean the scope of work include systems like smoke control systems and fire detection systems (not the intention of the determined scope of work). Literature (BSIs standard for components for gas extinguishing systems (multiple parts) (BSI, 2003a), DCLGs fire safety risk assessment guidance document (DGCL, 2006), (Mannan, 2012) determined that the term “fixed firefighting system” is in fairly common use as a generic descriptor for any fixed (installed and non-portable) firefighting (with *suppression* or *extinguishing* objective) systems. Therefore this term was considered more suitable to adopt in view of the feedback received. The project title therefore becomes:

"Decision Problem Structuring for Selection of fixed firefighting systems" (as adopted in later work (Bird et al., 2013, Bird et al., 2014)). The significant project output; the software tool becomes known as the Fixed Firefighting System Selection Tool (or FFSST for short).

4.2 PROGRESS BY TASK

This section summarises the research undertaken thematically, by the 10 project tasks (which are stated in full at section 1.4.2).

4.2.1 TASK 1: EVIDENCE OF THE PROBLEM, JUSTIFICATION FOR THE RESEARCH

This aspect of the research was pursued by literature review, review of field experience and participatory consultation.

The literature review (chapter 2 of this thesis) records the approach adopted and findings of the review undertaken throughout the duration of the research. Section 2.2 focuses upon the evidence of the selection problem. The Introduction (Chapter 1) in particular section 1.5 explains the justification for the research.

Review of field experience research activities included consideration of; FPA's large loss database, UK government fire statistics, FFS reliability studies, legal cases, participatory research leading to the development of documented case studies (as published in Paper 3 in Appendix C).

Other activities conducted, which help to provide evidence upon context and background to the perceived problem, included correspondence with CLG (the department for Communities and Local Government – the body responsible at the time for the building regulations with respect to fire safety). CLG were asked a number of times in an ongoing chain of correspondence:

- *How do CLG and its enforcing agencies assess whether a proposed alternative and/or innovative fire suppression system is fit for purpose? Do you have any guidance, standard tests or assessment criteria to be applied? If so are you at liberty to provide details?*
- *May alternative or innovative systems* [in earlier correspondence with CLG it had been established that 'alternative or innovative' meant systems other than those examples referenced in Approved Document B (DCLG, 2010)] *be adopted as a compensatory feature to address a specific risks or hazards? If so, how would CLG and its enforcing agencies assess whether a proposed alternative and/or innovative system is sufficient?*
- *Would claims of compliance with a BSI DD (Draft for Development e.g. DD 8458) be considered any differently by CLG and its enforcing agencies to claims of compliance with a full published national or international standard (e.g. BS 9251). Would the same (or a comparable) level of performance be expected?*

CLG was unwilling or unable to answer these questions which are key to fixed firefighting system selection. It is consistent with the overall theme of this research that it is often not currently possible to give properly informed consideration of these points. This is because there is insufficient data available to underpin what should be considered reasonably optimised fixed firefighting system selection (see section 4.2.6 which considers optimum selection in more detail).

4.2.2 TASK 2: DETERMINE SCOPE OF WORK

At the outset of the research, whilst there was conviction that a positive contribution to knowledge and innovation could be made, it was not clear to how and to what extent the aim and objectives of the research could be fulfilled. It was therefore considered particularly important to continually monitor the relevance of the scope of work as the research uncovered findings. Figure 3.1 (chapter 3) provides an overview of how the scope of work was refined as the research progressed.

The evidence of the problem, background and research justification information gathered in the course of undertaking task 1 (section 4.2.1) was instructive in the initial and ongoing refinement of the intended scope of work to be undertaken in the course of the research. The scope of the research was validated throughout the duration of the research. For example, early in research a specific question intended to do so was included in the questionnaire distributed (see section 3.3.1.1). The question was “Do you think the proposed Active Fire Protection System Selection Tool will be useful?”. Note that slightly different terminology (specifically “active fire protection”) was used at this time; see section 4.1 for explanation. The responses are reported in section 4.2.10.2 of this thesis and serves to demonstrate how the participatory elements of this research contributed to the refinement of the project scope and objectives. Participatory activities yielded opinions on the scope of the work, individuals’ and organisations’ experiences where selection had been a problem. The full questionnaire about the research and responses can be seen in Appendix G.

As the research progressed, having further researched the background and evidence to the problem and obtained stakeholder input, it became clear that there would be value in a decision aiding and signposting resource that both helped users with the logic of the fixed firefighting system selection decision making process (as central to the domain of Decision Support or Expert System) and provided additional educational and informative resources.

The ultimately derived scope of work is as stated in the aim (section 1.4.1) and objectives (section 1.4.2) of this project.

4.2.3 TASK 3: IDENTIFY TARGET FFS TECHNOLOGIES AND SUPPORTING KNOWLEDGE

In order to develop a decision support system and related supporting resources it is requisite that it shall be decided which fixed firefighting system technologies (or FFS system types) the decision support system shall include in the decision making process. It is also necessary that sufficient supporting knowledge as required to support the function of the decision support system and form the related supporting resources be available. Section 2.4 records that underpinning knowledge is required upon which to base both the logic and rules of the system (see for example the 'knowledge base' and 'inference engine' as depicted in Figure 2.2) and the supporting resources.

The Introduction and Literature Review record that the number of types of fixed firefighting systems now available to the user has increased. Fixed firefighting systems are generally specified by frameworks (of regulations, standards, guides and custom and practice) which have historically evolved in geographic regions of the world. It would be potentially desirable for this work to have global reach (for example to standardise the approach to protection in international or global organisations). However, currently there are obstacles to doing so. To do so would require that underpinning knowledge were derived from and compatible with regulations, standards, guides and custom and practice from all over the world. The primary source material (identified in Table 4.1) for UK is already quite a substantial body of material.

To broaden this further would render the work unfeasible with the resources available at this time. It is worth noting that initiatives to harmonize in Europe or Globally some of the sources of knowledge underpinning this research are ongoing. Review of literature (Chapter 2) determined that there was justification in limiting the scope of work to primarily consider domain knowledge from documents with UK (or English) jurisdiction (for example the English Building Regulations and British and European Standards). If so wished for any reason, it should be possible to review this decision and update the FFSST in future appropriately resourced work.

The literature identified as documenting the drivers for fire protection (listed in section 2.1) was reviewed, to identify the different types of fixed firefighting systems that were required or recommended in various circumstances. The corresponding system design specification documents (and in some cases supplemental guidance documents), with the most applicability to the UK jurisdiction were then identified. These documents are listed in Table 4.1. In this table they are assigned a general classification (column 1) which seeks to identify the fixed firefighting system technology type using terminology commonly encountered in the industry. These documents are important in the development of the tool. They could be considered as primary sources of knowledge, which combined with critical review, expert judgements and validation, are the basis for the logical rules of the tool. This aspect of the research is discussed in more detail in section 4.2.8. The title, standard or specification number and the reference are also provided in Table 4.1. The firefighting media type is also stated for information.

Table 4.1: Summary of sources of 'knowledge'

General classification	Standard	System type description	Firefighting Media	Reference
Sprinkler system	BS 9251	Sprinkler systems for residential and domestic occupancies - Code of practice	Water	(BSI, 2005)
Sprinkler system	BAFSA TGN1	Technical Guidance Note No 1 - The Design and Installation of Residential and Domestic Sprinkler Systems	Water	(BAFSA, 2012)
Sprinkler system	BS EN 12845	Fixed firefighting systems - Automatic sprinkler systems - Design, installation and maintenance	Water	(BSI, 2003b)
Sprinkler system	LPC Rules	LPC Rules for Automatic Sprinkler Installations 2009 Incorporating BS EN 12845	Water	(FPA, 2014b)
Sprinkler system	DD CEN/TS 14816	Water spray systems - Design, installation and maintenance	Water	(BSI, 2008e)
Water mist	DD 8458-1	Residential and domestic watermist systems – Part 1: Code of practice for design and installation	Water	(BSI, 2010b)
Water mist	DD 8489-1	Industrial and commercial watermist systems – Part 1: Code of practice for design and installation	Water	(BSI, 2011b)
Water mist	DD 8489-4	Tests and requirements for watermist systems for local applications involving flammable liquid fires	Water	(BSI, 2011c)
Water mist	DD 8489-5	Tests and requirements for watermist systems for the protection of combustion turbines and machinery spaces with volumes up to and including 80 m3	Water	(BSI, 2011d)
Water mist	DD 8489-6	Tests and requirements for watermist systems for the protection of industrial oil cookers	Water	(BSI, 2011e)
Water mist	DD 8489-7	Tests and requirements for watermist systems for the protection of low hazard occupancies	Water	(BSI, 2011f)
CO_2	BS 5306-4	Fire extinguishing installations and equipment on premises - Part 4: Specification for carbon dioxide systems	Gas	(BSI, 2012)
Inert Gas	BS EN 15004-1	Fixed firefighting systems - Gas extinguishing systems - Part 1: Design, installation and maintenance	Gas	(BSI, 2008c)
Halocarbon Gas	BS EN 15004-1	Fixed firefighting systems - Gas extinguishing systems - Part 1: Design, installation and maintenance	Gas	(BSI, 2008c)
Powder	BS EN 12416-2	Fixed firefighting systems - Powder systems - Part 2: Design, construction and maintenance	Chemical	(BSI, 2001b)
Foam	BS EN 13565-2	Fixed Firefighting systems - Foam systems - Part 2: Design, construction and maintenance	Chemical	(BSI, 2009b)
Aerosol	PD CEN/TR 15276-1	Fixed firefighting systems. Condensed aerosol extinguishing systems - Requirements and test methods for components	Chemical	(BSI, 2009c)
Kitchen protection	LPS 1223	LPS 1223 - Fixed Fire Extinguishing Systems for Catering Equipment	Water or Chemical	(LPCB, 2009)
Permanent O_2 displacement	PAS 95	Hypoxic air fire prevention systems – Specification	O_2 displacement by Nitrogen	(BSI, 2011g)

None of the fixed firefighting systems now offered, as reflected by those listed in Table 4.1 are equally mature in terms of; cost, supporting knowledge, experience and overall performance. Case studies (Bird et al., 2014) have demonstrated that understanding of performance and limitations of fixed firefighting systems (suitability, cost, benefit and in-service reliability) may not be widely appreciated by specifiers or users. This research must overcome these issues if it is to be successful in developing a useful fixed firefighting system decision support system and related supporting resources. The progress achieved in this regard is reported in section 4.2.6.

The approach to protecting objects is somewhat different to that of buildings. Objects in this context could be almost anything, but would typically be a high risk and/or high value and/or high criticality pieces of equipment (a few examples: Magnetic Resonance Imaging (MRI) scanner, mission critical IT infrastructure and data, process machinery involving high energy levels and/or large quantities of combustible substances). Objects may have more specific traits and features (and certain particularly high risk aspects, such as inherent propensity to catch fire, associated with the function), which present both challenges and opportunities to allow the design to be honed. Buildings, which are often subject to reasonable variations in use, may require a more versatile solution. An example of an existing document written to provide guidance on how to protect objects is the European Standard BS EN 13478 “Safety of machinery - Fire prevention and protection” (BSI, 2008b). It states that the risk of fire in machinery shall be determined by analysis. The assessment is to consider the fire hazard, probability of occurrence and severity of possible consequence, as illustrated in Figure 4.1 (reproduced from BS EN 13478):

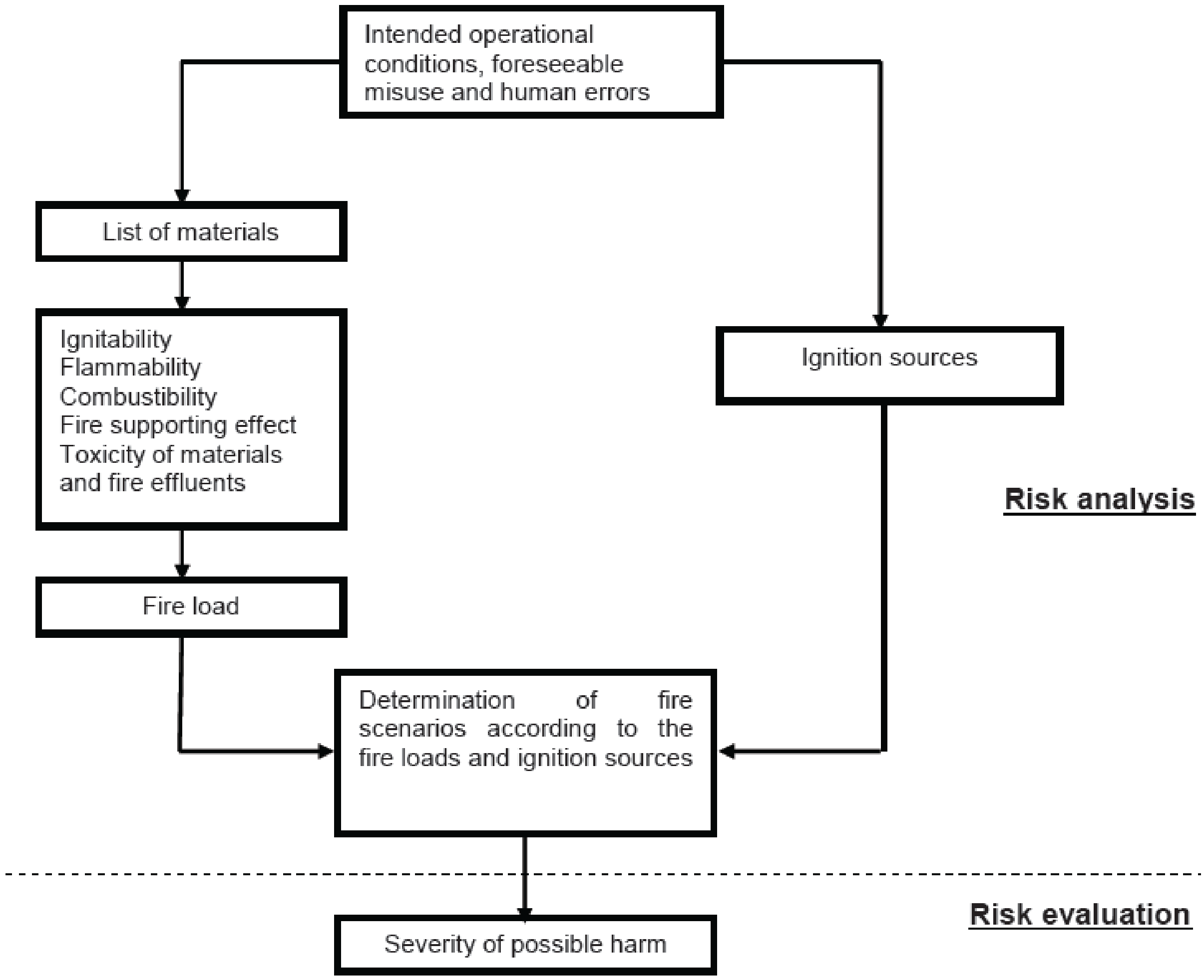


Figure 4.1: Risk analysis and evaluation (BSI, 2008b)

BS EN 13478 then goes on to make it clear that fire risk should be managed by a strategy that eliminates by design and management as far as possible the likelihood of a fire event occurring at all. Only if the residual fire risk is significant would one expect to reach the threshold at which it is decided that further protection is necessary, which may take the form of a fixed firefighting system (BSI, 2010a, Clause 7.1., p. 14.). The risk evaluation step shall take into consideration all expected harm from a fire (for example the fire itself, thermal radiation, effluent and discharge) (BSI, 2008b, Clause 5.3.). For further guidance on the steps required to evaluate whether the combined measures constitute a sufficiently safe solution, BS EN 13478 cross-refers to EN 1050 “Safety of machinery - General principles for design - Risk assessment and risk reduction” (BSI, 1997), which has been replaced by BS EN ISO 14121 “Safety of machinery - Risk assessment - Principles” (BSI, 2007) which in turn has been replaced by BS EN ISO 12100 “Safety of machinery - Principles for risk assessment” (BSI, 2010a).

Aside from noting the fragmented record of knowledge (thus making a complex topic even harder to follow for the practitioner), it is worth noting that these standards are primarily intended to deal with safety issues and not necessarily property protection (Clause 1., p. 1., BSI, 2010a). Whilst there is often overlap in these objective and outcomes, this is not always the case. Paper 2 in Appendix B and Paper 3 in Appendix C discuss the implications arising from the differing design concepts of life safety and property protection in more detail but as a generalisation, a reasonable property protection will generally exceed life safety design. No such comparable sources of information to this series of European Standards have been identified dealing with protection of equipment from a property protection perspective. In summary, documented knowledge for object protection scenarios was found to be incomplete and very difficult to follow. It may not seek to achieve protection to the level appropriate to the user. Further, no guidance is given upon the selection of fixed firefighting systems, where there may be an apparent choice of system. This has implications in that it lends further support to the justification for the research and means the available (documented) useable knowledge for these types of scenario is at quite a basic level. Where published guidance has been comprehensive, it has been possible to make some progress in pursuing the project aim in relation to object protection scenarios. A limited number of object scenarios have been incorporated into the FFSST. However because of the bespoke nature of object protection it is considered that to properly address such scenarios within the FFSST, each case which is not currently provided for should as future work be analysed and incorporated into the tool when the case is sufficiently well understood.

4.2.4 TASK 4: IDENTIFY AND ADDRESS GAPS IN KNOWLEDGE

It is perhaps noteworthy that in the documents listed in Table 4.1 generally do not discuss fire size in terms of heat output, total energy or heat release rates. These are common concepts in the discipline of fire engineering and might be expected as a prominent feature of this research. It is understood that such considerations are in effect embedded into the documents listed in Table 4.1; the documents instead generally specify fire scenarios they will be able to cope with. By implication they also exclude scenarios they will not be able to cope with, or where their ability is unknown. Whilst this may be considered at limitation of the work by fire engineers, it provides a potentially useful simplification in terms of the development of the tool, which is intended for use by a broader audience that just expert fire engineers. It means the tool will not need ask the user about heat output, total energy or heat release rates. Instead it can focus upon asking about the building occupancy or application of the object to be protected and determine likely suitability based upon the intended scopes of application of the documents identified in Table 4.1.

Section 2.4 records that underpinning knowledge is required upon which to base both the logic and rules of the decision support system (see for example the ‘knowledge base’ and ‘inference engine’ as depicted in Figure 2.2) and the supporting informative resources. Section 4.2.3 is concerned with reporting the progress achieved in identifying existing supporting knowledge as required to support the function of the decision support system and form the related supporting resources. However, in seeking to consolidate all the information required to develop a decision support system and related supporting resources, it was anticipated that gaps in knowledge would be identified. Some of the gaps encountered in these two types of knowledge are discussed in the following sub-sections.

4.2.4.1 Decision support system underpinning knowledge

Aside from BS 5306-0 "Guide for the selection of installed systems and other fire equipment" (BSI, 2011a) (which was found to be of very limited use; see section 1.5 of this thesis), no resources were found with the stated intention providing fixed firefighting system selection guidance. So whilst plenty of documents exist (for example those listed in Table 4.1) which generally seek to provide design information one fixed firefighting system type at a time, there is very little information on how to choose between the different system types. This could be considered a fundamental gap and a considerable part of the justification for this research. This knowledge gap was filled, as far as reasonably possible primarily by review, analysis and interpretation of the sources identified in Table 4.1 (in section 4.2.3). Table 4.4 (in section 4.2.8) serves as an example of the process used and outcome of this 'pulling together' (or elicitation) of underpinning selection knowledge required, from disparate sources. This process was repeated for each FFS type featured in the system.

4.2.4.2 Supporting informative resources

When reviewing the sources of knowledge identified in Table 4.1 to capture the knowledge (as reported in section 4.2.8) required to develop the decision support system and supporting resources, it was identified from the experience of the industrial sponsor that several important issues were not addressed by existing published guidance. Examples of supporting resources developed as part of this research intended to help users understand and contemplate issues such as cost, benefit and reliability (and for incorporation in to the FFSST) include:

- "TB234 Protection of High Hazard Storage (HHS) configurations" (in Appendix D, Technical Output 1, (Bird, 2014b)) from the need for more detailed technical guidance upon how to protect modern, very large storage facilities, as identified and reported in Bird et al. (2012). The need being for more detailed technical guidance upon the design and specification of fixed firefighting system for use in a relatively new type of building that arises as a consequence of the contemporary supply chain; very large warehouses and distribution centres. This 47 page technical supplement (Appendix D) (Bird, 2014b) has been authored (with input from a small sub-committee of fire risk management experts by a series of meetings). It was extensively peer-reviewed by experts from the fire protection industry and recently published. It now forms a part of the widely used firefighting system standard "LPC Rules for Automatic Sprinkler Installations - Incorporating BS EN 12845" (FPA, 2014b). It also contains material which is informative and educational upon aspects of fixed firefighting system design and specification in such circumstances. It has been signposted to in relevant circumstances (for example, when it has been identified by the tool that the user is considering how to protect a warehouse) from within the FFSST. It has also been submitted to CEN (European Standardisation Committee) for consideration for adoption in future editions of EN 12845 (the British and European sprinkler standard).
- "Interactive Questionnaire One (IQ1): Water Mist Questionnaire: Building Protection" (at Appendix E, Technical Output 2, (Bird et al., 2011a)). This questionnaire was developed to allow a more detailed 'audit' and investigation of the suitability of proposed water mist firefighting systems for the protection of buildings (and contents). It seeks to gather information on design, quality and anticipated performance of water

mist systems. It was peer reviewed by a panel of insurance risk managers (subject matter experts) and was published in 2011. Since its publication it has been well used and feedback received by the FPA is that it is extremely useful to insurers, risk managers and end users. It is now additionally made available as a resource for users from within the FFSST.

The informative and educational resources which have been created or utilised to fill identified knowledge gaps in support the task of FFS selection and the aim to develop a decision support system and related supporting resources are listed in Table 4.2. These are in addition to the ‘help text’ provided to the user as they progress through the tool. For an example of the Graphical User Interface (GUI) showing some ‘help text’ see Figure 4.6. Links (or ‘signposts’) to these supporting resources and to other external pre-existing published sources of information are incorporated into the GUI of the FFSST.

Table 4.2: Summary of incorporated informative educational resources		
Title	**Form and description**	**Reference**
TB234 Protection of High Hazard Storage (HHS) configurations	47 page supplement to widely used technical specification	(Bird, 2014b)
Hyperlink: Not available		
IQ1 - Water Mist Questionnaire: Building Protection	Interactive questionnaire intended to probe design integrity of prosed solutions. Accessible from within FFSST or as standalone document.	(Bird et al., 2011a)
Hyperlink: http://xpr.riscauthority.co.uk/xraoutput/assets/pdf/IQ1.pdf		
IQ2 - Water Mist Questionnaire: Building Protection	Interactive questionnaire intended to probe design integrity of prosed solutions Accessible from within FFSST or as standalone document.	(Bird et al., 2011b)
Hyperlink: http://xpr.riscauthority.co.uk/xraoutput/assets/pdf/IQ2.pdf		
Fixed Firefighting System - Reliability estimation method [draft]	PDF document with explanatory text and estimation table to complete. Accessible from within FFSST or as standalone document.	(Bird, 2014a)
Hyperlink: http://xpr.riscauthority.co.uk/xraoutput/assets/pdf/ReliabilityEstimationTable.pdf		
Gaseous fire extinguishing system animation	Informative animation. Accessible from within FFSST.	
Hyperlink: http://xpr.riscauthority.co.uk/xraoutput/assets/scenario1a.swf		
Video clip	Informative animation (proprietary system). Accessible from within FFSST.	
Hyperlink: http://www.youtube.com/watch?v=BggnHKCQITY		

4.2.5 Task 5: Identify target users

Target users of the decision support system and related supporting resources were identified and engaged with. This was so that the work could seek to understand the problem from their perspectives and seek to address their needs.

The same questionnaire (Appendix G) about the research sought to identify potential system users asked "Which of the following best describes your role?". A number of anticipated responses were provided and an 'other' field was provided to allow any unanticipated roles to be recorded. Of the total 64 responses, 16 responses identified as 'other'. Responding 'other' allowed a comment to be added and user roles were described as: 'insurance surveyors' or 'insurance risk managers' and 'consultants'. These responses are summarised in Figure 4.2.

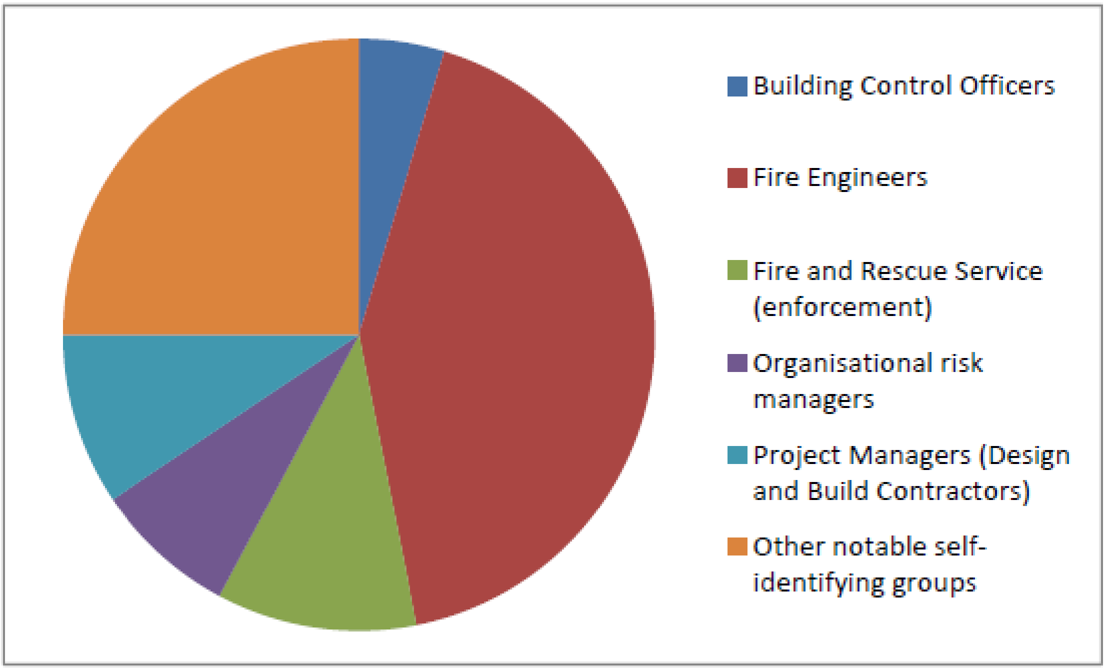


Figure 4.2: Responses to questionnaire question

It is notable that in the absence of any clearly defined requirements, almost anyone of any competence level may assume the role or responsibilities of an 'organisational risk manager' or 'consultant'. This means that it is foreseeable that there will be instances where people may lack the expertise required to make good fixed firefighting system selections, yet nevertheless be charged with making these decisions. Whilst this should not be considered best or reasonable practice, it is a reality the FFSST and this research may wish to contend with. It is not considered reasonable to expect this research to fully resolve such competency issues, but a decision support system and related supporting resources may be able to make a positive contribution to fixed firefighting selections and ultimately outcomes such circumstances. Considering this, any tool that is developed for such a diverse user group would need careful consideration, especially since technical (expert) information would be exchanged between the tool and a non-technical (non-expert) user (as reported in Paper 2 in Appendix B). Bearing this in mind and that the subject area is not without considerable complexity (as the ‘other’ survey responses in section 4.2.2 serve to highlight) appropriate cautions and disclaimers alerting users to the reasonable limits of what can be achieved by a Decision Support system in this area are considered appropriate and necessary. With such an approach it is believed that a tool can be developed which will render a range of new (created for this research) and pre-existing advice and information, tailored to their specific circumstances, available to a diverse user base.

4.2.6 TASK 6: OPTIMUM FFS SELECTION

There are a variety of sources of knowledge guiding system specifiers on the basic suitability of system for numerous applications. These include regulations, guidance and standards many of which are reported in previous work (Paper 1 in Appendix A, Paper 2 in Appendix B and Paper 3 in Appendix C) (Bird et al., 2012, Bird et al., 2013, Bird et al., 2014) and sections 2.4 and 4.2.3 of this thesis. This section and subsections report the progress achieved in building upon the findings of the literature review and to focus upon developing the identified key facets of optimal FFS selection criteria. Figure 4.3 illustrates the FFS selection factors identified as important. This figure is built up from a variety of sources of quantitative and qualitative data including BSI’s “Guide to reliability and maintainability” (BSI, 2014) and “Quality vocabulary” (BSI, 1991). Looking further afield; “U.S. Experience with sprinklers and other extinguishing equipment” (Hall, 2010) and “Guide for Achieving Reliability, Availability, and Maintainability" (US Department of Defence, 2005).The figure seeks to portray that Availability, Reliability and Maintainability (ARM) ought to be the dominant factor (see section 4.2.6.3). However, based upon observations from the experience of the FPA, this imperative is often somewhat concealed from the users' vantage point, by factors affecting Cost or Customisation.

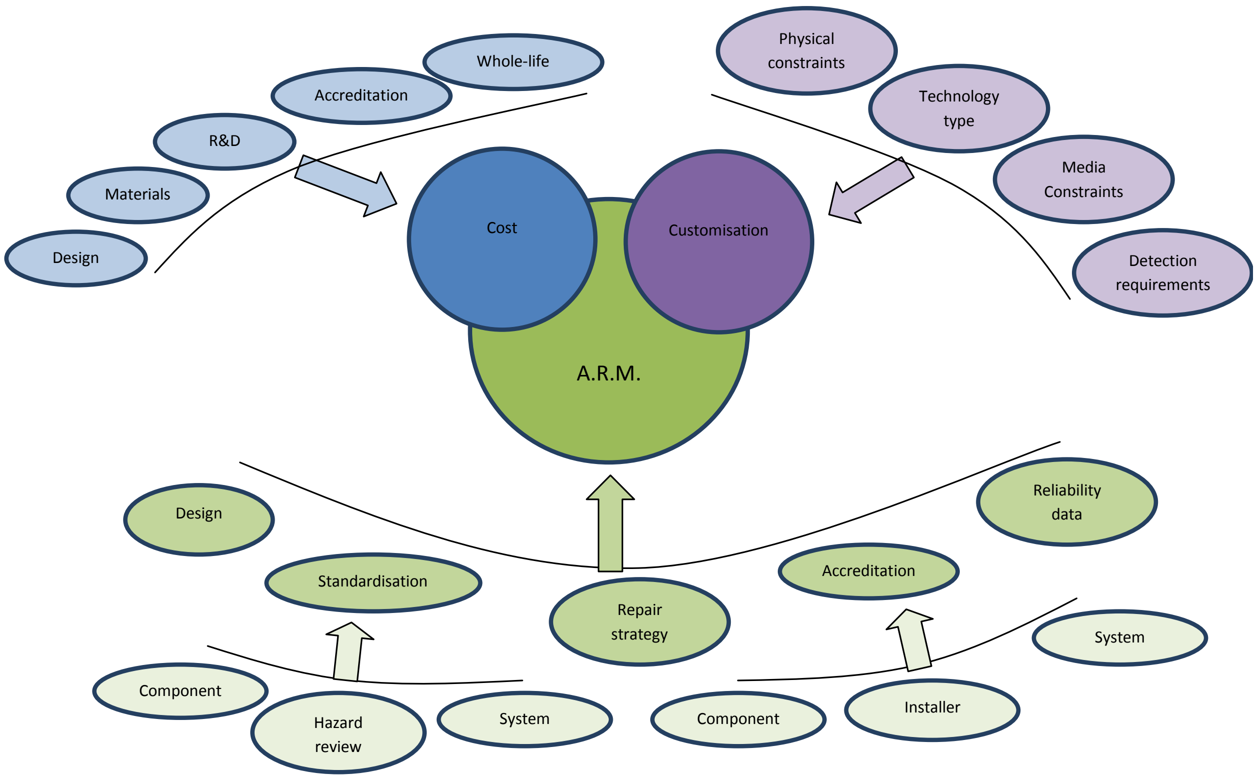


Figure 4.3: Significant factors effecting FFS choice

As can be seen from Figure 4.3 the selection problem has both technical and financial dimensions (with considerable interplay between the two) and the subsections that follow seeks to further articulate of the issues to be considered.

4.2.6.1 FFSs Scopes of Application

At the most fundamental level, some FFS technologies are simply not suited to certain applications. For example, a gaseous system relies upon displacing atmospheric air with 21%

Oxygen, with a gas to achieve a mixture of much lower oxygen concentration to extinguish a fire (Cote, 2008). It follows that such gaseous systems do not work if the lower oxygen content gaseous mixture cannot be retained for sufficient time to extinguish the fire. Water based systems would be a poor choice where a fundamental incompatibility with water exists, for example, where it would be unsafe to apply water in the case of the presence of certain high voltage equipment (BSI, 2009a). The position becomes less clear with water as a medium where the negative consequence of applying water to the objects or materials to be protected would also be significantly adverse when considered in the context of the potential fire damage. The use of other systems incorporating chemical mediums (such as powders and foams), whilst very desirable in certain circumstances (such as in the presence of water immiscible liquid fuels (BSI, 2001b, BSI, 2009b)), are likely to be limited in application by considerations such as contamination of the micro or macro environment, clean-up implications, effect upon personnel and activities in the vicinity. Beyond the choice of firefighting media (only one of innumerable potential customisations of the design of a fixed firefighting system) there are many other permutations (designs or customisations) possible. Examples would include: the means of delivery (as a spray, mist, jet), rate of delivery, means of fire detection, means of system actuation to name a few. As a generalisation it might be that the issue that these examples speak to is that of overall expected advantage afforded by a FFS (the balance of positive effects against negative effects).

Such considerations are recognised to varying extents in the existing sources of knowledge (such as those identified in sections 2.4 and 4.2.3 of this thesis), in the subject area. However this work has identified that from existing sources of knowledge this type of limited heuristic information can be found typically in the ‘Scope’ section of documents, where the intended application of a technology is given. Other limitations upon the use of the technology can be found elsewhere throughout some of the documents. Some of this information can be used to derive underpinning ‘rules’ for use in the FFSST. The selected source material and findings of this knowledge elicitation step are reported in sections 4.2.3 and 4.2.8.

4.2.6.2 Cost and benefit

In seeking to improve understanding of what constituted optimal fixed firefighting system practice, system cost and benefits afforded were considered. The general principles of cost-benefit analysis (CBA) appeared to transferable and desirable to this research area. In doing so, a link was established between the research direction and benefit the outcomes of the research could deliver to the user. In this subject area, the ‘cost’ parameters were identified as potentially including: system purchase and installation costs, cost of ongoing maintenance, negative aspects of having a system (such as unwanted activations and media discharge) and perhaps opportunity cost (what else could have been purchased instead (Mankiw, 2011), like for example other fire prevention or safety measures). The ‘benefit’ parameters can be described as firefighting performance or the consequence of damages arising from fire without a fixed firefighting system compared to the same fire with a firefighting system; this would characterise the positive difference the fixed firefighting system made to an outcome in the event of a fire. This is perhaps too simplistic as it should be acknowledged that different systems have different ambitions; for example to ‘suppress’ fires, to ‘control’ fires (FPA, 2014b), to ‘extinguish’ (BSI, 2008c) fires or to ‘prevent’ (BSI, 2011g) fires. Therefore it seems possible that there will be a relationship between the design objective of a system and the expected residual benefit (after considering the damage incurred in suppressing, controlling or fighting a fire is taken into account) of a fixed firefighting system. The extent to which the decision support system and related supporting resources developed by this work incorporate such considerations in the FFSST is at this time necessarily limited due to the complexity and limited data available. This is discussed further in the recommendations of section 5.5.

Fixed firefighting systems, like any system are not 100% reliable (see section 4.2.6.3), so in some instances will fail to deliver some or all of the potential benefits. It would be reasonable to expect different FFS, comprising very different sets of components and design philosophies to have different levels of reliability. It may also be reasonable to expect different FFS to have different levels of reliability when they are used to protect different scenarios. The environmental conditions associated with one particular scenario might affect different types of fixed firefighting system quite differently. For example when considering fixed firefighting system actuation, thermally responsive glass bulbs are largely immune to the effects of raised levels of dust in the atmosphere (as quite common in some manufacturing and process scenarios), whereas optical smoke detection systems might very adversely affected by such conditions.

Depending upon what is being protected, it is expected that each of these factors (fixed firefighting system objectives, design and whole life reliability) would have an effect on the 'benefit' (and the 'cost') of a FFS. Detailed CBA study of fixed firefighting system performance appears to be in its relative infancy (recent examples of such work have been published by BRE (BRE Global, 2013) and CEBR (CEBR, 2014) and whilst comprehensive in depth the work is very limited in that they are confined to one risk category (warehousing) and one FFS technology (sprinkler systems) only. Thus, no comparison which might be useful in a selection problem is facilitated. These studies are considerable in their size and as such attest to the complexity of properly investigating CBA (and selection issues) in this area even with very constrained parameters inputs. Quantitative investigation of such matters (as undertaken by BRE and CEBR), whilst being important in considering the whole picture of

FFS selection was therefore identified as being necessarily out of scope of this research. Instead, it was decided that the tool must provide a means by which users may identify these issues so that they make their own investigations if they so wish (examples of such resources are given in section 4.2.4). Further, it should become a recommendation arising from this research that this aspect is inseparable from any detailed selection exercise; data on 'benefit' and 'reliability' would be a useful asset to further such investigations.

4.2.6.3 Reliability

The combination of reliability and maintainability determines the amount of time that a system is available for use (Smith, 2011). FFS reliability, or the quality of being reliable "able to be trusted, predictable or dependable" (Collins, 1994) has emerged as an important aspect (because of its link to 'benefit' discussed in the preceding section) to be considered in the selection of a FFS. The Society of Fire Protection Engineers (SFPE) "Handbook of Fire Protection Engineering" (DiNenno, 2002) does contain a comprehensive section on how, in theory, the expected reliability of a fixed firefighting system might be modelled. Literature review (US Department of Defence, 2005, Bukowski et al., 2002, Hall, 2010, Zalosh et al., 1996, Ejrup, 2011, Xu and Fuller, 2008, Hall, 2013) has yielded only a limited amount of subject domain reliability data and evidence that the theory (e.g. as published in the SFPE handbook (DiNenno, 2002)) has ever been put in to practice and published. However the material identified has been useful in forming an appreciation of what constitutes and contributes to 'reliability' in the context of this selection problem. In turn this has been useful in the development of supporting resources (examples are given in section 4.2.4 and Table 4.2) of this research.

In the course of undertaking the research it became clear that circumstances which require fixed firefighting systems have features that combine to make availability, reliability and maintainability of the FFS of the upmost importance. This is because:

- Given that the need for a FFS has been correctly determined (a starting assumption of this research), it is reasonable to assume the scenario features a foreseeable risk of a fire occurring, taking hold and that the consequences have also been identified as significant (i.e. the system may be required for the protection of multiple lives and/or property, assets and businesses of exceptionally high value), and;
- Given that fires are relatively rare events, most FFS will only be called upon to operate very infrequently, if ever. Thus the system must be capable of being maintained in a state of optimum readiness (or available) at all times (and systems of 50 years of age or greater are commonly encountered), yet remaining idle.

The magnitude and combination of these factors appear to render Availability, Reliability and Maintainability as the stand-out determinants in overall performance. Or to put it another way, if Sprinkler Systems are 91% ‘reliable’ as determined by Hall (2010) and such systems are used to help protect and estimated £20 trillion pounds of insured assets, as revealed by insurance industry insider, Hanks (2014), even very small fluctuations in ‘reliability’ will have a very marked economic effect at a macro-scale.

In order to address this selection consideration in the FFSST, in the absence of existing reliability data allowing comparison of difference FFS performance, methods were found, such as the work by (Xu and Fuller, 2008) which seek to comprehensively model the expected reliability. However to apply such involved numeric methods was not considered practical within the resource and time constraints of this research. Instead a ‘scoring sheet’ for incorporation into the tool and use by users was devised. The ‘scoring sheet’ is made available to users upon completion of them using the FFSST. An example screenshot illustrating the form the output from the tool takes, including onward signposting to resources such as this scoring sheet can be seen at Figure 4.8). Where users are faced with more than one system recommendation, the scoring sheet invites them 'score' their recommended systems in several areas all considered to be key influencing factors upon system reliability, as determined by the study of BSI's "Guide to reliability and maintainability" (BSI, 2014) and "Quality vocabulary" (BSI, 1991), "U.S. Experience with sprinklers and other extinguishing equipment" (Hall, 2010) and "Guide for Achieving Reliability, Availability, and Maintainability" (US Department of Defence, 2005).

It should be noted that this scoring sheet approach produces scores which are based upon the subjective judgement of users, who may have very limited familiarity with the subject matter that they are being asked to score. Whilst it gives them some guidance upon the issues they are being asked to score, and it is hoped that one user will apply fair judgement from one system type to another, this is a crude method from which to approximation anticipated levels of reliability. Nevertheless it is considered to be the best solution that can be achieved in the circumstances. This is scoring sheet is listed in Table 4.2 in section 4.2.4. It is a recommendation of this research that consideration be given to future work to seek to improve the data available to characterise different types of fixed firefighting system. This is reported in section 5.5.

4.2.7 TASK 7: DERIVE AN ENVIRONMENT CONDUCIVE TO DEVELOPING SELECTION PROCESSES AND SUPPORTING RESOURCES.

Throughout the research, the progress achieved towards the declared objectives had been iteratively shaping the overall projects ambition. An initial search was undertaken to increase familiarity with existing knowledge management-type applications, systems and terminology.

System types and ontological divisions were identified, assessed for their relevance and if considered applicable used to form new keywords (e.g.: decision support systems, knowledge management, information management processes and software, decision aiding process or software, self-service software or technology) to support more rigorous subsequent literature searching. A number of examples of approaches to decision aiding processes that frequently occurred during the literature review are given here:

- Decision Support Systems (DSS): Computer based system drawing upon data and models to help decision makers solve (semi-structured) problems. There is no universally accepted definition of what a DSS is (Turban and Aronson, 2001).
- Geographic information systems (GIS): Computer based capability for the manipulation of geographical data (Bernhardsen, 2002). The project under consideration is not judged to be a geographical problem.
- Genetic Algorithms (GA): genetic algorithms are described as "adaptive algorithms for solving practical problems and as computational models of natural evolutionary systems" (Mitchell, 1998) or a heuristic technique, based upon the theory of evolution suitable for large solution spaces (Banerjee et al., 2006). Application is best suited to circumstances that require some kind of iterative or self-tuning functionality. There does not currently appear to be any application of this approach to the fixed firefighting system selection tool, which is considered to be a more rule-based problem.
- Linear programming (LP): a mathematical programming technique with linearly defined objective functions and problem constraints (Nguyen et al., 2008). This technique may be incorporated in a hybrid expert system, where both logical rules and mathematical rules feature. It may prove useful in future if the recommendations

arising from this work (see 5.5.2) are implemented and attempts are made to innumerate risk or performance aspect of the selection problem.

- Expert Systems (ES): Whilst undertaking the literature review, reoccurring themes were found to be the subject domains Artificial Intelligence (AI) and Expert Systems (ES). Expert systems are considered a subset of Artificial Intelligence, alongside Robotics and Natural Language processing (Wilson and Welsh, 1986, Giarratano, 1998).

A few examples of Expert Systems in application follow:

Agricultural pump selection (Seflek and Çarman, 2010): This example sought to develop a system to assist with selection of pumps for irrigation in Turkey, where it is noted a suitable expert is not always on hand to consult about the many parameters of a pump specification. The system seeks to optimise performance parameters and energy consumption. This system uses a rule-based approach. Although this system is comparatively simple, it is useful in that it uses similar data types to those anticipated for this research and it also illustrates how a modular development approach can be adopted.

An expert system development tool for non AI experts (Ruiz-Mezcua, 2011): This work considers the complexity and cost associated with developing a traditional expert system. In order to try to mitigate some of the complexities the paper goes on to report how work to define a tool intended for use by non-Artificial Intelligence (AI) experts to develop expert systems progresses. In testing the tool, it was found as the paper concludes that non-AI experts could develop effective web based Expert Systems for the needs of their companies in short periods of time.

MYCIN: The MYCIN expert system is a well reported case study. It is reported in the book by Alty and Coombs (1984). The system (a medical diagnostic tool) uses data (facts) with a certainty factor associated with it to deal with the problem of inexact knowledge. Confidence factors are appended to facts. As facts are combined according to the rules of the system, the confidence factors are computed to produce new confidence factors associated with the outputs (diagnoses). Where multiple outputs would be obtained, the confidence factors are used to sort and carry forward only plausible diagnoses. To increase confidence in the system, it has facilities to provide an explanation of the decision taken.

Building on this research, early work reported in Paper 1 in Appendix A had determined that a Knowledge Management (KM) approach would be suitable, such as a Decision Support (DS) or Expert Systems (ES) approach. Decision support or Expert Systems can be populated with knowledge and used to automate part of the expert decision making process. The development of a limited scope prototype system early in the research was instructive in the approach that would need to ultimately be arrived at to fulfil the project aim. This step verified that part of the technical ambition of the project (to develop a decision support system) was possible and gave an understanding of how the existing forms of the knowledge base could be adapted to form the requisite underpinning knowledge (see sections 4.2.3 and 4.2.8). The prototyping work is reported in Paper 1 in Appendix A. This work determined that the underpinning knowledge available (see sections 4.2.3) was generally suited to develop a rule-based system using heuristic techniques (see the process described at section 4.2.8). Factors affecting the suitability of a system choice are considered in more detail in section 4.2.6. It was judged that currently such an heuristic approach could support making fixed firefighting system recommendations to users in the form of a traffic light system (for example a ‘Green’ result meaning this particular technology type is likely to be a good choice, ‘Amber’ meaning it might be suitable, and ‘Red’ meaning it is unlikely to be suitable). However, and ideally for future work, the development environment should be capable of incorporating other more quantitative and precise modelling techniques (which it is anticipated could be used further address the selection considerations such as cost-benefit and reliability identified in section 4.2.6), should future work (see section 5.5) ever allow such approaches to be implemented.

Upon successful completion of the prototyping step, the progress achieved was considered sufficiently mature (progress at this stage was reported in Paper 2 in Appendix B) to commit to specifying and procuring the development environment intended to be used for the remainder of the research. A number of off-the-shelf packages were identified (Exsys Corvid's Expert System Development Tool, Vanguard's Studio, eXpertise2Go's Rule-Based Expert System and XpertRule's Knowledge Builder). Based upon consideration of cost and functionality, none were considered entirely suitable as supplied for efficient progression of the development work. At this point, the decision was taken to engage some external expertise to broaden the search for and advise upon the suitability of potential development environments. In order to consult with software experts, a specification was developed.

The specification used to communicate with the software experts outlined that: the FFSST is to ask the user a series of questions to elicit the required knowledge pertaining to their circumstances in order to make recommendations and signpost users to tailored relevant informative material (in a variety of web accessible formats) that may be useful to them in making their FFS selection from a number of potentially suitable system choices. Recommendations are to be in the form of 'Green' meaning this particular technology type is likely to be a good choice, 'Amber' meaning it might be suitable, and 'Red' meaning it is unlikely to be suitable. The process should conclude with a report being produced, recording the recommendations to the user in relation to each system type. Each recommendation will be accompanied by any relevant application notes and links to other relevant resources. These resources may be in a various media formats (i.e. documents, animations, videos, pictures). Figure 4.4 depicts the overview of the desired FFSST architecture, presented graphically in a style inspired by the work of Nilsson (1998, p. 281.) and Giarratano (1998, p. 3.).

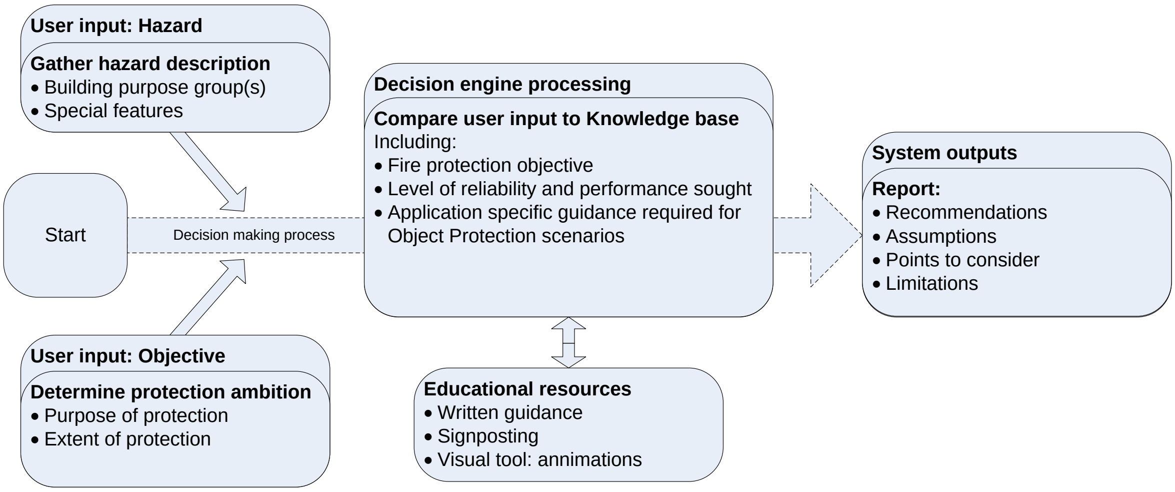


Figure 4.4: Overview of derived FFSST architecture.

The external experts' advice was that although XpertRule's "Knowledge Builder" software was expensive it offered advantages including being a highly customisable package (which they felt was necessary) and XpertRule were a UK based supplier capable of offering more local support (the other suppliers were all based in the US). Having considered the recommendations received from the external experts, costs and expected benefits of each package, it was decided to select XpertRule's "Knowledge Builder" software. This software can automate business decisions and deliver intelligent user interfaces (XpertRule, 2014). The software is highly customisable and the first step in developing a decision support application is usually to tailor the package to suit the specifics of the problem. This was undertaken in collaboration with the software house and some further customisation of the reporting capability as required was achieved with the input of an external programmer. The continuation of the FFSST development process is reported in section 4.2.8, where the process is described and screenshots are presented.

4.2.8 TASK 8: DEVELOP TOOL

This task was concerned with aggregating all of the research progress achieved to date and developing the software forming the decision support system; part of the aim of this research. It may be helpful to refer back to Figure 4.4 "Overview of derived FFSST architecture." when reading this section. Incrementally, previous work (Paper 1 in Appendix A; Paper 2 in Appendix B; and Paper 3 in Appendix C) had established that underpinning knowledge is available which is suitable for use as rules to guide the selection process or information to accompany recommendations arising from the process. The development environment and process adopted was now sufficiently mature to facilitate Rapid Application Development (RAD) development of the FFSST (without the need for detailed pre-planning). This was to avoid the need to attempt to list and inter-relate all the knowledge (rules, decision trees and supporting resources); a task which was considered too complex and unmanageable given the scope of the project. As such the derived (and customised) development environment is both the software FFSST compiler and the primary record of the aggregated identified knowledge. This method of development allowed rules to be created as work progressed, supported by critical review of: the sources of knowledge documented in Table 4.1: Summary of sources of 'knowledge', expert judgments and other technical references. Final evaluation (see section 4.2.10.5) of the research provided an opportunity for validators to comment upon the logic (rules) adopted for use in the tool. An explanation of the development process follows:

Within the development environment, a framework of rules is established as *Attributes*. An attribute is essentially a question with two or more answers. Attributes (or questions) may be relevant to one or more FFS technologies.

A *Tree* is created for each FFS technology. FFS technologies are grouped by the most relevant design and installation standards applicable in UK. This was found to be a convenient (and most fully-formed pre-existing) way to demark one technology from another. Horizontal 'Trees' are used to structure together 'Attributes' and serve to structure the knowledge elicitation process in relation to the suitability of each FFS technology in the users circumstance. It was found that an efficient way to develop each tree was to consider it to be an elimination process, for example by adopting the stance of asking "when is this technology not suitable?" (and what do I need to ask to find that out as early as possible in the process? Doing so makes progress through the tool more efficient for the user). By way of example, Figure 4.5 shows one of simpler decision trees (for "LPS 1223 - Fixed Fire Extinguishing Systems for Catering Equipment" (LPCB, 2009)) in the development environment. In the figure, each hexagonal cell denotes a question (the questions appearing in this example are listed in Table 4.4). The possible answers are shown in boxes connected to each hexagon by lines (which may contain single or multiple answers grouped together). Progress is made through the tree from left to right. During this passage the next question or other boxes (containing an @ symbol) may be encountered, which are appending information and recommendations to the report that will ultimately be produced (see Figure 4.7 and Figure 4.8) or the next question. Each branch terminates in either 'Red', 'Amber' (not shown in this example) or 'Green'. Depending upon which branch is traversed, the assignment of the terminal node (along with any information appended along the way) is what will be reported for that particular firefighting technology in the output report. Figure 4.7 and Figure 4.8 present examples of an output report.

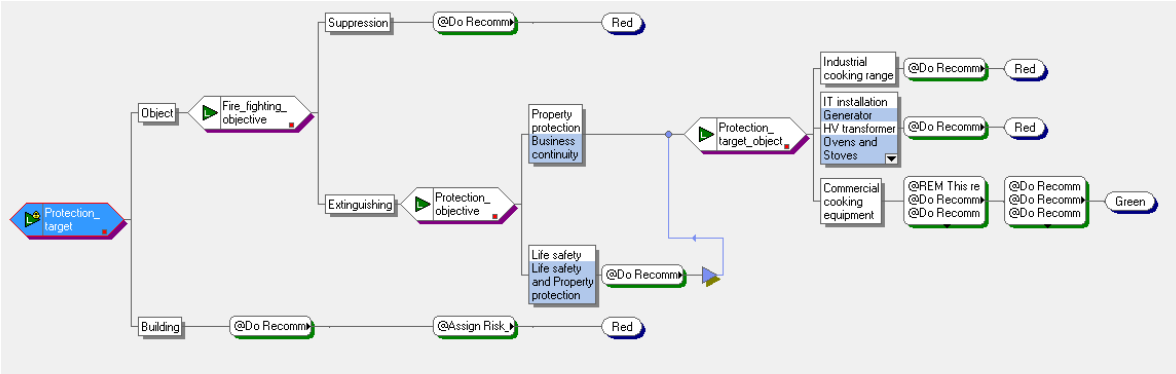


Figure 4.5: Example decision tree

As the user progresses through the tree they will see a graphical user interface having an altogether different appearance; see Figure 4.6. Additional information (such as that detailed in the fourth column of Table 4.4) may be provided to them intended to help make the meaning of questions clearer or illustrate various points considered important.

Figure 4.6: Example of Graphical User Interface (GUI)

This method of development was found to offer the following advantages:

- Where attributes (questions) are shared between trees, for efficiency, the user will only be asked that question once;
- In structuring trees from attributes, in practice it was found that it was possible to minimise the number of questions that would be put to the user by asking the most impactful (usually the most frequently invoked) questions earlier in the process. Thus irrelevant branches of trees may be closed off sooner (and subsequent questions on that branch not asked of the user). This optimisation required a combination of thinking ahead and trial and error, and;
- The development environment (and process) effectively becomes the repository of knowledge, eradicating the need for an abundance of complex documentation (it would be slow and burdensome to document each tree as illustrated in Figure 4.5, Figure 4.6, Table 4.3, Table 4.4 and accompanying commentary, especially when considering how frequently trees may change during the development process).

Having established that the development environment is both the software FFSST compiler and the record of the identified knowledge, for illustrative purposes, it is necessary to undertake a reverse-engineering exercise in order to extract the assembled rules and knowledge to document the elements that come together to form one tree. As an example a record of such an exercise is presented in Table 4.3 and Table 4.4.

Table 4.3: Examples of derivation of rules for commercial catering equipment, serves to demonstrate the relationship between derived Rules or Attributes (column 1), possible answers (column 2) and the underpinning knowledge on which the rules are based (column 3). It provides examples of the critical review of available source material, combined with expert judgement and validation to result in heuristically derived rules for incorporation into the tool.

The underpinning knowledge in this case primarily being LPS 1223 (LPCB, 2009). Although other sources of knowledge (as referenced in Table 4.4) were also used from which to draw related information.

Table 4.3: Examples of derivation of rules for commercial catering equipment

`Attribute` and Question	Possible answers	Derivation
`Protection_target` What is the type of protection?	Object Building	Critical review of LPS 1223 ("Scope", LPCB, 2009) determines that the approach is applicable to the protection of local object (commercial cooking ranges) rather than whole buildings. See Table 4.4 for implications.
`Firefighting_objective` What is the firefighting objective?	Suppression Extinguishing	Critical review of the title of LPS 1223 makes it clear that the intent of systems to this specification is to "extinguish" fires. This is consistent with expert opinion on the practical necessity of a system in such application. Given that fires in such equipment are rapidly developing and often located at the heart of buildings, fire extinguishment (as opposed to fire suppression) is necessary, otherwise a suppressed fire would quickly re-establish. See Table 4.4 for implications.
`Protection_target_object` What is the protection target?	Commercial cooking equipment Industrial cooking equipment All others	Critical review of LPS 1223 ("Scope", LPCB, 2009) determines that it is applicable to deep fat fryers and other catering equipment. The documents makes no reference to industrial cooking equipment or the motive equipment one might expect to accompany industrialised cooking process. Therefore the expert judgement is made that, for the purposes of the FFSST at least, the scope of application of this protection approach should be limited to commercial cooking equipment. See Table 4.4 for implications.

Table 4.4: ‘Rules’ and ‘Knowledge’; then expands this by exploring the answers to each question and what they mean both in terms of the decision making process and accompanying information to be communicated to the FFSST user.

Table 4.4: ‘Rules’ and ‘Knowledge’; implications

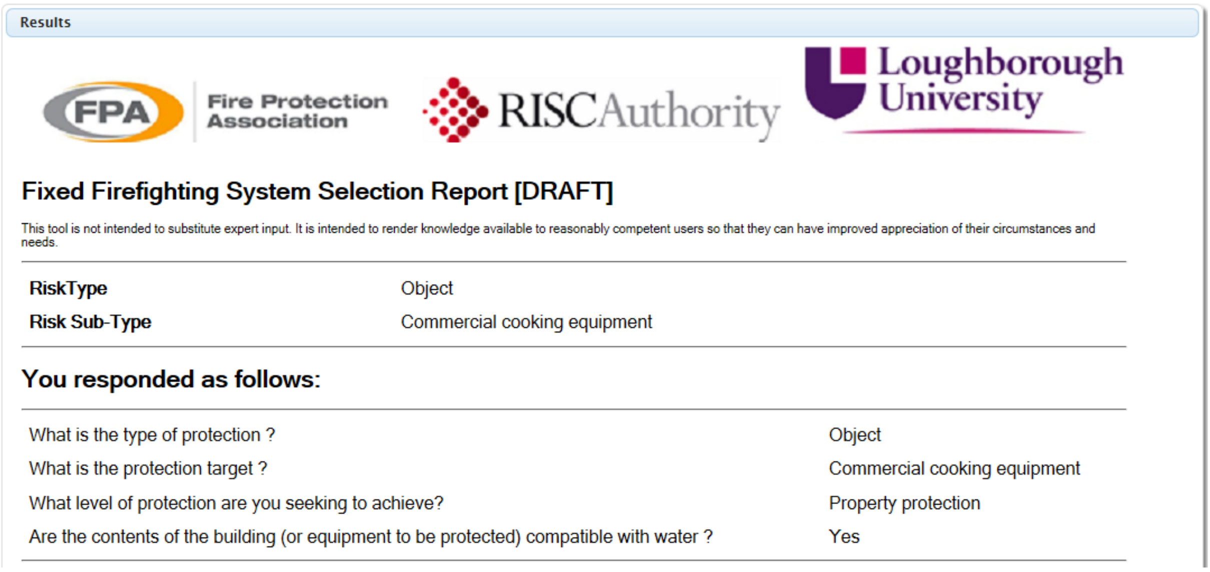
`Attribute` and Question	**Possible answers**	**Significance**	**Related information to be communicated to the user**
`Protection_target` What is the type of protection?	Object	Within scope: proceed to next question	State FFSST limitation: only one object can be considered at a time. Expand on what is meant by ‘object’. Give examples. Signpost to: BS EN 13478 “Safety of machinery - Fire prevention and protection” (BSI, 2008b) and BS EN ISO 12100 “Safety of machinery - General principles for design - Risk assessment and risk reduction” (BSI, 2010a)
	Building	Recommendation : RED	Record note: *‘This FFS technology is not suitable for the protection of whole buildings’*
`Firefighting_objective` What is the firefighting objective?	Suppression	Acceptable variation to scope: proceed to next question. Note variation.	Record note: ‘*This is an extinguishing technology, so it should exceed your requirement to suppress a fire*’
	Extinguishing	Within scope: proceed to next question	None
`Protection_objective` What level of protection are you seeking to achieve?	Property protection	Within scope: proceed to next question.	None
	Business continuity		
	Life safety	Acceptable variation to scope: proceed to next question. Note variation.	Record note: *'This method of protection is primarily intended to protect an object (cooking equipment) but in doing so may bring life safety benefit'*
	Life safety & property protection		

Table 4.4 (continued)- ‘Rules’ and ‘Knowledge’ tree in LPS 1223 (LPCB, 2009)

<table>
<tr><th><code>Attribute</code> and Question</th><th>Possible answers</th><th>Significance</th><th>Related information to be communicated to the user</th></tr>
<tr><td rowspan="3"><code>Protection_target_object</code>
What is the protection target?</td><td>Commercial cooking equipment</td><td>Last question.
Recommendation: GREEN</td><td>Expanded definition of ‘commercial cooking equipment’. Illustrative figure of such cooking equipment.
Signpost to: RC44 “Risk Control - Recommendations for Fire Risk Assessment of Catering Extract Ventilation” (FPA, 2006) and LPS 1223 (LPCB, 2009)
Make (and record) assumptions: as we know this is a cooking range it is reasonable to expect there to be water and personnel present and that there will not be a sufficiently gas-tight enclosure to render gaseous systems as likely to be feasible.
Record notes: various recommendations are made based upon field experience of the use of this type of system.
Video: A video animation of an example of this system type in operation is provided</td></tr>
<tr><td>Industrial cooking equipment</td><td rowspan="2">Recommendation: RED</td><td>Expanded definition of ‘Industrial cooking equipment’. Illustrative figure of such cooking equipment.
Record note: ‘This approach is for Commercial cooking equipment, not Industrial cooking equipment’</td></tr>
<tr><td>All others</td><td>Expand on what is meant by this object type. Give examples.
Record note: This FFS technology is not suitable for this scenario</td></tr>
</table>

As the user progresses through the process of answering questions, more becomes known about their circumstances. The derived GUI (see Figure 4.6 for an example, displaying ‘object’ protection scenarios and help text, hyperlinks and graphics for ‘Commercial cooking equipment’) is capable of responding in a number of ways; question text and selectable answer options change each time a new question must be posed. Help text is dynamic and may include hyperlinks (useful for signposting towards related documents for reading outside the tool, explanatory videos or animations) and images. The signposting (directing users to other relevant material) is 'dynamic' in that it adapts to the circumstances the user describes and thus seeks to avoid overloading the user with irrelevant material and only refers them to material that is likely to be applicable. If the FFSST has determined that the scenario involves commercial cooking equipment, it will make available related further reading to the user if it is considered important to do so. For example LPCB's LPS 1223 "Requirements and testing procedures for the LPCB certification and listing of fixed fire extinguishing systems for catering equipment" (LPCB, 2009) and the FPAs additional guidance "RC44 - Fire risk assessment of catering extract ventilation" (FPA, 2006) are considered essential further reading for the user who is seeking to protect commercial catering equipment. This dynamic signposting is believed to be a facet of the work of considerable value in that it efficiently directs the user towards focused and related material.

An example of the output report presented to the user upon completion of the process is shown at Figure 4.7 and Figure 4.8.


Results

FPA Fire Protection Association | RISCAuthority | Loughborough University

Fixed Firefighting System Selection Report [DRAFT]

This tool is not intended to substitute expert input. It is intended to render knowledge available to reasonably competent users so that they can have improved appreciation of their circumstances and needs.

RiskType	Object
Risk Sub-Type	Commercial cooking equipment

You responded as follows:

What is the type of protection ?	Object
What is the protection target ?	Commercial cooking equipment
What level of protection are you seeking to achieve?	Property protection
Are the contents of the building (or equipment to be protected) compatible with water ?	Yes

Figure 4.7: Example of an output report (header and summary of input data)

The recommendations are:
(Green = Likely to be suitable, Amber = potentially suitable, Red = unlikely to be suitable):

LPS 1223 - Fixed Fire Extinguishing Systems for Catering Equipment

Commentary
1) We have assumed that the firefighting objective should be extinguishment
2) We have assumed that the cooking range will be operated by personnel and therefore a solution that reduces ambient oxygen would not be suitable
3) We have assumed that the cooking range is not in an enclosure with gaseous extinguishing media retaining capability
4) We have assumed that there is a water supply as this is a food preparation environment

Notes
1) Fire testing to verify performance is recommended
2) Ensure extraction systems are appropriately interlocked as required by the firefighting approach
3) Ensure the energy supply required to deliver the media is sufficiently robust
4) Consider whether system requires a power supply and water supply, and the resilience of these supplies
5) An example (a manufactorers proprietary solution) of such a system can be seen here: Wet chemical system Animation
6) LPCB certified systems (which may use different types of firefighting media) can be seen listed here
7) If you are considering two or more competing system options, you may wish to try to evaluate the likely reliability of each using this RISCAuthority checklist .

LPC Rules sprinkler system

Commentary
1) We have assumed that the firefighting objective should be extinguishment
2) We have assumed that the cooking range will be operated by personnel and therefore a solution that reduces ambient oxygen would not be suitable
3) We have assumed that the cooking range is not in an enclosure with gaseous extinguishing media retaining capability
4) We have assumed that there is a water supply as this is a food preparation environment

Notes
1) A risk assessment should be undertaken to determine whether the benefit of sprinklers in the vicinity would outweigh risk that might be posed as a result of, for example, water spray being applied to cooking oil in deep fat fryers
2) LPC Rules sprinkler systems may provide some benefit by providing a level or protection, however they would not normally be the first choice for protecting a specific object as described
3) The sprinkler system is intended to extend throughout the premises with only limited exceptions. [ref BS EN 12845, Introduction]
4) Whilst sprinkler protection may be used to good effect to protect many objects (including ovens, stoves and plant), there are few prescriptive design requirements laid down. As such each design will be somewhat bespoke.
5) Sprinkler protection should not be used in cases where water is an unacceptable media (for safety reasons or where water damage is likely to be at least as severe as fire damage).
6) LPC Rules sprinkler systems can be applied to ovens, stoves and plant. Guidance is somewhat limited but follow it as best you can.
7) Wet pipe installations shall only be used in locations where ambient temperatures in excess of 95 deg C are not expected. [ref BS EN 12845, clause 11.1.1]
8) Upright sprinklers can be less prone to mechanical damage and collection of foreign matter in the sprinkler fittings. As such they may contribute to overall improved levels of system reliability. [ref BS EN 12845, clause 12.1.3]
9) All system installers should be certified
10) Sprinkler systems are generally designed to cope with single fire seats
11) Sprinkler systems will cope well with moderately ventilated conditions
12) If you are considering two or more competing system options, you may wish to try to evaluate the likely reliability of each using this RISCAuthority checklist .

DD 8489-5 - Combustion turbines and machinery spaces with volumes up to and including 80 m3

Notes
1) This approach is not suitable for the circumstances described

Figure 4.8: Example of an output report (report body)

A Fixed Firefighting System Selection Tool, with numerous supporting informative and educational resources has been developed and is now available[1].

[1] The current version of the tool (version 1.10 at the time of writing) can be access freely at the following internet address: http://xpr.riscauthority.co.uk/xraoutput/main.html

4.2.9 TASK 9: SYSTEMS MAINTENANCE AND UPKEEP CONSIDERATIONS.

The derived development environment and means of development closely adhere to the 12 principles of Agile Software Development (Beck et al., 2001). In particular the first "our highest priority is to satisfy the customer through early and continuous delivery of valuable software" (Beck et al., 2001). The development environment allows very efficient alternation to the FFSST to be made, by a suitable competent and skilled 'knowledge engineer'. This flexibility will greatly assist with system maintenance and upkeep, which will from time to time be necessary. For example, when an underpinning standard (or source of knowledge) changes in a way that affects the FFSST, it will be possible to update as necessary.

All the time the tool is to remain published and available for use, it ought to be incumbent upon the publisher to manage the ongoing validity of the tool. That is to say some kind of process should be initiated in order that any relevant changes to underpinning knowledge can be detected and acted upon as appropriate. Otherwise the recommendations and information provided by the tool may no longer represent appropriate practice.

4.2.10 TASK 10: EVALUATE RESEARCH FINDINGS AND PROGRESS ACHIEVED

Consistent with the two different approaches adopted at stages during the research; Rapid Application Development and Action Research, evaluation of different aspects of the research has occurred at different stage of the project, to ensure sound incremental progress is achieved. Many of the strands (or tasks) of research have served as a form of feedback-loops, each serving to cross-check the validity of each other to a degree. As such, much of the evaluation and validation work was continuous and in-built in to the research process. The following subsections explain in more detail some of the evaluation steps undertaken:

4.2.10.1 Literature review

The literature review served to ground much of the research in established and published fact or current best practice. Throughout the research critically review and the experience of the industrial sponsoring organisation (the Fire Protection Association) was used to identify literature (or sections within literature) which was considered of sufficient integrity and quality to be used as authoritative source material upon which to found further work. Much of the literature used in the research is identified in section 2.4 and Table 4.1. Parts of this literature (and other literature referenced elsewhere throughout this thesis and the published papers: Paper 1 in Appendix A; Paper 2 in Appendix B; and Paper 3 in Appendix C) have been used as the basis for the development of the decision support system and related supporting resources. In addition to the critical review, drawing upon the experience of the industrial sponsoring organisation in eliciting the required knowledge, the tool itself, outputs and supporting resources have also been the subject of further external and independent evaluation steps, such as those detailed in the remaining sub-sections of this chapter.

4.2.10.2 Questionnaire

A survey questionnaire was selected as a means of participatory consultation in order to engage with a larger number of parties with interest and experience relevant to the research project. The full questionnaire and responses can be seen in Appendix G. The survey questionnaire was considered a means by which to inform and validate key aspects of the evolving research. It was compiled using internet based tool Bristol Online Surveys (BOS). The survey aimed to ask a broad range of questions all intended to help with the process of gathering background information and validating the research. It was targeted at those with expertise and experience in the area of fixed firefighting system selection. Participation was widely invited via a variety of means, including the following:

- Existing network of relevant business contacts;
- Via trade associations and organisations:
    - Risk Engineers Data Exchange Group (REDEG);
    - British Automatic Fire Sprinkler Association (BAFSA);
    - Fire Industry Association (FIA);
    - RICS building control professional group; and
    - Building Research Establishment (BRE).
- Via ‘Social networking’ website LinkedIn groups:
    - National Fire Protection Association (NFPA);
    - Society of Fire Protection Engineers (SFPE);
    - Fire Industry Association (FIA);
    - Centre for Innovative and Collaborative Construction Engineering (CICE); and
    - Underwriters Laboratories (UL)'s Global Fire Service Leadership group.

A total of 64 responses were received, which exceeded the ambition of achieving 50 responses (a figure arrived at by estimation and considering the degree of specialism of the subject area). Responses were received from the following groups: Building Control Officer, Fire Engineer, Fire and Rescue Service, Organisational risk manager, Project Manager (Design and Build Contractor). Other notable self-identifying groups were recorded: Insurance Surveyors and Consultants.

When asked “Do you think the proposed Active Fire Protection System Selection Tool will be useful?” Questionnaire respondents 55 (86%) out of a total of 64 responses replied ‘yes’, 5 (8%) replied ‘no’ and 4 (6%) replied ‘other’. Examples of remarks received back include (when asked the open question “Do you think the proposed Active Fire Protection System Selection Tool will be useful?”): “*Depends on its effectiveness*” [a fair comment], “*Maybe. It* *may cause problems by selecting a system that is adequate - but more expensive than an alternative system which is also adequate. Also, there are so many notes and appendices associated with all standards that keeping this tool up to date could be problematic. Will this consider just LPC or will it include FM, NFPA, APSAD, VDS etc..?*" [Highlighting the need to consider cost and benefit (see the work of section 4.2.6.2)], "*Possibly, but it should not be used as a substitute for experience*" [highlighting the need for suitable instructions and disclaimers], "*Providing recommendations are always to use third party certified systems. to ensure system is to an industry recognised standard.*" [Highlighting the need to consider reliability (see the work of section 4.2.6.3)]. It is believed this demonstrates a good level of support for the idea and the qualified responses all make valid points.

The questionnaire results were particularly useful in: identifying likely system users, technologies the FFSST should seek to provision for, validation of the need for and support for the work. The full questionnaire responses can be seen at Appendix G.

4.2.10.3 TB234 Protection of High Hazard Storage (HHS) configurations

One of the substantial information sources created as part of this research in order to address an identified knowledge gap (as per section 4.2.4 "Task 4: Identify and address gaps in knowledge") is TB234 Protection of High Hazard Storage (HHS) configurations (reproduced in full Technical Output 1 at Appendix D). The identified need for the work of "TB234 - Protection of High Hazard Storage (HHS) configurations" in connection with this research was recorded in (Bird et al., 2012). Subsequently this 47 page technical standard supplement has been authored (with input from a small sub-committee of experts by a series of meetings). It was extensively peer-reviewed by experts from the fire protection industry and published February 2014. It now forms part of the widely used firefighting system standard "LPC Rules for Automatic Sprinkler Installations - Incorporating BS EN 12845" (FPA, 2014b). It also contains much material which forms a useful information/education/standard resource which has been signposted to in relevant circumstances from the FFSST. In such circumstances, this resource provides detailed guidance upon design aspects of protection of HHS occupancies. The process of drafting this document has re-enforced that there is only one FFS technology currently considered suitable for this application (protection of HHS), and this resource may help to clarify this to users of FFS protection.

It has also been submitted to CEN (European Standardisation committee) for consideration for adoption in future editions of EN 12845 (the British and European sprinkler standard).

4.2.10.4 IQ1 Water Mist Questionnaire: Building Protection

Other of the significant information sources created as part of this research, already having an impact and which much feedback has been received upon is IQ1 interactive “Water Mist Questionnaire: Building Protection” (reproduced in full Technical Output 2 at Appendix E). This questionnaire was developed to allow a more detailed ‘audit’ and investigation of the suitability of proposed firefighting systems. It seeks to gather information on design, quality and anticipated performance of water mist systems. It was peer reviewed by a panel of insurance risk managers (subject matter experts) and has been published since 2011. Since its publication it has been well used. Feedback received can be summarised as follows:

- Insurance risk managers have been finding it extremely useful as a tool to help them investigate and articulate why certain proposed FFS solutions are less suitable than others for particular circumstances;
- Some system suppliers have been protesting that it is difficult to answer some of the questions and that they perceive this is hindering their ability to sell systems. Each such case has been taken seriously and investigated thoroughly. After all if such a

claim were found to have substance; it could be considered anti-competitive and therefore illegal. The fact that no such case has yet been found to have substance is cited as evidence that the initial drafting and peer review work was effective and the document is both reliable and valid, and;

- The document and its underpinning principles have been shared freely with British Standards Institution committees responsible for maintain and draft FFS standards as it is believed it would be of considerably benefit the quality of the output of these committees. Several of the principles (e.g. that components to be used in FFS ought to be specified and third-party certified) of the document have been accepted by the committee and are being incorporated in documents currently being updated e.g. DD 8489 Water mist series (BSI, 2011b).

4.2.10.5 Active Design Review of the FFSST

Previous work (Bird et al., 2012, Bird et al., 2013) and section 4.2.5 of this thesis has identified and reported the user groups that are either expected to benefit directly or indirectly from the FFSST (users, benefactors). In order to keep the evaluation activity to a size considered reasonable, a limited number of groups considered likely to have well-informed opinions from a range of perspectives were targeted as evaluators.

Concluding the final loop of the research spiral, an active design review approach (as explained in section 3.3.8) was utilised for this part of the evaluation. The parties and the rationale behind the decision to include them in this detailed evaluation step is outlined in Table 4.5.

Table 4.5: Evaluator credentials and selection justification

Individual	**Organisation**	**Justification and expertise**
Senior Risk Manager (22 years related experience)	Insurance provider	As part of any insurers risk management strategy, fixed firefighting systems are one of the risk management tools available to the insurer to help manage their financial exposure in respect of fire losses. Risk Managers are therefore very familiar with numerous fire risk scenarios. Risk Managers are expected to have good awareness of the overall suitability of recommendations from the FFSST in an insurers risk mitigation context.
Risk Manager (18 years related experience)	Insurance provider	
Fire Safety and IRMP Advisor (33 years related experience)	FBU (Fire Brigades Union)	FBU have a broad range of experience in the subject area, from field experience (firefighting), fire prevention and fire engineering. They are therefore seen as a stakeholder that may bring several dimensions of experience (that of a first responded to fires, approving authority and fire engineer) to the tool evaluation process.
Technical Director (>20 years related experience)	The Fire Protection Association	*** Declaration of interest *** the fire protection association is the Industrial sponsor of the research. However input from the Technical Director is considered indispensable because of his subject area knowledge. Critical feedback was found to be useful in the evaluation.
Secretary General and Director (40 years related experience)	BAFSA (British Automatic Fire Sprinkler Association) and LPC Consultants	BAFSA is a trade association for installers of sprinkler and other fire protection equipment. The Secretary General has extensive industry experience and is recognised as an expert in the field of fixed firefighting system selection and specification. He is therefore considered a source of potentially deep expertise in the underpinning knowledge incorporated into the tool.

The identified parties were invited to participate in the evaluation. Once it had been established that they wished to do so and gave informed consent for their feedback to be used, they were given access to the FFSST (version 1.09) and some guidance upon the intention of the evaluation process. The process was:

- Introductory correspondence;
- Invitation to provide feedback (either by writing, meeting or telephone interview) based upon interaction with the tool;
- Recorded feedback and tracking of actions arising (i.e. completed, to be completed or to be deferred to a future development cycle), and;
- Optionally, an interview (telephone or face-to-face) to allow exploration of points in more depth.

Examples of feedback received are summarised in Table 4.6. The feedback was analysed and grouped into three categories:

- Validation (or comments in support of the work and progress achieved);
- Critical feedback giving rise to improvements which have been implemented, and;
- Critical feedback which it is currently impractical to undertake and must be deferred beyond this phase of work.

The FFSST that has been created will allow considerable further development (to the point where in theory it could seek to aim to capture all current and emerging knowledge in the subject domain). As such feedback received includes many more ideas than it is currently practical to pursue (examples of which are included under deferred actions).

Table 4.6: Examples of feedback received (summarised)
Feedback in support of the work: • "I would find it a useful tool, especially because it signposts me to the appropriate standards and guidance" • "The tool is looking good and beginning to contribute to supporting the needs of the Industrial sponsor" • It was reported that the FFSST loaded and operated correctly on various Microsoft Windows and Mac OS machines
Critique of the work and improvement actions arising: • Fault with logic associated with "Gaseous Halocarbon Systems" identified and rectified by alteration to the logic tree (see Figure 4.9 and Figure 4.10). • Where possible (where copyrights and permissions permit), the external informative resources were obtained and placed in the 'Assets' folder of the Tools website. From here they can be obtained by the user with a single click (rather than having to register or log-in to view external resources). • Further explanation of 'HV equipment' (voltage thresholds) would be helpful. "IEE wiring regulations" definition added (Institution of Electrical Engineers., 2011). • Note added to FFSST output to inform user of the possibility of HF production from the use of FK-5-1-12 (BSI, 2008d) extinguishant.
Critique of the work and deferred actions arising: • Optimise GUI for multi device use (i.e. tablet devices in addition to personal computers). • Further develop the meaning, explanation of and philosophy behind terms used: property protection, life safety and business continuity. • One glitch with a graphic placeholder was reported, but this could not be replicated. No further action to be taken at this time. • A new detailed case study (a radioactive sterilisation bunker) was offered for consideration and incorporation into the tool. • The tool could seek to take over the function of the design and installation standards that it currently signposts to. The value in doing this would be that errors of interpretation (reported as frequently encountered) could be irradiated or reduced. Whilst this may be a valid ambition, it is significantly different ambition to the scope of this work.

Illustration of the process of adjusting logic in a decision tree for maintenance purposes or in response to feedback can, for example, be seen in Figure 4.9 (before adjustment) and Figure 4.10 (after adjustment). In this situation (the circumstances (or input data) are described in Table 4.7) the intention is to alter the FFSST recommendation from 'Red' to 'Amber'.

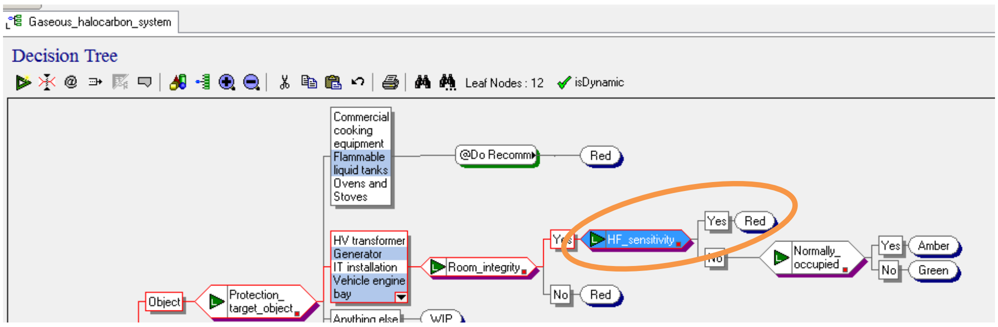


Figure 4.9: Compiler view (before Modification):

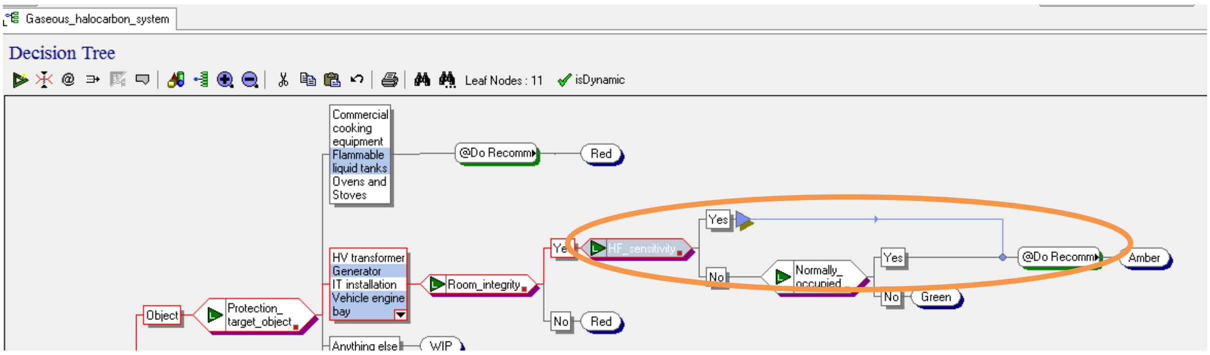


Figure 4.10: Compiler view (after Modification):

Table 4.7: Input-output data capture in fault remediation

Question	Response
What is the type of protection?	Object
What is the protection target?	IT installation
What level of protection are you seeking to achieve?	Property protection
Is the object to be protected in an enclosure with a sufficient level of integrity to maintain the firefighting or prevention media?	Yes
Does the protected space contain anything (such as people or equipment) sensitive to Hydrofluoric acid (HF)?	Yes
Is there any reason why low oxygen levels might not be suitable?	Yes
What is the firefighting objective?	Extinguishing
Is the space to be protected ever occupied by people?	Yes
Are the contents of the building (or equipment to be protected) compatible with water?	No
Are 'deep seated' fires expected?	No

4.3 SUMMARY

Supported by this research, a Fixed Firefighting System Selection Tool, with numerous supporting informative and educational resources has been developed, evaluated and is now available[2].

[2] The current version of the tool (version 1.10 at the time of writing) can be access freely at the following internet address: http://xpr.riscauthority.co.uk/xraoutput/main.html

5 FINDINGS AND IMPLICATIONS

This chapter presents and discusses the key findings and implication of the research.

5.1 THE KEY FINDINGS OF THE RESEARCH

In pursuit of objective 1, a broad range of sources were reviewed which served to provide evidential background to the problem. Current sources of knowledge and commonly used fixed firefighting system design approaches were identified. It was found that there has been a recent proliferation of design approaches for potential fixed firefighting systems for the mitigation of fire risks in buildings and equipment. Accompanying this trend, there has been observed to be increasingly overlapping ambitions in terms of scope of application of some FFS types. Yet, this research has confirmed it is unreasonable to consider that competing fixed firefighting system technologies are likely to be equal in terms of the benefit they offer.

Through the knowledge review processes necessitated by this research, considerable gaps in fixed firefighting system design, specification and performance knowledge were identified. Where necessary and possible, these gaps have been filled by this research (for example, in addition to the FFSST itself, see the resources created and incorporated into the tool listed in Table 4.2).

Aside from the knowledge gaps identified by this research, in some cases, decisions about fixed firefighting specification and selection are made before the details of the occupancy of a building (and therefore the characteristics of the risk) are known, as highlighted by the study by CEBR (2014) and the experience of the industrial sponsor. Whilst this research and its outputs cannot solve this supply-chain problem, by promoting awareness upon fixed firefighting system selection best practice, in time it may help to further expose this part of the problem. Given the magnitude of losses which can be experienced when a Fixed Firefighting System does not perform satisfactorily, even a single positive intervention by the tool could make millions of pounds worth of savings in terms of improved fire outcomes.

In pursuit of objective 2, to assess current practice of selecting the most suitable FFS with a view to understanding the decision processes that lead to the selection of FFS, it was found that at the heart of this research is the problem of selecting optimally performing fixed firefighting systems for a variety of given circumstances. Optimal performance (or cost-benefit optimisation) breaks down in to several constituent parts: system purchase and installation costs, cost of ongoing maintenance, negative aspects of having a system (such as unwanted activations and media discharge), opportunity cost and whole life firefighting system performance. FFS design becomes a critical and complex part of the optimisation, particularly in regard to whole life firefighting system performance. Good FFS design specifications should consider: the ability of a system to fight a fire, comprehensive description of the limits of application and the expected reliability of a system. Some of the more recent initiatives to market newer FFS technologies have focused too heavily on satisfying a perceived important requirement; to demonstrate in a laboratory the ability to fight a fire. However, through necessity to keep research and development costs down, newer technologies may be ignoring arguable more important whole life considerations, such as reliability and maintainability. By contrast, the foreword to the LPC Rules for Automatic Sprinkler Installations (FPA, 2010) records that the first set of sprinkler rules was composed in 1885 and has continued to evolve through research and development ever since. Such established and mature technologies have addressed most of these aspects through decades of operational experience in a competitive marketplace.

Objective 3, to develop and evaluate a tool to help improve fixed firefighting system selection has been achieved. A fixed firefighting system selection tool and supporting sources of informative material in a variety of media and formats have been developed and are now available[3]. The FFSST seeks to assist the user by helping with the decision making process and providing useful information throughout the process. A variety of largely heuristic techniques have been used to aggregate data, form knowledge and to underpin the FFSST in its current state of development. The FFSST in this form has been validated by experts as being a useful resource. The FFSST also provides ample opportunity for useful ongoing future development.

Objective 4 was to make recommendations for future developments, which are reported in section 5.5.

5.2 CONTRIBUTION TO EXISTING THEORY AND PRACTICE

The research has been greatly assisted by the unparalleled access to experts afforded by the role of the industrial sponsor, the Fire Protection Association. The research has delivered an applied example of knowledge management in the form of the decision support or expert system (the FFSST). Several new supporting resources have been created and the body of knowledge in the subject area has been further developed. Notably the publication TB234 Protection of High Hazard Storage (HHS) configurations. This important addition to a well-used document will now make a significant positive impact upon the fire protection industry,

[3] The current version of the tool (version 1.10 at the time of writing) can be access freely at the following internet address: http://xpr.riscauthority.co.uk/xraoutput/main.html

by improving protection practice in this area. This new technical resource adheres to the applicable principles of the key findings of this research; that all the constituent parts of FFS optimal performance must be addressed in achieving good FFS design specification. Since its publication "TB234 Protection of High Hazard Storage configurations", which can be seen in Appendix D, Technical Output 1, (Bird, 2014b) has also been submitted to CEN (European Standardisation Committee) for consideration for adoption in future editions of EN 12845 (the British and European sprinkler standard).

"IQ1: Water Mist Questionnaire: Building Protection" (at Appendix E, Technical Output 2, (Bird et al., 2011a)), has been well used since its publication. Feedback received by the Fire Protection Association is that the resource has been well used and that it is extremely useful in providing efficient means by which to identify a broad range of design, specification or potential performance shortcomings of some proposed fixed firefighting systems. This gives users the opportunity to address these shortcomings or consider an alternative approach to providing protection. It is now additionally made available as a resource for users from within the FFSST. This resource has been used as primary source of reference in developing material which had been submitted to BSI in support of committee standard drafting activity in relation to the DD 8489 (Water Mist) series (BSI, 2011b).

5.3 IMPACT ON THE SPONSOR

The business of the sponsor is to affect loss prevention. This is achieved by production and dissemination of information and advice through a variety of means. Uptake is critical to the effectiveness of all of the organisations' initiatives, therefore innovative and contemporary means to achieve maximum impact are always sought. A virtuous circle effect can be established; the better the advice (quality, form and efficiency) the more benefit can be realised and thus by reputation and experience uptake improves.

The progress achieved, understanding gained and outputs of this research (an exciting, innovative, rigorous and very efficient means to access a broad range of information in a complex domain) have a strong alignment with the objectives of the sponsoring organisation and its stakeholders. A resource has been created, which makes a considerable contribution to the loss prevention aim and can support further incremental development. In the short term, the FFSST has been created along with supporting resources and this can offer considerable benefit to users of fixed firefighting systems when they are faced with a choice of types of systems. In the medium term, the progress achieved by this research is expected to increase awareness of the expected inequality of fire outcomes likely when comparing some types of fixed firefighting system in similar applications. It is also expected that it will highlight the remaining gaps in supporting information required to support some of the newer entrants to the fixed firefighting system market on an equitable basis. In the short, medium and longer term, having identified these knowledge gaps, it is expected that it will then become possible to seek to address these gaps by improving supporting design and specification resources. It may also be advantageous to amass, analyse and react to the findings of real-world fixed firefighting system performance data.

While the tool is to remain published and available for use, it will be necessary for the ongoing validity of the tool to be maintained. It is recommended that a process should be initiated in order that any relevant changes to underpinning knowledge can be detected and acted upon as appropriate. Otherwise the recommendations and information provided by the tool may no longer represent appropriate practice. This could have detrimental impact upon reputation, fire outcomes where fixed firefighting systems are a factor and the tool has been used and perhaps associated liabilities. The industrial sponsor wishes the tool to continue to be supported and is currently investigating the feasibility of providing such support. Further, the industrial sponsor is also seeking to apply some of the knowledge management techniques developed in this research to other of its information disseminating activities.

5.4 IMPACT ON WIDER INDUSTRY

The identified fixed firefighting system selection problem is of interest and importance to several identifiable groups: insurance surveyors and risk managers, organisational risk managers, fire engineers, consultants, project managers, building control officers, fire and rescue services, standards setting organisations and FFS equipment manufacturers and suppliers.

Given the increased number of FFS designs being offered in the market place, insurers (particularly surveyors and risk managers), building control officers, fire and rescue services and standards setting organisations are increasingly faced with proposed fixed firefighting systems, which they are uncertain about the suitability of for any given application. Insurers and regulators (who are to some extent supported by the activities of standards setting organisations) must balance their need to manage risk to the greatest extent reasonable practicable with the need to ensure they do not engage in practice that unduly affects markets and competition. Thus, they require robust technical information upon which to base their fixed firefighting system selection requirements. This is both to ensure protection specified is fit for purpose and provide a reasonable technical justification for excluding certain FFS types, if they are indeed unsuitable choices. The developed tool responds to these needs in a number of ways; it advises upon suitable FFS selections and provides a variety of supporting information in the process of doing so.

Similarly, organisational risk managers, fire engineers, consultants, project managers, FFS equipment manufacturers and suppliers all have a delegated duty (stemming from the Regulatory Reform (Fire Safety) Order (HMSO, 2005), Companies Act (HMSO, 2006) and also perhaps terms of insurance) to ensure that the best reasonable practical fire risk management practice is adhered to. So they also require robust technical information upon which to base their FFS selection decisions. The tool makes considerable progress in addressing these needs.

For all these user groups, the development of the tool and related supporting resources provides considerable additional material upon which these identified industry groups may draw when considering the suitability of a fixed firefighting system for an application. The research has confirmed that where Fixed Firefighting Systems are a feature, without adequet protection losses are likely to be considerable. It is expected that the tool will improve selection practice and even a small number of improvements in practice could lead to improved outcomes and the avoidance of millions of pounds of loss.

5.5 RECOMMENDATIONS FOR INDUSTRY AND FURTHER RESEARCH

5.5.1 RESPONSIBLE STANDARDS DEVELOPMENT

It is recommended that there should be a moratorium upon development of standards by authoritative bodies which in effect promote inferior or less mature FFS approaches. Owing to the standing of the authoritative bodies, and their publication of such standards, technologies may appear to the unwitting layperson to be equal. Such development activities should only be condoned when there is sufficient commitment to develop competing technologies to at least the same readiness levels as established approaches. Alternatively, such documents should be accompanied by abundantly clear disclaimers that such technologies may not be equal to those they are competing against.

5.5.2 FFS Performance data

Truly meaningful FFS selection advice can only be given when more is known about the comparative cost-benefit of competing FFS technologies. Therefore it would be highly desirable to have such credible and independent data collected analysed, processed and made available in the public domain. Firefighting System performance data would further inform the selection process and move industry beyond the theoretical model proposed to a position of using real data about genuine system performance and the impact upon outcomes. Performance (or reliability) data would also be fundamental underpinning data required to undertake a credible CBA, which ought to be a feature of a comprehensive selection exercise.

5.5.3 Limitations of documented knowledge

There are many scenarios, for example those listed in BS 5306-0 “Guide for the selection of installed systems and other fire equipment” (BSI, 2011a), which are not yet featured in the FFSST. These scenarios could be independently reviewed (for example by a balanced working group of experts, to moderate and ensure independence and rigor) and where there is sufficient experience of their use and consensus, additional hazard scenarios could be incorporated into the tool. This is considered to be a potentially worthwhile undertaking, as it would continue to expand the scope and usefulness of the FFSST, albeit one requiring considerable further ongoing effort.

5.5.4 FURTHER OPTIMISATION OF THE FFSST ITSELF

There is no shortage of opportunity for improving the FFSST further. It could be optimised for multi-platform (desktop computer and tablet computer) use. The development environment chosen already supports several other popular platforms (such as smart phones and tablet computers). With more time spent upon development, this capability could be exploited in an attempt to reach more users and enhance the usability of the offering. The richness of the graphical user interface could be further improved. Question-flow and logic could be optimised further.

The research achieved, as well as developing a tool, has developed a framework in which further development could take place. This framework would be well suited to receiving input from a community of experts (via forums or various of the options now facilitated by internet connectivity). Such input, with appropriate moderation, could prove to be an efficient way to gather intelligence to identify maintenance issues and drive forward development.

As a further step, supported by improved subject domain data, decision logic could be enriched by seeking to move from heuristically derived underpinning knowledge to knowledge improved by further inclusion of cost-benefit analysis and performance (or reliability) data.

5.6 CRITICAL EVALUATION OF THE RESEARCH

5.6.1 THE FFSST

The work to evaluate this research has validated the FFSST in its current form and the foundations of the work. Evaluation determined that the FFSST now serves as a useful and valuable resource. The evaluation process itself generated a high level of further interest in the work and perhaps the most heartening aspect of which was the plethora of ideas for improvement, enrichment and further development that were forthcoming at all stages.

A largely heuristic approach has been used in developing the rules and logic used in the FFSST. The research work has identified that there are theoretical opportunities to advance beyond a heuristic approach in some areas, by for example, developing supporting cost-benefit and performance (or 'reliability') models and incorporating them into the FFSST (see recommendation 5.5.2).

5.6.2 SUPPORTING RESOURCES

Supporting resource "TB234 Protection of High Hazard Storage (HHS) configurations" (at Appendix D, Technical Output 1, (Bird, 2014b)) was extensively peer-reviewed by experts from the fire protection industry and recently published. It now forms part of the widely used firefighting system standard "LPC Rules for Automatic Sprinkler Installations - Incorporating BS EN 12845" (FPA, 2014b). It also contains much material which forms an ideal information/education/standard resource which has been signposted to in relevant circumstances from the FFSST.

Similarly "IQ1: Water Mist Questionnaire: Building Protection" (at Appendix E, Technical Output 2, (Bird et al., 2011a)) has been peer reviewed by a panel of insurance risk managers (subject matter experts) and published since 2011. Several of the principles (e.g. that components to be used in FFS ought to be specified and third-party certified) of the document have been accepted by the committee and are being incorporated in documents currently being updated e.g. DD 8489 Water mist series (BSI, 2011b).

5.7 CLOSING REMARKS

This research finds that the perceived problem of fixed firefighting system selection has been confirmed as being founded. It has been found that the selection problem, at least in part, may stem from the transition which has occurred; from a niche, tightly regulated sub-sector within the fire protection and construction industries to the current less prescriptive framework. In the case of FFS selection, difficulty arises in part due to a proliferation of new technological approaches to FFS being marketed at areas that were traditionally, generally (but not without exception) well served by only a few technology types. In this transition, the resources required to support the newer technologies are poorly developed or absent at this time. Another part of the selection problem is the apparent difficulty that arises in appreciation and comprehension of the issues surrounding optimum FFS selection criteria. Whilst critical systems are not unusual and in such cases performance and consequence are capable of being well understood (e.g. aviation, nuclear industry) FFS are perhaps more unusual (but not unique) in that they are associated with low probability high consequence events and a critical system with low probability of use. This poses a number of design challenges in its own right. Furthermore, gathering performance data in order to prove or disprove emerging designs is difficult given the scarcity of fire events which serve to test the technology and absence of reporting mechanisms. Thus, this is an extremely difficult field in which new technology may flourish and be judged with confidence to be equivalent to more historic approaches, with decades of experience of practical use. These are problems that could doubtless be overcome with sufficient research and development activity (performance studies, performance modelling activities, standards writing activity), provided the problems were recognised and there was sufficient imperative to undertake the work. This work makes a contribution to identifying this aspect of the problem.

The insurance industry, which in high risk circumstances, has a business model that is dependent upon FFSs, has a considerable interest is such technology. However in the most part they already have tried and trusted solutions, so lack motivation to fund research in support of advancing new technologies. It is difficult to identify any other significant party with any motivation and substantial enough resource who could seek to adequately address some of the knowledge gaps identified that would need to be filled in order to allow some of the newer technologies to truly be considered equivalent.

If this could be overcome, the situation may improve over time although this could give rise to a new problem; the hypothesis that some of the apparent competitive advantage of the newer technologies may recede once they are established on a more equal footing when compared to historical custom and practice. After all, the newer technologies identified by this work are generally more complex systems. If they were sold on an equal footing, would they remain competitive? This research has found that there is ample opportunity for further research in the area of FFS specification. This additional work could be expected to fill the gaps identified by this work (such as improved knowledge of the performance of newer types of FFS and thus enable further improvements to selection practice to be made.

The main contribution of this research is the delivery of a substantial resource; the Fixed Firefighting System Selection Tool, in an exciting and innovative format. Understanding of the selection problem has been greatly expanded and documented adding to the body of knowledge in the subject area. The work has created several additional sources of education and reference material. The progress achieved is expected to contribute to improved outcomes in respect of fire safety and loss prevention in circumstances where fixed firefighting systems are specified.

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APPENDIX A PAPER 1

Full Reference

S. N. Bird, N. M. Bouchlaghem, J. Glockling, S. G. Yeomans (2012).

Decision Problem Structuring Method for the Specification and Selection of Active Fire Protection Systems.

Proceedings of the 7th International conference on innovation in architecture, engineering and construction. 15th – 17th August 2012, The Brazilian British Centre, São Paulo, Brazil.

Abstract

The UK along with the EU has witnessed a recent proliferation of designs for potential active fire suppression systems for the mitigation of fire risks in buildings and equipment; from five in 1986 (BSI, 1986) to eleven in 2011 (BSI, 2011a). However, each technology remains limited to the protection of certain types of application only, rather than offering a solution to guard against all possible hazards. This trend occurs at the same time as a transition from *prescriptive* to *performance based* standards and against the backdrop of the current *non-prescriptive* regulatory frameworks including the Building Regulations (HMSO, 2010), The Regulatory (fire) Reform Order (HMSO, 2005) and associated guidance (Approved Documents, standards, codes of practice and guides). Hazards can be difficult to assess and describe and the inequality or absence of satisfactory methods is notable in many recently published guidance documents.

Active fire protection systems are installed to meet legislative requirements (to protect life), and / or when identified as appropriate by a cost-benefit analysis (e.g. to achieve risk

reduction for business resilience purposes or to historic assets). There are many guidance documents available to assist users and designers in choosing and specifying appropriate active fire protection. These documents vary in age, relevance, scope, quality, impartiality and suitability.

The Fire Protection Association (FPA) and several leading insurers who participate in its risk management work, have identified the requirement for assistance with the decision making process of analysing fire hazards and matching them to appropriate candidate systems, in order to make informed and impartial recommendations. This has led to the undertaking of a four year research project aimed at developing a decision problem structuring method and a software tool (Expert System), for the specification and selection of Active Fire Protection Systems. The research aim is to develop a tool that will assist users in making an informed selection of a system that is likely to best suit their needs and thereby contribute to overall improvements in fire safety and outcomes. This paper presents a summary of the work to date, focusing on the demand for the work, development of the methodology and practical application of the emerging Expert System.

1 INTRODUCTION

1.1 BACKGROUND

There are a variety of sources that report the financial and societal cost of fire within the UK. The Association of British Insurers (ABI) in its' paper "Tackling Fire: A Call for Action" (ABI, 2009) estimates the insured cost of fire is £1.3bn. It also reports that 443 deaths and 13,200 casualties were caused by fire in 2007. The UK Government in its' report "The Economic Cost of Fire: Estimates for 2004" (Office of the Deputy Prime Minister, 2006) reports a projected figure of £7.03bn for the cost of fire for the year 2004. The consequence and cost of fire remains significant.

To appreciate the research problem, it is necessary to develop an understanding of two concepts: *Fire safety provisions* and *fire engineering.* These concepts form the core challenge for anyone who seeks to make improvements to fire safety of an object or building. In the context of this paper *fire safety provisions* are defined to mean anything that is done (materially or procedurally) to reduce the likelihood of or consequences from a fire. The Institution of Fire Engineers make the following definition "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" (Institution of Fire Engineers, 2011). The majority of built or manufactured objects and buildings have *fire safety provisions* incorporated within them; Fire guards to protect from open household fires, over-current fuses protecting electrical appliances, use of non-combustible materials, thermal cut-out devices, gas safety shut-off valves, compartmentation in buildings, manual first aid (such as fire extinguishers, fire blankets, hose reels), fire service intervention, active fire protection systems (such as fixed local systems, fixed building systems). These few examples vary in scale, complexity and approach. This project focuses on the challenge of selecting appropriate Active Fire Protection Systems.

1.2 ACTIVE FIRE PROTECTION SYSTEMS

Active fire protection systems (or *suppression* or *extinguishing* systems) are systems which use "the application of agents to control, suppress, and/or extinguish fires" (DiNenno, 2002, p. 3-143). So much the better if this is done in a fashion commensurate with the mitigating need and protection objective. In order to achieve this, they must be selected, specified, installed and functioning correctly in order to provide maximum efficacy, should they be required. Suitability of the selection and design of the system for the application is critical. Points to address include: compatibility of extinguishing media with the construction and contents of the hazard (e.g. water in high voltage electrical installations can be problematic, gas in insufficiently sealed enclosures will be ineffective, etc.) Installation and maintenance are also critical; poor standards often adversely impact upon the reliability of the system and probability of success against the design objectives.

Other fire safety provisions such as passive fire protection, smoke control systems, fire detection and alarm systems may also have an impact upon performance of active systems (and vice versa). For example, the effect of interactions on smoke venting systems and sprinkler systems has been extensively studied with the objective of optimising complex building (e.g. shopping centre) tenability to occupants (public and Fire and Rescue Service personnel) during a fire and evacuation (Morgan et al., 1999). It is also proven that gaseous systems must be able to hold extinguishing agent at the requisite concentration for a specified period; this necessitates a controlled relationship between enclosure integrity, quantity and release rate of media. Active fire protection systems are part of a range of tools available to those seeking to manage risk from fire. Because of their additional cost and complexity they tend to be incorporated in to more complex designs or higher risk/consequence scenarios.

1.3 SYSTEM SELECTION CHALLENGES

The UK and EU has witnessed a recent proliferation of different types and designs of potential active fire suppression systems for the mitigation of fire risks in buildings and equipment. This has coincided with a move from prescriptive to performance based standards for example; the BS 5588 series (BSI, 1990) was replaced by BS 9999 (BSI, 2008a) . It also forms the backdrop of the current 'non-prescriptive' regulatory frameworks; including the Building Regulations (HMSO, 2010) and associated guidance such as the Fire Safety Approved Document B (DCLG, 2007), the Regulatory Reform (Fire safety) Order (HMSO, 2005) and by extension BS 9999 (BSI, 2008a) and other standards and guides. At the same time, the number of candidate active fire protection solutions has significantly increased, for example in British Standards' "Guide for the selection of installed systems and other fire equipment" (BSI, 1986) there were five fixed suppression system design standards referenced whilst in the 2011 edition of the guide (BSI, 2011a) there are eleven, yet each technology remains limited to the protection of certain types of hazard only.

Increasingly UK insurers and the Fire Protection Association (FPA) are confronted with fire losses that are greatly exacerbated by the misspecification of extinguishing technology to the hazard and the poor implementation of appropriately selected extinguishing technologies. Hazards can be difficult to assess and describe as attested to by the complexity of the storage risk hazard evaluation method in LPC Sprinkler Rules (FPA, 2010) and the notable absence of equivalent methods from other system standards.

Field experience, supported by the BRE Global's guide titled "Sprinkler installation standards and rules" (BRE Global, 2009) indicates that active fire protection systems are installed mostly; to meet legislative requirements, or to achieve risk reduction for business resilience purposes. To aid users of suppression technologies there are many standards, guides and documents intended to assist in choosing and specifying appropriate active fire protection. These documents vary in age, relevance, scope, quality and suitability. Typically they are commissions by various parties: national or international standards bodies, such as the International Standards Organisation (ISO), the European Committee for Standardization (CEN), national standards setting bodies, or trade associations. Alternatively they may be product of certification bodies, such as the BRE Global, the Loss Prevention and Certification Board (LPCB), the FM Global or commercial organisations such as risk sharing user groups or system suppliers. All are authored by committees, groups or individuals with varying levels of independence.

Aside from the system design and installation standards identified in section "Knowledge Management" which are discrete to their technology of application; there is little useful material published offering guidance upon the selection of competing active fire protection systems. Two notable publication are the BSIs "Guide for selection of installed systems and other fire equipment" (BSI, 2011a)and PD 7974-4 (BSI, 2003a). However these documents are of limited use as they offer no quantitative information relating to system performance and little in the way of guidance upon suitability or otherwise for any given application. In the absence of this information, it remains unclear to the user whether different systems offer the same level of reliability and performance or not.

There is limited comparative performance or reliability data on such systems. The most comprehensive studies conducted to-date has been undertaken by the American organisation the National Fire Protection Association (NFPA). Their work (Hall, 2008, Hall, 2010) is mostly limited to studies on Sprinkler Systems and to a much lesser extent Gaseous Systems. In addition to this limited scope there is another problem with the dataset; due to the jurisdiction of interest to the NFPA, the systems they have studied would have tended to have been design and built to the installation standard NFPA13 (NFPA, 2010, NFPA, 1996) or the version appropriate to the year of installation. There are many other studies published that focus on very specific aspects of system performance such as the “Halon Alternatives” report (The Loss Prevention Council, 1996). With the phase out of Halon gaseous extinguishing agents, this work sought to compare the firefighting efficacy of a number of alternative gaseous extinguishing agents.

Until recently, the scarcity of this type of information was not a significant problem as there was little competition between the fewer technology types (the suitability of each was generally easily discernible). However as noted above, since then other technologies have emerged where there is considerable overlap between claims made about application suitability, without the support of mature and comprehensive national standards. For example DD 8489 series (BSI, 2011b) exists without any companion ‘component’ standards, thus the specification, quality and reliability of such system components is not assured to the same extent as it is in the case of Gaseous Systems to BS EN 15004 (BSI, 2008b) (utilising components to the BS EN 12094 series (BSI, 2003b)), Sprinkler systems to BS EN 12845 (BSI, 2009a) (utilising components to the BS EN 12259 series (BSI, 1999)), foam systems to BS EN 13565-2 (BSI, 2009b) and components to BS EN 13565-1(BSI, 2003c), etc.

There are various sources of evidence in relation to fire and consequence, with varying degrees of applicability to the Europe and particularly the UK. These include:

- UK Government and Fire and Rescue Service Statistics (DCLG, 2011)

- US (NFPA) data (Hall, 2008, Hall, 2010)
- FPA Large Loss Database (FPA, 2011)
- World fire statistics, The Geneva Association (Woodrow, 2011)
- Legal case rulings (various, details follow)

In the UK the government collates statistics. Summaries of this dataset are periodically reported in the “Fire statistics monitor” series (DCLG, 2011). This dataset is not reported in sufficient detail to allow any observations about Active Fire Protection Systems reliability or performance to be made.

In the US, a significant Fire Protection system reliability study by National Fire Protection Association (NFPA) (Hall, 2010) was found only to contain reliability and effectiveness estimates on sprinkler systems and chemical systems. It reports that the available data set for other types of system is too small to support estimates of reliability and effectiveness. This appears consistent with prevalence and numbers of system types installed in the field. In his 2008 summary, Hall on behalf of NFPA presents the following reliability figures (Hall, 2008); all sprinkler systems 90%, broken-down in to two system types; wet-pipe (most common) sprinklers 91 % reliable and dry-pipe (less common) sprinklers 83 %. The main reason for sprinkler systems not operating were found to be as a result of the water supply being turned off prior to the fire starting (typically due to maintenance or inspection). Other reasons found included lack of maintenance, incorrect intervention measures at the time of the fire or inappropriate system for the type of fire. For comparison, figures are given for dry powder and CO_2 systems of 49% and 90% respectively. These figures as reported by Hall in 2008 are based upon 2002 to 2004 US fire department statistics. As noted previously, no such equivalent dataset exists which is directly relevant to the UK experience.

There have been a number of legal cases where Active Fire Protection presence or absence has been subject to legal scrutiny:

- Lord Justices Stuart-Smith Potter Judge in *DEC v HANTS CC* (1997)
- Mr Justice Cresswell in *Gan Insurance v Tai Ping Insurance* EWHC 1210 (1998)
- Lord Justices Chadwick Clarke and Sir Glidewell in *Pride Valley Foods v Independent Insurance* QBENF 1701 (1999)
- His Honour Judge Peter Coulson QC *LMS International v Styrene Packaging and Insulation* EWHC 2065 (2005)
- Lord Justices Brooke Thomas and Jacob *ID & Ors v The Home Office* EWCA Civ 38 (2005)
- Mr. Justice Akenhead in *Fosse Motors v Conde Nast & Ors* EWHC 2037 (2008)
- Mr Justice Patten in *Ansari v New India Assurance Ltd* EWHC 243 (2008)

And one other identified where lack of efficacy due to poor design or specification has been subject to legal scrutiny:

- The Honourable Mr. Justice Coulson in Cadbury v ADT (2011)

All these cases have in common that the recorded judgements make comment on the adverse impact the omission or non-operation of protection had on events and/or critical of the selections of active fire protection technology that were made.

2 PROTOTYPE SYSTEM DEVELOPMENT PROGRESS

2.1 KNOWLEDGE MANAGEMENT

Expert Systems, with their ability to store and reference *knowledge* and act in a fashion akin to that of an expert advisor, were identified as the system type most suitable for this project. Work by Giarratano (1998), Wilson and Welsh (1986) reports that (at that time), many fortune 500 companies were seeking ways to exploit the capability of expert systems. Giarratano goes on to state that this is because they believe "there is substantial commercial value in using machines to emulate portions of human behaviour". Expert systems arise as the result of efforts to automate decision making processes. In order to achieve this, the nature of the data and processes involved must be represented in computer software (Alty and Coombs, 1984). The following (Figure 1) shows the main elements and interaction of a typical expert system. It has been developed by combining figures from Nilsson (1998, p. 281) and Giarratano (1998, p. 3). The key elements of the expert system identified in Figure 1 are described as follows:

- Knowledge base – The part of the system that contains the expert's knowledge. Composed of domain facts and heuristics based upon experience. (Medsker and Liebowitz, 1993, p. 71).
- Inference engine – Processing part of the system that combines knowledge with data.
- Explanation facility – explains the reasoning of the system to the user (Giarratano, 1998, p. 23).
- User interface – the interface with which the user can interact with the expert system. (Medsker and Liebowitz, 1993, p. 70)

Knowledge representation and processing. Knowledge can be encapsulated in a number of ways. It can be encapsulated in rules and objects. A common type of rule is an IF…THEN rule (Alty and Coombs, 1984, p. 19-21, Giarratano, 1998, p. 5). For example “IF the light is red THEN stop” (Giarratano, 1998, p. 6).

2.2 SOURCES OF KNOWLEDGE

The literature review identified many sources of knowledge upon which to base the development of a knowledge management system for assisting in the selection of active fire protection systems. Figure 2 provides a basic illustration of the selection problem and sources of knowledge. The selection task begins with a fire hazard ‘Problem’ (which may or may not have been properly identified). Usually some further work is then undertaken to further describe and understand the hazard, drawing to varying degrees upon recorded and unrecorded knowledge. The process then evolves to the protection specification giving rise to the ultimate solution. Recorded knowledge is typically gleaned from sources such as those identified in Table 1 and other published guides and documents. Unrecorded knowledge is that which tends to be unpublished or more difficult to access, for example the knowledge of experts or knowledge enshrined in ‘custom and practice’.

In order to develop the tool it was necessary to capture relevant knowledge from both recorded and unrecorded sources.

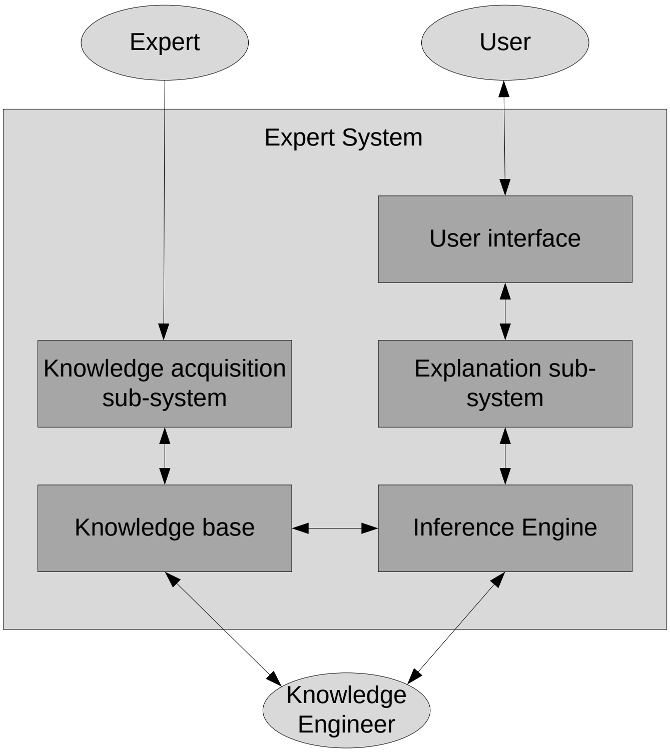

Figure 1 - the main elements and interaction of a typical expert system

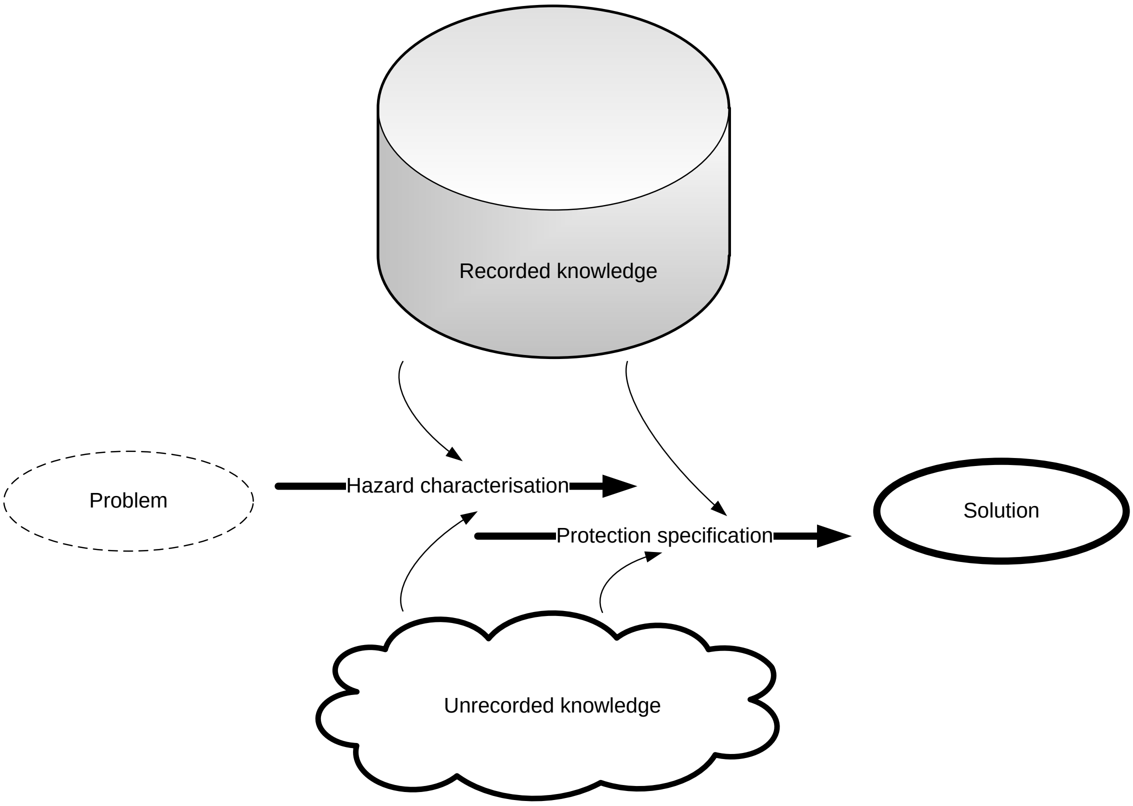

Figure 2 - The selection problem

Several Guidance Documents (Design Standards, Codes of Practice, Guides and other Documents) were identified during the literature review. One of which was BS 5306-0 "Fire protection installations and equipment on premises: Guide for selection of installed systems and other fire equipment" (BSI, 2011a), this, supplemented by sector knowledge of the research engineer confirms the identity of all notable and the most common active protection approaches found in UK. The active fire protection approaches are presented in Table 1 divided by suppression media and then further sub-divided by protection technology description. The third column provides the reference to the de facto standard, specification or document for the UK jurisdiction.

Protection systems by Extinguishing Media	**Protection technology description**	**Standard, Specification or Document (s)**
Water	Industrial and commercial sprinkler systems	BS EN 12845 (BSI, 2009a)
	Industrial and commercial sprinkler systems	LPC Rules (FPA, 2010)
	Domestic and residential sprinkler systems	BS 9251 (BSI, 2005)
	Water spray systems and deluge systems	DD CEN/TS 14816 (BSI, 2008c)
	Domestic and residential watermist systems	DD 8458 (BSI, 2010)

	Commercial and industrial watermist systems	DD 8489 series (BSI, 2011b)
Gaseous	Inert gas and halocarbon agent systems	BS EN 15004 (BSI, 2008b)
	Carbon dioxide systems	BS 5306‐4 (BSI, 2001a)
	Halon. Obsolescent for use in the built environment as outlawed by the Montreal Protocol (United Nations Environment Programme, 2000) and The Environmental Protection (Controls on Ozone ‐ Depleting Substances) Regulations 2002 (U. K. Parliment, 2002) on the grounds of being an Ozone depleting substance.	
Other Chemical	Foam systems (Low, Medium and High expansion systems)	BS EN 13565-2 (BSI, 2009b)
	Powder systems	BS EN 12416-1 (BSI, 2001b)
	Aerosol systems	CEN/TR 15276-2 (BSI, 2009c)
Hypoxic Fire Prevention	Oxygen displacing systems	PAS 95 (BSI, 2011c)

Table 1 – Active fire protection approaches

In the process of developing the first prototype module of the selection tool, limited to one *end user purpose group* (this term is defined in section "system application by 'end user purpose groups'") it became evident that there were many key parameters, limitations or other information essential to the process not recorded in the cited documents. For example:

- Good quality hazard classification (required by all approaches) was only present in BS EN 12845 (BSI, 2009a) and the LPC Rules (FPA, 2010)

- Although widely known, there was a lack of any clear written exclusion of storage from Light Hazard (LH) hazard group in both BS EN 12845 (BSI, 2009a) and the LPC Rules (FPA, 2010)
- Outdated requirements for sprinkler protection design details to suit modern HHS storage configurations in both BS EN 12845 (BSI, 2009a) and the LPC Rules (FPA, 2010).

The first point determines that for all practical purposes of developing this module the rules of the expert system ought to lead only to these documents (BS EN 12845 (BSI, 2009a) and the LPC Rules (FPA, 2010)) as they are the only ones judged capable of adequate assessing the hazard for this module. The second point is remedied for the purposes of the development of this module by simply including this *custom and practice* knowledge in the expert system (much of the knowledge required to overcome these design challenges is known only to experts and not documented in primary UK documents and guides. This type of knowledge is of the type referred to as *custom and practice*). The solution to the third is more complex. In recent years there have been a number of developments which have fundamentally altered the nature of this type of hazard, including:

- Automation of storage systems / stock control / stock picking systems
- Changes to products stored in warehouses (More plastic in goods and packaging and handling equipment ('totes'))
- Anticipated changes to value density of stored goods (i.e. proliferation of small high value consumer goods).

The work of Factory Mutual Insurance Company in the U.S. is perhaps the most advanced as documented in their datasheet “Property Loss Prevention Data Sheets 8-9: Storage of class 1, 2, 3, 4 and plastic commodities” (Factory Mutual Insurance Company, 2011). Much of the practice identified in this document has become adopted by more advanced users on a custom and practice basis (in that it is not formally specified by any of the documentation applicable to the UK or Europe). To formally capture such knowledge a working group was convened with the objective of overseeing the researching and authoring of standard technical requirements to address these issues for the UK. The working group was composed of several insurance risk management professionals and representation from the fire protection design and installation industry. The output of the group is to be published in draft form to allow for peer review by other insurance risk surveyors the fire protection industry and the public. When completed and consensus ("general agreement, characterized by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments" (BSI, 2011d, p. 4)) is achieved, the new requirements would become part of the next edition of the LPC Rules.

2.3 THE PROTOTYPE EXPERT SYSTEM

Having identified all protection technologies currently available and suitable to the project requirements, it was necessary to conduct a systematic review of the intended scope of application of each of the candidate technologies against subdivisions of application. By considering system application by 'end user purpose groups' it was possible to modularise development of the Expert System. 'Application' headings and subdivisions (as shown in Figure 3) are based upon Department for Communities and Local Governments (DCLG) Incident Recording System (IRS). This naming convention is used elsewhere ("The Building Regulations 2010" (HMSO, 2010) and associated guidance "The building regulations 2010 fire safety approved document B" (DCLG, 2007), BB 100 (Department for Education, 2007), LPC Sprinkler Rules (FPA, 2010), BS 5306-0 (BSI, 2011a), BS 9999 (BSI, 2008a)). It is intended that (where possible) using such common vocabulary will assist in the development and maintenance of the system as well as assisting the user to understand the system.

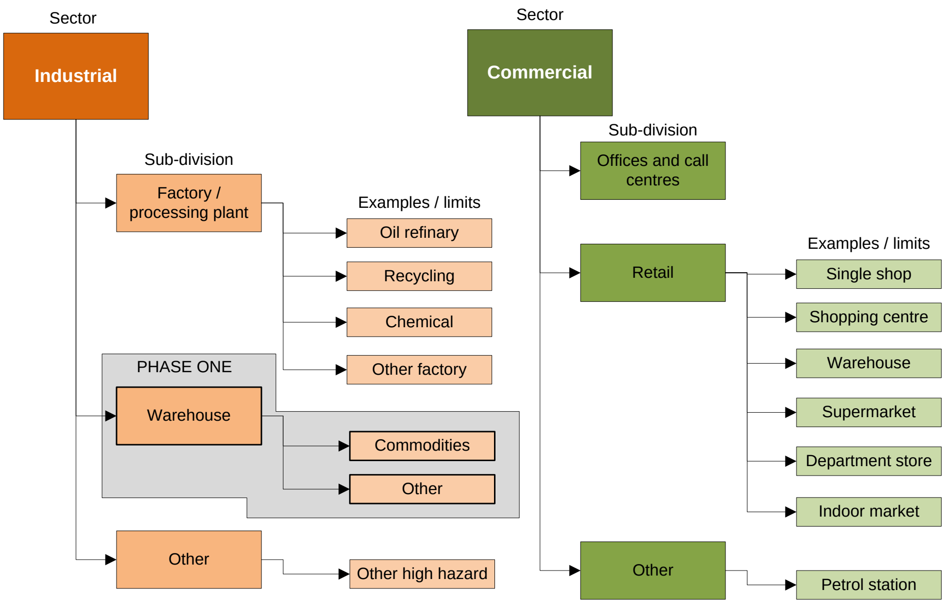

Figure 3 - Building purpose groups by Sector and Sub-division (note Sectors “Residential” and “Other” are intentionally omitted from this figure as not relevant at this stage)

Work completed so far, focusing on developing one module of the Expert System for Warehouse (as identified in Figure 3 as the region labelled “PHASE ONE”) fire protection has shown it is necessary to develop a more fully formed definition to properly describe and identify this type of risk. Notable further distinctions of interest to fire protection include: Type of goods stored, fire risk posed by goods and storage configuration, geometry of storage, automation features within the risk, etc. This further level of definition has been accomplished by reviewing available standards (as summarised in Table 1) and adopting elements from the most useful hazard classification system(s) within these documents for use in the Expert System. In the process of doing so, it was noted that the only documents that deal with hazard classification with any level of rigor were BS EN 12845 (BSI, 2009a) and the LPC Rules (FPA, 2010).

2.4 KNOWLEDGE EXTRACTION FROM THE IDENTIFIED GUIDANCE DOCUMENTS - REVIEW OF SCOPES

For a type of protection technology and associated Guidance Documents to be considered suitable for this application (warehouse protection), they must:

- reasonably be expected to be able to suppress (or extinguish) fires in this class of hazard
- be compatible with the typical uses of such buildings;
    - Containing stored goods in various complex geometric configurations
    - Occupied by humans
    - Large volumes with potentially frequently used large openings
- have either a proven history of being appropriate and successfully used in such circumstances, or for novel protection approaches, be supported by sufficiently robust and appropriate evidence of performance in equivalent circumstances.

These terms of reference give rise to three initial broad assessment criteria:

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

Undertaking a systematic review against these criteria eliminated all candidate protection approaches for this type of end user purpose group except BS EN 12845 (BSI, 2009a) and the LPC Rules (FPA, 2010). It should be noted that certain types of Gaseous protection systems might be considered in very exceptional circumstances. It also gives rise to some of the 'rules' which can subsequently be used in this module of the Expert System.

2.5 DEVELOPMENT OF THE PROTOTYPE EXPERT SYSTEM

With understanding of the information that must be elicited from the user to match against system suitability as determined by the knowledge elicitation phase, it is possible to assemble the 'questions' in to a flow chart (Figure 4) and then input this information in to a proprietary Expert System development environment.

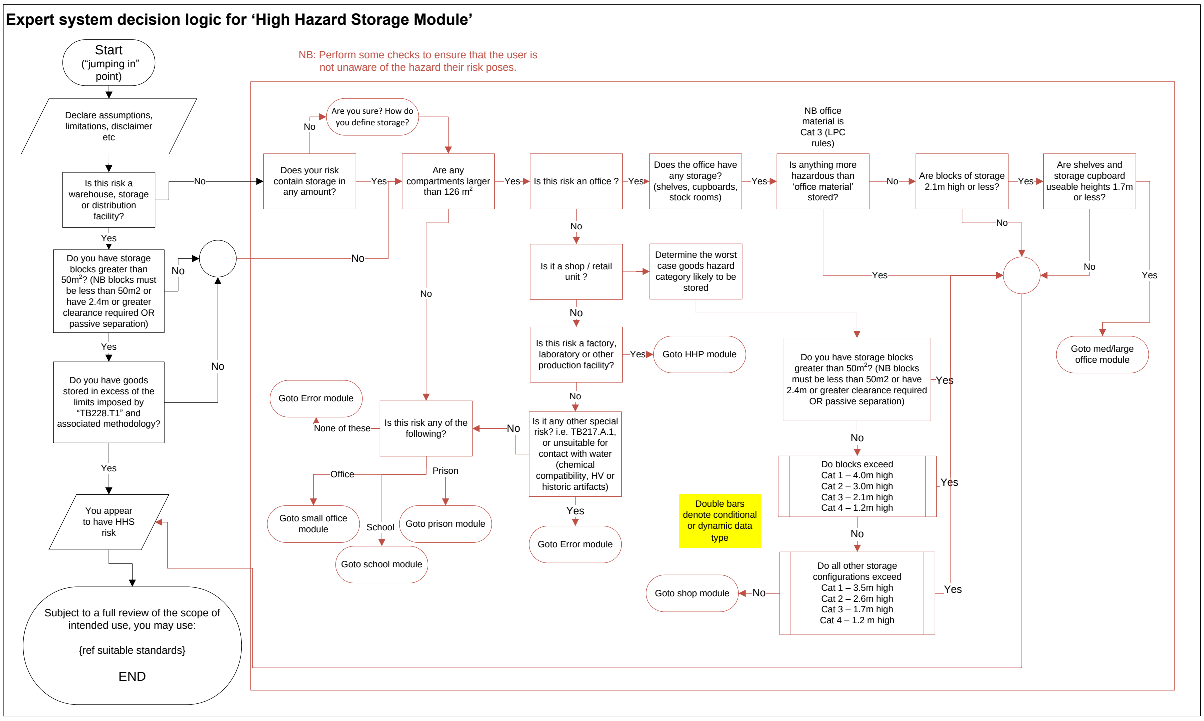

Figure 4 - First presentation of all Decision Problem Structuring Information

The “Corvid” development environment by “Exsys” was used for this phase of the research project. This development environment was found to be comparatively simple to use and incorporated all features required to efficiently develop this phase of the system. Figure 5 shows a screenshot of ‘variables’ and a ‘logic block’ as input in to the development environment. Figure 6 shows the system output obtained after the ‘user’ has input data about a (fictitious in this case) warehouse building. In this case the output is achieved having followed the simplest path through the question set (the Expert System ensures that as the user answers questions, subsequent questions rendered redundant are not asked (unless there is a reason to do so). The simplicity of this case is in the extreme, but is used to illustrate the principles of operation of the system.

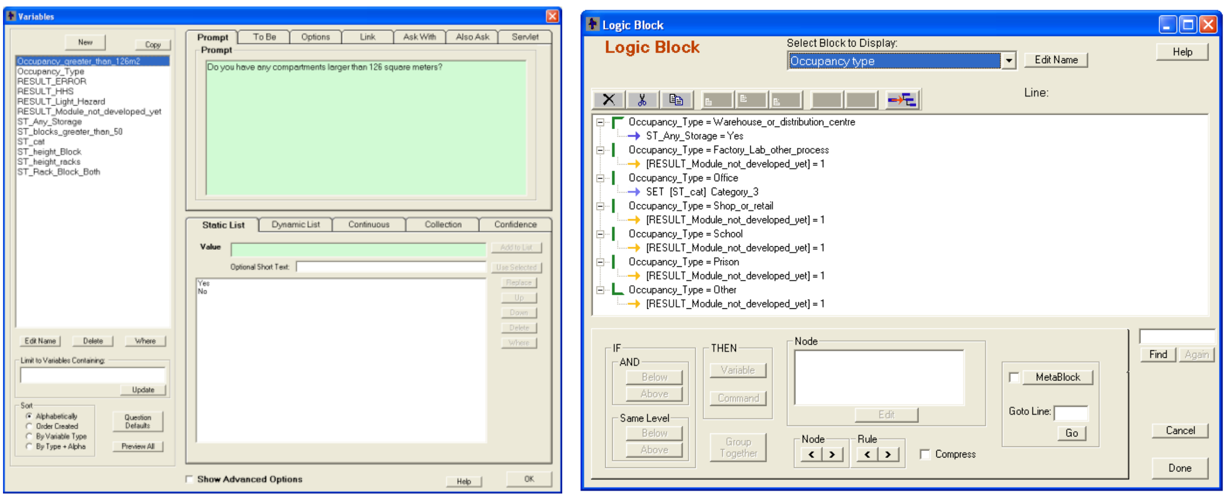

Figure 5 - screenshot of ‘variables’ and a ‘logic block’

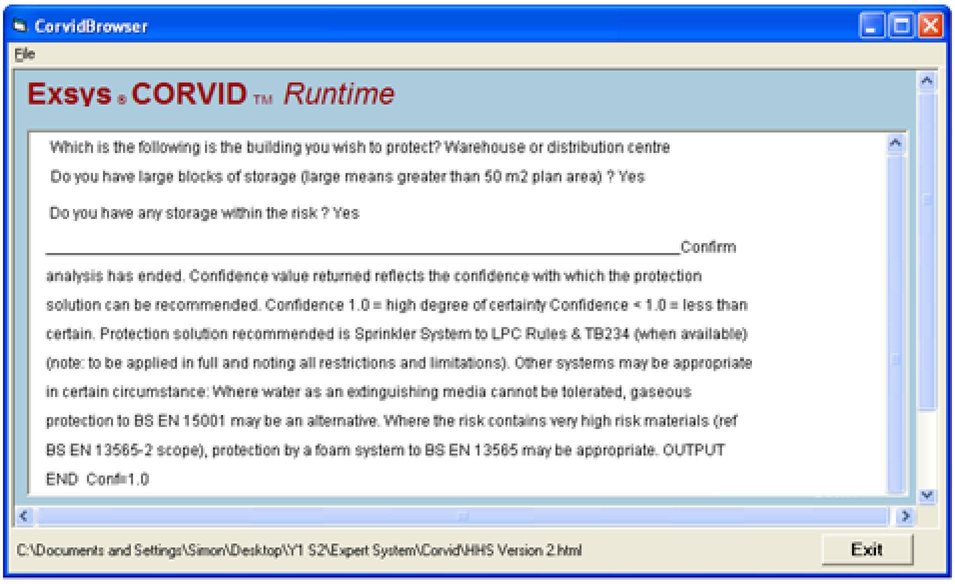

Figure 6 - screenshot of Expert System output

3 CONCLUSION

3.1 SUMMARY OF PROGRESS

The research and prototyping work completed to-date demonstrates the ambition to assist users of Active Fire Protection Systems by giving them and automated and independent way to check upon the suitability of a protection technology type to their particular needs will be possible.

The literature review has uncovered extensive documentation that could form the majority of the knowledge base. However, gaps in knowledge have been identified and a methodology has been developed and tested in order to fill such knowledge gaps. Methods have been derived to ensure that underpinning knowledge (both that enshrined in documents and *custom and practice* knowledge) used to form the logic of the system is peer reviewed and acceptable to the intended users of the system. To aid the development process, the task of developing the Expert System has been broken down in to modules (by hazard Purpose Group). This is to keep the work manageable and to enable development by a rapid application development type approach; developing a module at a time, and subjecting it to each of the development cycles.

The first module of the Expert System has been developed to prototype level, which has provided invaluable knowledge acquisition and learning of how to approach the complexity of such an approach within this field. The next phase of the research project will focus on advancing the development of the tool to increase the breadth of industry participation and awareness of the tool and the process. In order to support the development of the tool, a number of future stakeholder engagement activities are planned, including workshops, correspondence and questionnaires all intended to improve understanding and targeting of the system selection tool. Key stakeholders are identified by group and sub-group below in Table 2.

Group	Sub-group
Users	Insurers
	End users
Standards setting bodies and Regulators	Department for Communities and Local Government
	Building control officers
	Fire & Rescue Services
	BSI (British Standards Institution)
	BRE (Building Research Establishment)
Trade	Fire Engineers and IFE (Institution of Fire Engineers)
	Architects
	Project managers (of ‘design and build’ contracts)
	BAFSA (British Automatic Fire Sprinkler Association)
	FIA (Fire Industry Association)
	RSA (Residential Sprinkler Association)
	IWMA (International Water Mist Association)

Table 2 - Key stakeholders by group and sub-group

To assist with delivery of the remainder of the Expert System modules, a phased approach is considered appropriate. The next phase will focus on delivery of a simplified Expert System, putting to the user questions from reduced question set and handling residual uncertainty in the output reports generated, by way of general commentary and recommendations. For example such an output might only eliminate obviously unsuitable technologies and accompany any recommendations made with advice and best practice information about each technology put forward. This would continue to leave a degree of the decision making to the user. Subsequent phases would seek to reduce the amount of uncertainty passed to the user by systematically closing the knowledge gaps, achieving as far as possible the original aim of the research project.

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APPENDIX B PAPER 2

Full reference

S. N. Bird, K. Ruikar, L. Bosher, N. M. Bouchlaghem, J. Glockling (2013).

Development of a Fixed Firefighting System Selection Tool for Improved Outcomes.

Journal of Information Technology in Construction, No. 18, pp. 353-371.

Abstract

The UK along with the European Union has experienced a recent proliferation in design approaches for potential fixed firefighting systems. Such systems are installed to mitigate fire hazards in buildings and equipment. In the UK, for example there were five general design approaches to fixed firefighting systems protection in 1986. This had increased to eleven in 2011. This is against the backdrop of the current non-prescriptive regulatory frameworks including the Building Regulations, the repeal of so-called 'local acts', the Regulatory (fire) Reform Order and associated guidance (Approved Documents, standards, codes of practice and guides).

In response to this trend, as was intended, the market place is becoming increasingly competitive. However, the capability of each technology remains limited to protection against certain hazards, rather than offering a solution to guard against all possible scenarios. When selecting a fixed firefighting system, fire hazards and interactions can be difficult to assess and describe and the inequality or absence of satisfactory methods is notable in many recently published guidance documents. The absence of good quality guidance for non-expert practitioners (specifiers) and regulatory changes means a good quality source of impartial and expert knowledge is increasingly desirable. The challenge is to amass this knowledge and render it in an accessible format to the non-expert user. This paper reports on progress to-date;

understanding the problem, amassing and structuring the knowledge base and developing a suitable knowledge management tool.

1 INTRODUCTION

1.1 BACKGROUND

Fixed firefighting systems are installed to meet legislative requirements (to protect life), and / or when identified as appropriate by some form of cost-benefit analysis process; for example to achieve risk reduction for business resilience purposes or to protect irreplaceable assets. The United Kingdom (UK) along with the European Union (EU) has witnessed a recent proliferation of design approaches for potential fixed firefighting systems for the mitigation of fire risks in buildings and equipment; from five in 1986 (BSI, 1986) to eleven in 2011(BSI, 2011a). This occurs at the same time as a trend of deregulation in relation to requirements invoking installation of, and for, fixed firefighting systems. The Fire Precautions Act (HMSO, 1971) generally followed a prescriptive regulatory model, whereas the Building Regulations (HMSO, 2010) and the Regulatory Reform (Fire Safety) Order (HMSO, 2005) provide a less prescriptive set of requirements. All Local Acts relating to requirements for buildings, some of which created the requirement to install fixed fire protection systems (i.e. sprinkler systems) were repealed on 9th January 2013 (DCLG, 2012) as part of the Government's 'Red tape challenge'. Some absolute regulatory requirements to install fixed firefighting systems in the form of sprinkler systems to BS EN 12845 (BSI, 2009a) have since been removed and are replaced with either a recommendation to install an unspecified type of fixed firefighting system or no such requirement at all.

There is now increased potential in the fixed firefighting system industry for adopting similar approaches to that recommended by the fire engineering community, where client teams can adopt a fire engineering approach to overcome novel design challenges (Wilkinson et al. (2012), and/or reduce the costs of implementing fire protection (Sugden, 1998). The temptation to place too much emphasis on the latter is obvious and regulatory changes have paved the way to make this more likely.

This research identified numerous instances of multi-million pound fire losses, where, had the suppression system been fundamentally better suited to the hazard; the fire loss would have been negligible. By way of examples, it was the view of the experts appointed to the court (Cadbury v ADT (2011)) that a gaseous system was installed where surrounding enclosures stood no chance of retaining the media as required to extinguish the fire. The selection of an inadequate system to mitigate the fire risk was thus, a key contributing factor that led the fire incident to escalate out of control. From other cases, forensic evidence suggests that the water mist systems have failed, when they have not been interlocked to air extraction systems of the equipment they protect. The result; the fire fighting media (the ‘water mist’) has been extracted to atmosphere (away from the location it needs to be in order to fight the fire) before it can take effect. In some instances, sprinkler systems, although installed only offered partial protection, because the provision of sprinkler heads had not been continued in to the building voids. Thus a decision, which is evidently made to cut costs (an effect of value engineering), can result in rapid, severe and extensive fire spread around a building; challenging the very ethos of active fire protection. The examples cited here, have been encountered during the course of this research, unfortunately these and similar instances are not always widely reported due to the sensitivity of the information and potential grounds for claims and litigation.

This adverse effect of over value-engineering can be somewhat ameliorated if the motivations of the client (Sugden, 1998) and their subsequent impact on design decisions are clearly understood (e.g. selection of fixed firefighting systems) and examined. This constitutes the knowledge elicitation phase, with the help of which future recommendation(s) for a well-reasoned fixed firefighting system can be made.

In the built environment, as opportunities for greater efficiencies are frequently sought, and with a proliferation in fixed firefighting system design approaches, it is unsurprising that there is increasing commercial competition between the vendors of each type of fixed firefighting system. However, it remains the case that each fixed firefighting system type is suited to offering protecting against certain hazards, rather than offering a solution to guard against all possible scenarios (e.g. water is incompatible with electronic equipment and gaseous extinguishing media is prone to escaping). When a fixed firefighting system is incorrectly matched to the characteristics of a hazard, the likelihood of an adverse outcome in the event of a fire will increase, resulting in damages to life and property. To safeguard against this, there are several guidance documents available to assist users and designers in choosing and specifying appropriate active fire protection measures. Examples of such guidance documents include, the BSi's "Guide for selection of installed systems and other fire equipment" BS 5306-0 (BSI, 2011a), BRE's "guide to the sprinkler installation standards and rules" (BRE Global, 2009), and BAFSA's "Technical Guidance Note - Watermist Systems" (BAFSA, 2012). A desk study of these documents confirms that they vary in integrity, age, relevance, scope, quality, impartiality and suitability. None are deemed to be adequate to resolve the identified problems.

Hazards and interactions can be difficult to assess and describe and the inequality or absence of satisfactory methods is notable in many recently published guidance documents. The absence of good quality guidance for non-expert practitioners (e.g. specifiers) and regulatory changes means a good quality source of impartial and expert knowledge is increasingly desirable. The challenge of this research is to amass this knowledge and render it in an accessible format to the non-expert user (e.g. clients and occupants).

The Fire Protection Association (FPA) is the UK's national fire safety organisation. It is recognised as an independent and authoritative source of information and advice relating to all aspects of fire safety, risk management and loss prevention. The FPA, and several leading insurers who participate in its risk management work, have identified the requirement for assistance with the decision making process of analysing fire hazards and matching to them appropriate types of fixed firefighting system choices. This is so that informed and impartial system selection recommendations are made. This has led to the undertaking of a four year research project aimed at developing a decision problem structuring method and a software tool (Expert System), for specifying and selecting fixed firefighting systems so that fire risks are better managed or mitigated. The aim is to develop a tool that will both; assist non-expert users in making an informed selection of a system that is likely to best suit their needs; and educate non-expert users by highlighting key selection principles. It is indented that the tool would thus; contribute to improvements in levels of fire safety and outcomes. This paper presents a summary of the work undertaken, focusing on the demand for the work, the criticality of system reliability, development and evaluation of the decision methodology and practical application and evaluation of the emerging Expert System.

1.2 FIXED FIREFIGHTING SYSTEMS

For the purposes of this research project, the term *Fixed Firefighting System* means any fire suppression, control or extinguishing system for use as a fixed installation in a building, protecting the whole or part of the building and/or objects within. Examples of such systems, as given by the National Fire Protection Association's Fire Protection Handbook (Bendelius, 2008), would include; automatic fire sprinkler systems (the most common type) and other approaches such as deluge systems and water mist systems. The scope of this work also includes consideration of gaseous extinguishing systems, oxygen reduction systems and other installed fire fighting systems using alternative media.

There are a variety of sources that report the financial and societal cost of fires within the UK, Europe and other developed nations. A summary of published figures is presented here. The Association of British Insurers (ABI) in its paper, “Tackling Fire: A Call for Action” (Association of British Insurers, 2009) estimates the insured cost of fire is £1.3bn. It also reports that 443 deaths and 13,200 casualties were caused by fire in 2007. The UK Government in its report, “The Economic Cost of Fire: Estimates for 2004” (Office of the Deputy Prime Minister, 2006) reports a projected figure of £7.03bn for the cost of fire for the year 2004. The corresponding projections for the years 2006 and 2008 are £8.2bn and £8.3bn respectively (Office of the Deputy Prime Minister, 2011a, Office of the Deputy Prime Minister, 2011b). Whilst not markedly out of step with other developed nations (The Geneva Association, 2011), such figures illustrate that the risk, consequence and cost of fire remains significant to the built environment in the UK.

During the course of this research, several documents purporting to offer potential users guidance on system selection have been identified. Examples include, BSi’s “Guide for selection of installed systems and other fire equipment” BS 5306-0 (BSI, 2011a), BSi’s fire engineering suit of standards BS 7974 series (BSI, 2001), specifically part PD 7974-4 (BSI, 2003b), BRE’s “guide to the sprinkler installation standards and rules” (BRE Global, 2009), and BAFSA’s “Technical Guidance Note - Watermist Systems” (BAFSA, 2012); among others. A review of these documents finds that none of the documents offer sufficiently complete or impartial guidance to achieve the objectives of this undertaking. Previous research by the authors (Bird et al., 2012) identified potential fixed firefighting system technologies for inclusion within the tool and developed an outline method for considering the applicability of each firefighting system type. No other work to further develop a solution to the identified problem has been identified since. This paper aims to bridge this gap through achieving a set of objectives as follows, by:

- Understanding the need for fixed firefighting systems;
- Understanding factors influencing current selection practices;
- Identifying target hazard groups (i.e. building usage or occupancy process fire risk and consequence characteristics);
- Identifying current sources of selection ‘knowledge’ (standards, guides, custom and good practices);
- Identifying potential users;
- Developing a knowledge-based tool to automate as far as possible system selection decision-making steps; and
- Addressing maintenance and upkeep considerations associated with the tool.

2 METHOD

A tangible and useful deliverable is sought in the form of the “Fixed Firefighting System Selection Tool” (FFSST) to enable a real improvement in system selection and outcomes to be made. To meet the projects objectives, Rapid Application Development (RAD) and Action Research (AR) approaches have been adopted. The RAD approach is often used when a degree of incremental development is acceptable (or desirable i.e. where requirements change often) rather than an approach whereby whole new systems are developed each time there is a change (Avison and Fitzgerald, 2003). This technique has the potential to facilitate iterative system developments with more efficient resource usage and allowing a solution to be incrementally developed and improved with the experience gained of practical application of the preceding version of the development.

Action Research (AR) is defined by Stringer (2007) as "a systematic approach to investigation that enables people to find effective solutions to problems they confront in their everyday lives". Denzin and Lincoln (2003, p. 28.) introduce the word "participatory" to form the concept of "participatory action research" to reflect the perceived diminution of the number of aloof observers' content to let the research pass without comment. "Participatory action research is a contested concept applied to a variety of research approaches" (Denzin and Lincoln, 2003, p. 336) in essence they argue special acknowledgement should be given to action research where a high degree of stakeholder input is to be expected. It is anticipated this will be the case here, given the level of commercial vested interest in the fire protection industry, disparate stakeholders (e.g. owners, specifiers, users/benefactors, regulators and insurers) and the value of the assets dependant on being protected by such technology.

Drawing further on the work of Stringer (2007), his "action research interacting spiral" is adapted to describe the broad development cycles of this project (see Figure 1).

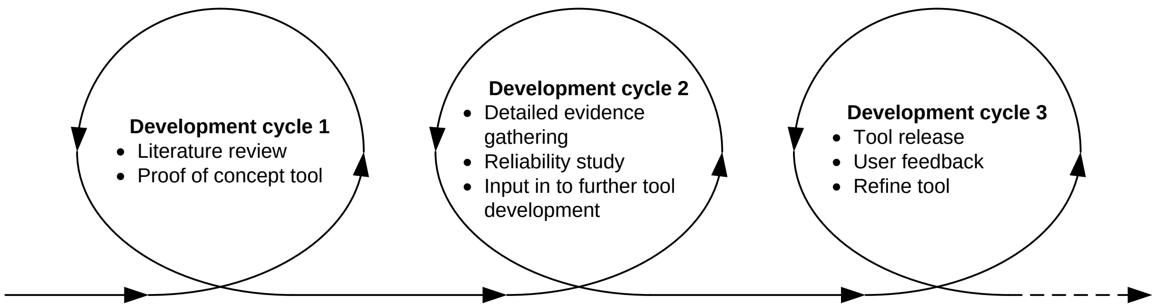

Figure 1 – Adaptation of "Action Research interacting spiral" (Stringer, 2007)

In practice, the research has employed the following techniques: Initial and on-going literature review, quantitative and qualitative methods. Quantitative methods being defined as those which gather evidence which is measureable and quantifiable, being characterised by having adopted “scientific method” (Calado et al., 2009). Whereas qualitative methods are said to be more suited to in depth study of opinions, origins of opinions and associated consequences (Easterby-Smith et al., 2002) being ‘subjective’ in nature emphasising meanings, experiences and descriptions. The former has been achieved through review of regulations (The Regulatory Reform (Fire Safety) Order (HMSO, 2005), The Building Regulations (HMSO, 2010)), standards (national, international and sector specific fixed firefighting design, installation and components standards; for sprinkler systems (FPA, 2011, BSI, 2009a, BSI, 1999), water mist systems (BRE Global, 2012, BSI, 2011d, BSI, 2010), foam-based systems (BSI, 2009b), gaseous systems (LPCB, 2005, BSI, 2003c, BSI, 2008b), oxygen reduction systems (BSI, 2011e) and aerosol systems (BSI, 2009c) to name a few) guides and practice documents (BRE Global, 2009, BSI, 1986, BSI, 2011a, The Fire Protection Association, 1999, Williams, 2009). The latter includes interactions with several subject experts (Building Control Officers, Fire Engineers, Architects, Fire and Rescue Services, Organisational risk manager, Project Managers (Design and Build Contractors), Insurance Surveyors and Consultants and expert colleagues) and undertaking a survey by questionnaire to gather input from a much wider audience on aspects of the research. These subject area experts have been engaged with in various ways: day-to-day discussions with expert colleagues in the course of undertaking the research and in the conduct of the sponsoring organisations (the FPAs) business. In conducting the business of the FPA, quarterly meetings between insurance industry risk surveyors (drawn from ABI membership), fixed firefighting system industry and representatives from applicable test and certification house convened by the researcher. This yields much insight in to the successes and failures of the industry.

Wider contact with experts was sought by means of a survey. The survey aimed to identify the requirements of a fixed firefighting system, with input from those with expertise and experience in the area of fixed firefighting system selection. Participation was widely invited via a variety of means, including the following:

- Existing network of relevant business contacts;
- Via trade associations and organisations:
    - Risk Engineers Data Exchange Group (REDEG);
    - British Automatic Fire Sprinkler Association (BAFSA);
    - Fire Industry Association (FIA);
    - RICS building control professional group; and
    - Building Research Establishment (BRE).
- Via 'Social networking' website LinkedIn groups:
    - National Fire Protection Association (NFPA);
    - Society of Fire Protection Engineers (SFPE);
    - Fire Industry Association (FIA);
    - Centre for Innovative and Collaborative Construction Engineering (CICE); and
    - Underwriters Laboratories (UL)'s Global Fire Service Leadership group.

A total of 64 responses were received, which exceeded the ambition of achieving 50 responses (a figure arrived at by estimation and considering the degree of specialism of the subject area). Responses were received from the following groups: Building Control Officer, Fire Engineer, Fire and Rescue Service, Organisational risk manager, Project Manager (Design and Build Contractor). Other notable self-identifying groups were recorded: Insurance Surveyors and Consultants.

3 REQUIREMENTS CAPTURE

The requirements capture phase has considered the following issues: the need for fixed firefighting systems, factors influencing selection, current selection practice, identification of target hazard scenarios, identification of current sources of knowledge and target system user groups.

3.1 THE NEED FOR FIXED FIREFIGHTING SYSTEMS

As a result of the longstanding threat posed by fire, the majority of built or manufactured objects and buildings have *fire safety provisions* incorporated within them. These include, among other examples, fire guards to protect from open household fires, over-current fuses protecting electrical appliances, use of non-combustible materials, thermal cut-out devices, gas safety shut-off valves, compartmentation in buildings, manual first aid (such as fire extinguishers, fire blankets, hose reels), fire service intervention and fixed firefighting systems (such as local application systems, whole building protection systems). These examples vary in scale, complexity and approach. The Institution of Fire Engineers define Fire Engineering as “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” (Institution of Fire Engineers, 2011). BS ISO 31000 “Risk management - Principles and guidelines” states that “*Organizations manage risk by identifying it, analysing it and then evaluating whether the risk should be modified by risk treatment in order to satisfy their risk criteria*” (BSI, 2009d, p. v.). Fixed firefighting systems are one of the approaches (or ‘risk treatments’) that may be employed when one seeks to engineer improvements to fire safety provisions. They may offer considerable benefit when used alone, or, better when used as an integrated approach as is more often the case (Bird et al., 2012). As such they are one of the tools available to help manage the exposure of society to the hazard and the consequence arising from a fire. Deployed correctly they have a significant beneficial role to play in reducing the direct and indirect costs, terms used by Roy (1997) and many others to describe the costs arising following the material damages arising from a fire and the often greater costs and disruption caused by the aftermath of fire.

According to the BRE Global (2009) guide, fixed firefighting systems are installed mostly; to meet legislative requirements, or to achieve risk reduction for business resilience purposes. These ideas may be supplement and developed further in the context of current requirements and practice; fixed firefighting systems are installed to:

- Meet the intent of the Building Regulations (HMSO, 2010) and Regulatory Reform (fire safety) order (HMSO, 2005). The primary objectives being to protect life of those (all potential occupants including fire fighters and those in the vicinity) exposed to the structures should a fire occur. Routes to achieve this can be further subdivided as follows:
    - By following the prescribed guidance on how to achieve acceptable levels of ‘life safety’ protection using “Approved Document B” (Department for Communities and Local Government, 2010); and
    - By demonstrating at-least-as-good protection by following one of the fire engineering approaches set out by BS 9999 (BSI, 2008a) or BS 7974 (BSI, 2003a) series of documents.
- To manage risk for commercial or operational reasons (The Fire Protection Association, 1999), which could be broken down as:

- In support of obtaining fire insurance or obtaining a discount for an element of risk (Hall and Watts, 2008) (or for organisations who self-insure as a fire risk management measure);
- In support of obtaining business interruption insurance (or for organisations who self-insure as a business continuity measure) (Watts, 2008);
- For process continuity (where fires occur ‘routinely’ and need to be dealt with – i.e. some types of industrial frying); and
- Where the object(s) or building to be protected is irreplaceable and of sufficient value (financial or cultural, i.e. historic) to justify the outlay.

Assuming fixed firefighting systems are correctly specified, designed, installed and maintained, they have a very good reputation for reliability. A United States based organisation, the National Fire Protection Association (NFPA), publish reliability data on some types of fixed firefighting systems. It states that overall when considering all possible modes of failure (a key concept, discussed at length within the work), wet sprinkler systems are 91% reliable (Hall, 2010). This reputation for reliability is further attested to by the fact that large and high consequence fires, where active fire protection is featured are currently quite rare events as determined by the distribution of data collected by the FPA in its “Large Loss Database”. The database is held in trust by the FPA on behalf of a group of UK insurers. Contractual requirements exist which require insurance loss adjusters to input data following a fire. The eligibility criteria for reporting are simple; the database aims to capture reports on all fires where the financial cost of the fire is £100,000 or greater and/or where one or more fatalities have occurred. The database clearly demonstrates the trend that for every large and high consequence (high profile) fire in a warehouse building featuring a suppression system there will have been many others where the fire was suppressed or controlled in its incipient stages and thus, a large scale catastrophic event was averted (Glockling, 2012).

3.2 FACTORS INFLUENCING CURRENT SELECTION PRACTICE

Many of the factors influencing fixed firefighting selection practice can be summarised in Figure 2, an extract from PD 7974-4 (BSI, 2003b).

Figure 2 highlights various essential aspects to consider and the issues they give rise to. By way of a limited number of examples:

“At what stage of fire growth will discharge be initiated by?” this question should trigger the specifier to consider how involved the fire might be, how much heat needs to be removed, how much media might be required and of what type, how it might be applied, to name a few considerations.

“What will the impact of a false discharge be?” Inevitably, although rare, unintended system activations do occur from time to time. To minimise as far as possible the consequence of such an event the specifiers should consider this issue. This may, for example, give rise to a gaseous media being selected in place of a water-based system if the (very remote) prospect of water damage to electronic equipment is unacceptable. This scenario commonly occurs in facilities such as datacentres.

To support this research, supplementary annotations have been added to the figure where desk review has determined that insufficient published data exists (for systems other than sprinkler and gaseous systems) for users to reasonably be expected to follow the guidance outlined. The supplementary annotations are assigned the following meanings:

- Blue circles, discontinuous line = limited guidance available; and
- Blue circles, continuous line = no guidance available.

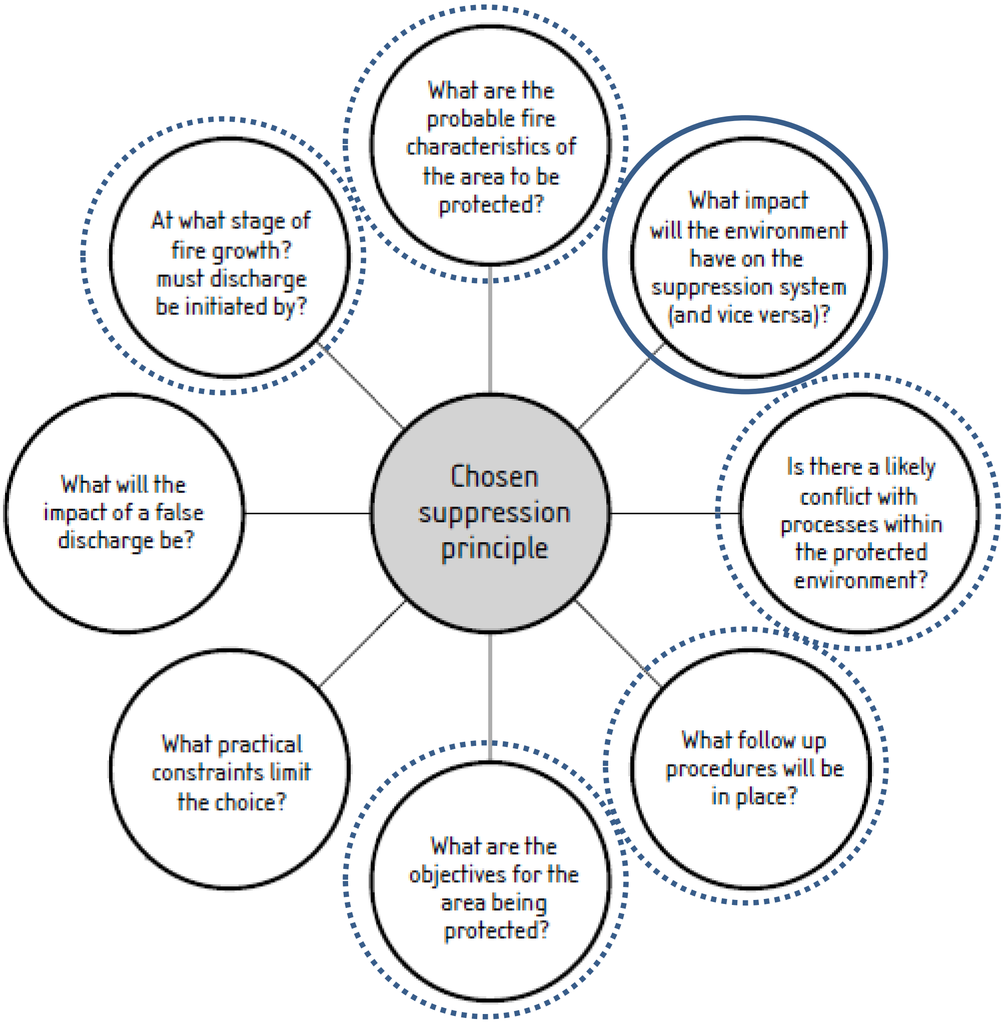

Figure 2 - A Reproduction and Adaptation of "Fire Suppression System Choice Matrix" (BSI, 2003b, p. 20)

A notable omission from Figure 2 is any direct mention of the specifier giving consideration to the overall 'fire performance of suppression technology against hazard to be protected'. This is important with any system, but a frustrated objective as this data is often scant or not available at all. The only credible data identified is that previously of the NFPA, which states that overall when considering all possible modes of failure (including failures at the design stage), wet sprinkler systems are 91% reliable (Hall, 2010). None of the other system types are dealt with. Ideally, such data obtained on an equitable basis across a range of fixed firefighting system types would allow a ready evaluation of their performance. The usefulness of such data for reliable cost-benefit analysis is unquestionable. However, such data is currently unavailable and not considered to be readily obtainable.

Active fire protection systems are unlike many other systems in that failure, when they are called upon to operate, is highly likely to give rise to dire consequences. In practice, it is common knowledge that many lives and billions of pounds worth of assets are protected from fire by fixed firefighting systems. By way of one example, several of the high-rise buildings at Canary Wharf in London are sprinkler protected for both life safety and property protection purposes. Each building houses thousands of people and enterprises worth multiple millions and/or billions of pounds. Without sprinkler protection, in the event of a fire, a total loss of one or more of the buildings is entirely conceivable. The ambition to maximise reliability of the necessary fixed fire fighting systems must therefore bear very considerable weight when considering options. To complicate things further and unlike many other systems fixed firefighting systems are mostly only required to function once, having remained dormant for an unspecified, but very challenging period (e.g. 1, 2, 5, 10, 25, >25 years) for an engineered system.

It therefore seems appropriate to consider reliability in the context of this project in greater detail. 'Reliability,' i.e. *the ability to be trusted, predictable or dependable* ((Collins, 1994)); and 'resilience' i.e. *the quality of recovering easily from a shock, illness and hardship* ((Collins, 1994)); are found to be key attributes of the performance of a system in the application of fixed firefighting. The concept of *reliability* and *resilience* of such systems is perhaps better expanded to 'RAM' (Reliability, Availability, and Maintainability) (DoD,

2005) or as more commonly expressed in the UK 'ARM' (Availability, Reliability and Maintainability) (BSI, 1991).

Clearly there is a need to consider system 'ARM' when making a fixed firefighting system choice, but currently there is no ready means to do so. As obtaining such historic data is not feasible, an alternative means is required. It is proposed that as a future step of this work a methodology be developed (for incorporation into the selection tool) to consider factors likely to have a bearing upon system ARM, when comparing available fixed firefighting system types.

3.3 IDENTIFY TARGET HAZARD SCENARIOS

Any attempt to design a system to mitigate against a hazard must be underpinned by information about the nature of the hazard. To illustrate the point, as a general rule, dwelling houses tend to pose more or less the same fire challenge as one another. These challenges differ from those posed to warehouses, schools and factories. Building usage type provides a useful initial clue as to the likely magnitude and nature of the fire hazard to be controlled. The prototype development work has proved that this is a useful way to start to systematically assess and describe the hazard. The usage groups and sub-groups proposed for adoption within the tool are based upon the Department for Communities and Local Governments (DCLG) Incident Recording System (IRS) (Home Office, 1994). Figure *3* illustrates the usage groups and sub-groups considered to be most applicable to this research. In Figure 3 sector headings and sub-division headings are derived the from Department for Communities and Local Governments (DCLG) Incident Recording System (IRS) (Home Office, 1994) and the examples/limits are derived from a review of fixed firefighting system design standards (Bird et al., 2012).

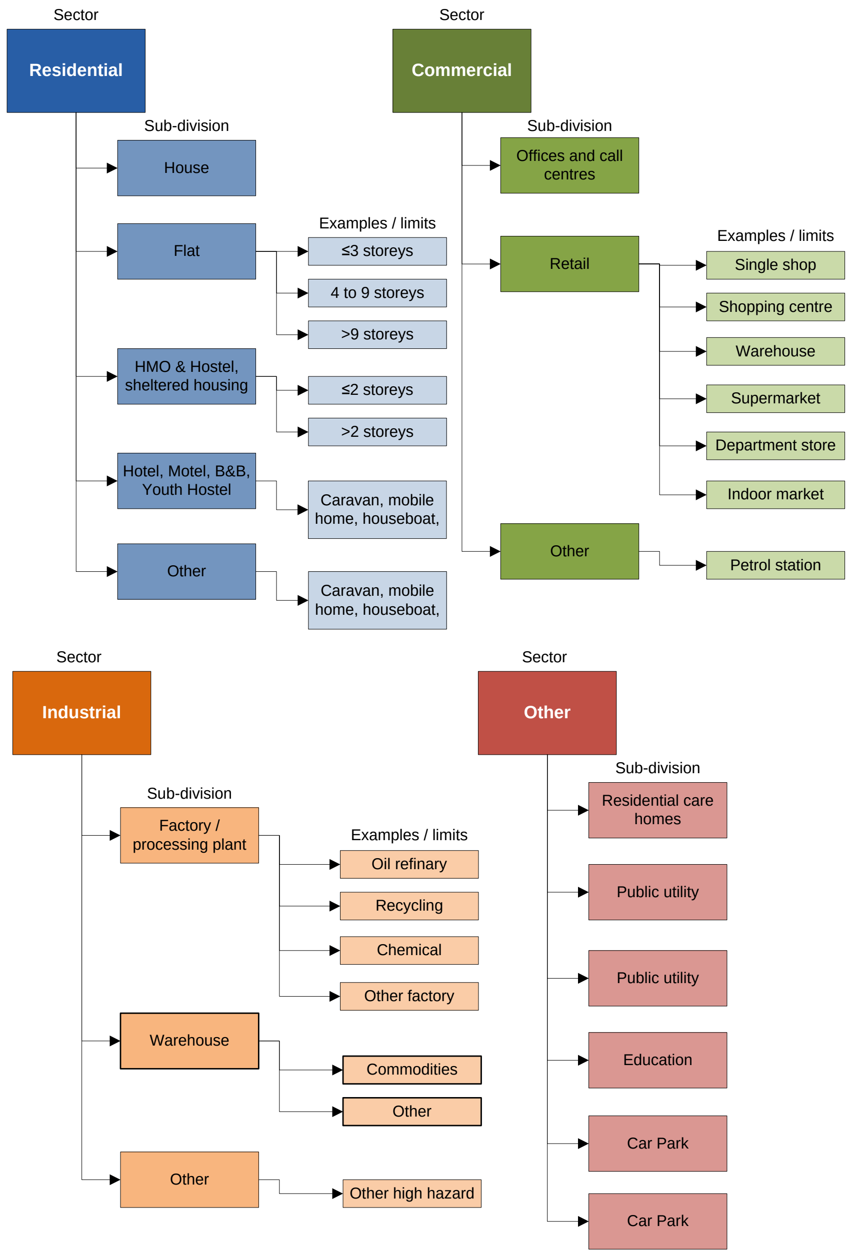

Figure 3 – Available Building Purpose Groups (adapted from Incident Recording System (Home Office, 1994))

It is intended that protection of all 'hazard groups' identified in Figure 3, will be provisioned for within the tool. It is hoped that adopting a pre-existing convention will ease some aspects of the uptake and integration of the tool into the established framework within which everyone operates.

3.4 IDENTIFY CURRENT SOURCES OF SELECTION 'KNOWLEDGE'

The 'knowledge' discussed here is that which underpins the design of fixed firefighting systems. It includes such considerations as: firefighting media suitability for various combustible materials/scenarios, system efficacy against scenario type, media application rates and methods and all other design considerations. The on-going literature review has identified:

- Fire safety provisions in the context of the UK legislative position;
- The regulatory framework;
- Key standards which are typically used to contribute to the demonstration of compliance with sound engineering practice;
- Various approaches to Knowledge Management (KM) and Expert Systems (ES); and
- Underpinning knowledge (partial) in support of the ES.

The review has also identified gaps in:

- The technical knowledge base that will be used to derive the 'rules' to be used in the KM system;
- Meaningful data allowing comparison of performance of different approached to active fixed automatic firefighting systems; and
- Guidance on active fixed automatic firefighting system selection or evaluation.

While the identified knowledge gaps do require work to address the issues, none are thought to prevent the tool from coming to fruition.

3.5 IDENTIFY TARGET USERS

To identify the primary target user groups (i.e. groups who have a role in fixed firefighting system selection) a survey was undertaken. The 64 collated responses identified the following groups as those who are involved with fixed firefighting system selection (illustrated in Figure 4):

- Building Control Officers (3 responses);
- Fire Engineers (27 responses);
- Fire and Rescue Service (enforcement) (7 responses);
- Organisational risk managers (5 responses);
- Project Managers (Design and Build Contractors) (6 responses); and
- Other notable self-identifying groups (16 responses):
    - Insurance Surveyors; and
    - Consultants.

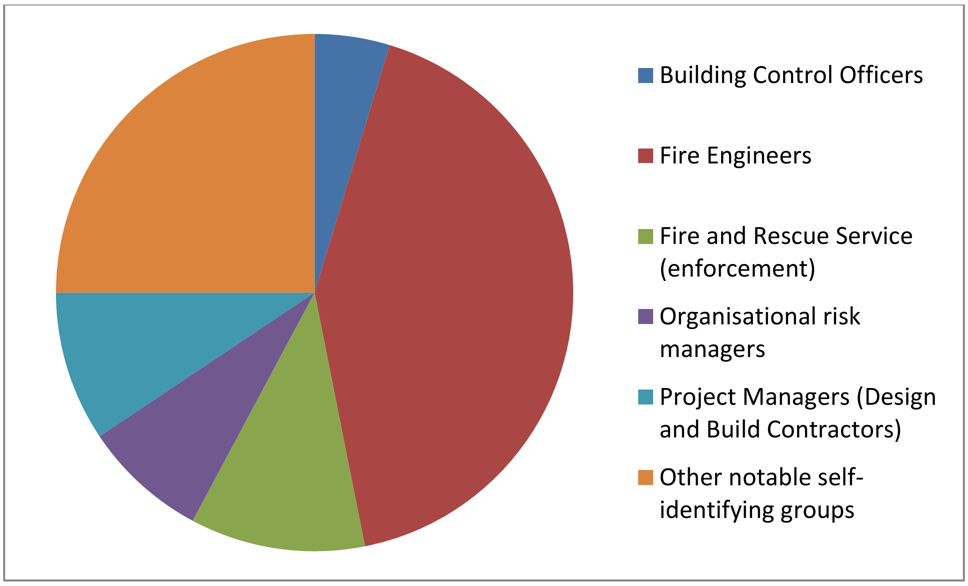

Figure 4 – Distribution of Respondents' Roles in Specifying Fixed Firefighting Systems

The tool is intended for users from any one of the groups identified here. It is notable that almost anyone of any competence level may assume the role 'organisational risk manager' or 'consultant'. Considering this, any tool that is developed for such a diverse user group, would need careful consideration, especially since technical (expert) information would be exchanged between the tool and a non-technical (non-expert) user.

4 DEVELOPMENT OF THE FIXED FIREFIGHTING SYSTEMS SELECTION TOOL

The problem was identified as one belonging to the KM domain in the early stages. Various approaches to KM were investigated and Expert Systems (ES) were found likely to be the most suitable vehicle for encapsulating the requisite knowledge, managing the information exchange with the user and culminating in a set of outputs consistent with the project objectives.

The research completed so far has allowed the outline system architecture shown in Figure 5 to be created.

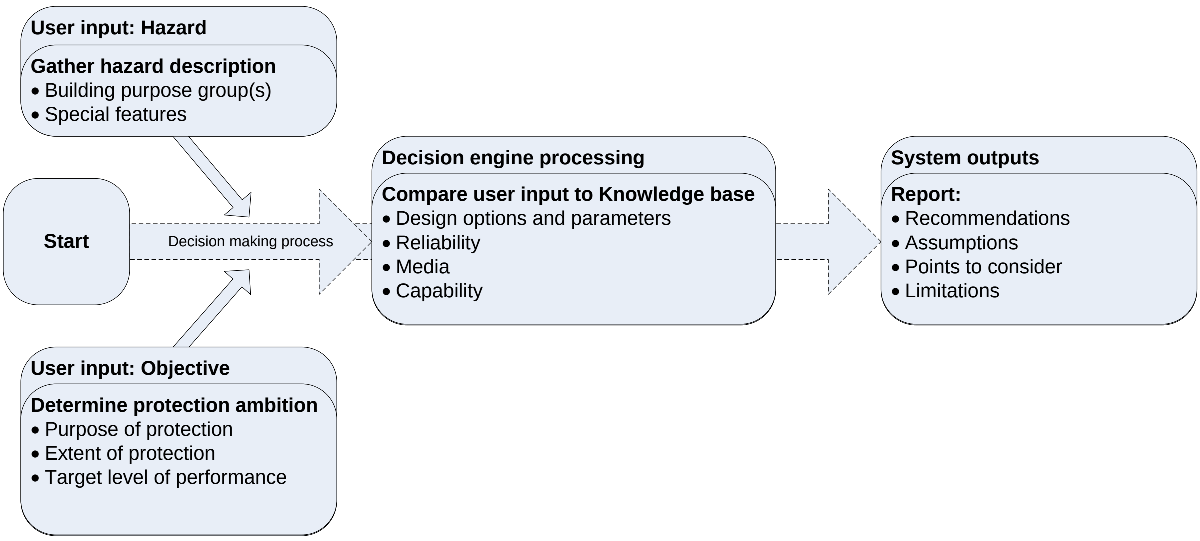

Figure 5 – Fixed Firefighting System Selection Tool Architecture

An underpinning assumption is that the process is initiated by a user who has already identified the need for a fixed firefighting system. User input on the hazard and protection objective is then required. This information is then used by the processing part of the tool, with reference to the systems knowledge base (the part of the system that contains the expert knowledge; derived from standards, guides, custom and practice) (Medsker and Liebowitz, 1993). Unsuitable options are eliminated and surviving system choice option(s) are presented as solutions. Each of the steps is considered in more detail, as follows:

User Input: Hazard

Building Purpose Group: The user is asked to choose from a limited selection of commonly found building purpose groups. The available purpose groups would be those illustrated in Figure 3. All that apply should be selected.

Special Features: The user would be asked whether the hazard to be protected includes any special features (which would preclude certain fixed firefighting system approaches). As a few examples: buildings of areas containing substances which expand on contact with water may not normally be protected by fixed firefighting systems that use water or water based fire fighting media (BSI, 2009a). It may also be undesirable in some (but not all) cases to protect areas densely populated with high value IT and or high voltage equipment by systems using water based firefighting media (BSI, 2011c). Systems using CO_2 as a firefighting media may not be suitable for use in occupied spaces, as CO_2 at firefighting concentrations would always be toxic (BSI, 2011b).

Another consideration would be if the fabric of all or part of the building itself were of a moderate to high level of combustibility. It is generally known that polystyrene (which may be used as an insulator) is highly flammable and that buildings incorporating such materials cannot expect the same levels of efficacy from fixed firefighting system as those without.

User Input: Objective

Purpose of Protection: It shall be determined here what the purpose of the protection is, the two significant distinctions being ‘life safety’ (protection sufficient to allow safe evacuation of a building) and ‘property protection’ (unconditional protection of property and business continuity) in parlance consistent with that used by the Department for Communities and Local Government (2010, p 11.) and The Fire Protection Association (1999, p 1.) respectively.

Extent of Protection: Another key piece of information that must be garnered is whether the intention is to protect part or the whole of a building, part or the whole of a piece of equipment or some combination of these options.

Target Level of Performance: A separate (unpublished) study (Bird, 2012) on the need for and role of reliability in fixed firefighting systems, highlights an issue the sector is yet to come to terms with; it ought to be difficult for anyone to justify anything but the most reliable form of fixed firefighting system from a choice of reasonably practical solutions. This may prove to be a dominant factor in the determination process.

Decision Engine Processing

This is a decision gate. It then becomes the job of the ‘decision engine’ to systematically compare the input(s) of the user with the knowledge base within the system to recommend ‘system outputs’.

System Outputs

The system will conclude its assessment by delivering, where possible, a report detailing recommended fixed fighting system choice(s), confirmation of the underpinning assumptions used to arrive at this conclusion, additional points to consider (based upon historic experience of selection failures) and any limitations associated with the recommendation(s).

5 THE EVALUATION OF THE SYSTEM

The work completed so far has focused on developing one module of the tool for *warehouse* fire protection (see Figure *3*). This work has shown it is necessary to develop a more fully formed technical definition to properly describe and identify this type of risk. Notable further distinctions of interest to fire protection include; type of goods stored, fire risk posed by goods and storage configuration, geometry of storage and automation features within the risk. This further level of definition has been accomplished by reviewing available fixed firefighting system design standards and adopting elements from the most useful hazard classification system(s) within these documents for use in the ES. In the process of doing so, it was noted that the only documents that deal with hazard classification with any level of rigour were the BS EN 12845 (BSI, 2009a) and the LPC Rules (FPA, 2010). With understanding of the information that must be elicited from the user to match against system suitability as determined by the knowledge elicitation phase, it is possible to assemble the 'questions' in to a flow chart. Figure 6 illustrates a small section of the decision flow diagram used for the prototype system; concerned with 'High Hazard Storage' scenarios) and then input this information in to a proprietary Expert System development environment.

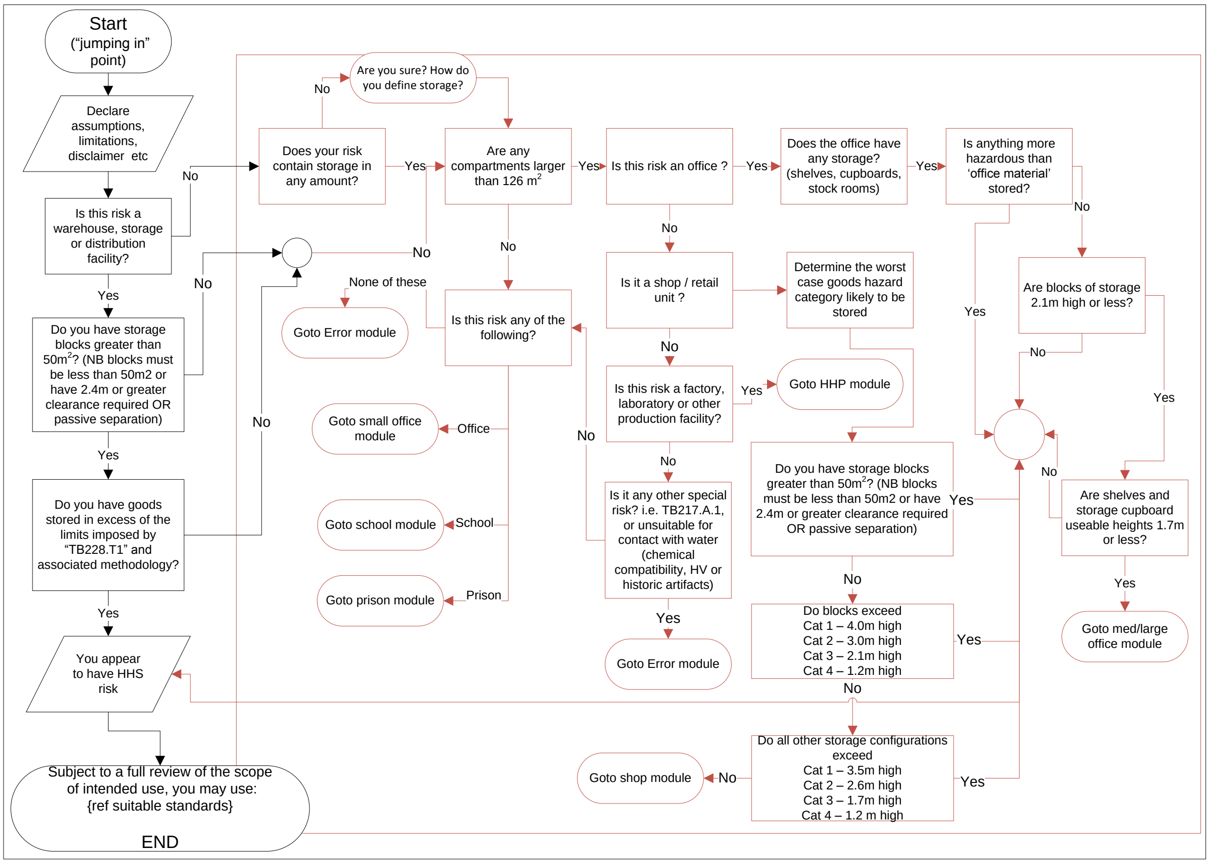

Figure 6 - Prototype System 'Logic'.

The "Corvid" development environment by "Exsys" was used for this phase of the research project. This development environment was found to be comparatively simple to use and incorporated all features required to efficiently develop this phase of the system. The compiled output may be hosted on a web page and requires a computer with internet access and JAVA support to run it. Figure 7 shows a screenshot of 'variables' and a 'logic block' as input in to the development environment. Figure 8 shows the system output obtained after the 'user' has input data about a (fictitious in this case) warehouse building. In this case the output is achieved having followed the simplest path through the question set (the ES ensures that as the user answers questions, subsequent questions rendered redundant are not asked (unless there is a reason to do so). The simplicity of this case is in the extreme, but is used to illustrate the principles of operation of the system.

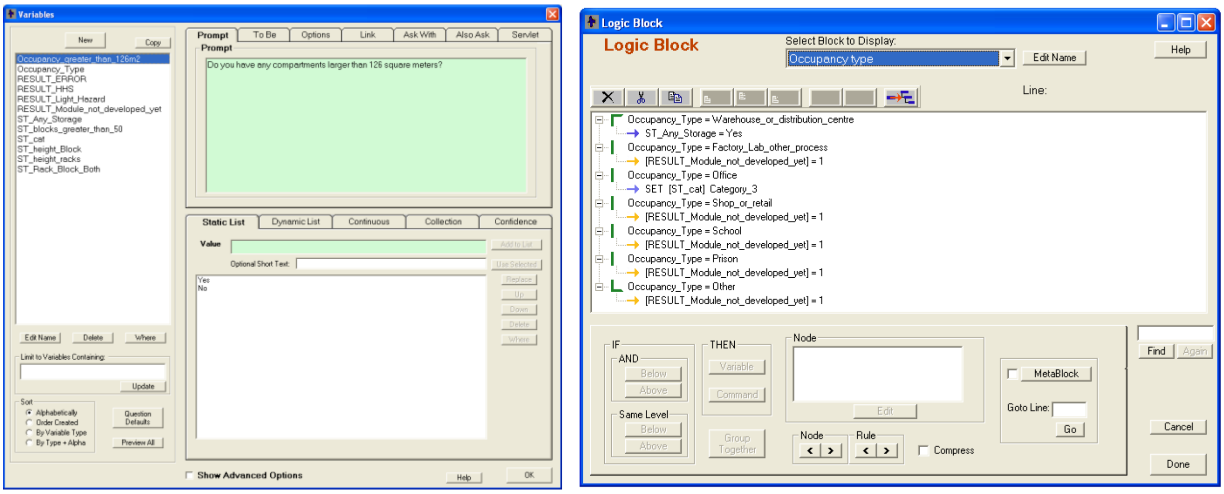

Figure 7 - Screenshot of ‘Variables’ and a ‘Logic Block’

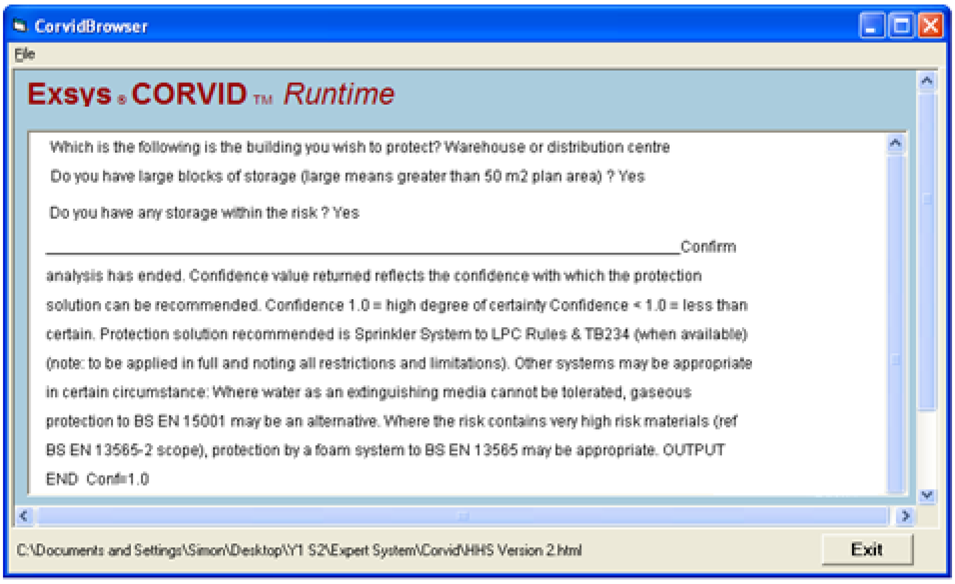

Figure 8 - Screenshot of Expert System Output

The Fixed Firefighting System Selection Tool has been developed to a limited scope prototype at this stage. This prototype was used to validate the concept and capture evaluation feedback (from a small group of expert colleagues; the Technical Director of the FPA, the Principal Consultant of the FPA). In summary the findings of the prototype evaluation were:

- The concept was proven successfully as achievable;
- Further gaps in the underpinning knowledge base were identified (e.g. absence of standardised hazard assessment methodologies); and
- The desirability (and associated difficulties) of some cost-benefit analysis forming part of the assessment was highlighted.

As has been identified, the tool will draw upon material from multiple sources, many of which are subject to periodic review. The underpinning knowledge (source material) is drawn from a wide variety of sources (regulations (The Regulatory Reform (Fire Safety) Order (HMSO, 2005), The Building Regulations (HMSO, 2010)), standards (national, international and sector specific fixed firefighting design, installation and components standards; for sprinkler systems (FPA, 2011, BSI, 2009a, BSI, 1999), water mist systems (BRE Global, 2012, BSI, 2011d, BSI, 2010), foam-based systems (BSI, 2009b), gaseous systems (LPCB, 2005, BSI, 2003c, BSI, 2008b), oxygen reduction systems (BSI, 2011e) and aerosol systems (BSI, 2009c)) guides and practice documents (BRE Global, 2009, BSI, 1986, BSI, 2011a, The Fire Protection Association, 1999, Williams, 2009) to name a few of the published sources). Each of these source documents is subject to a periodic review and update process. To ensure the tool remains current it would therefore be necessary devise an on-going regime of identifying changes, evaluating the consequences (if any) of such changes upon the *knowledge* and *rules* used within the tool. Depending on the implementation route adopted for the development of the tool, the upkeep regimes would vary. For example, in the simplest implementation of the tool imaginable, periodic reviews of the ‘Scope’ sections of the underpinning documents may suffice. For example the British Standard for Residential and Domestic Sprinkler systems (BS 9251) (BSI, 2005) is currently under review. Currently a stipulation in the Scope is that the standard may only be applied to buildings less than 20m in height. The review panel is considering if this height limit should be relaxed to 30m. If this change were to go ahead, then it can be envisaged that such a change may render it necessary to re-word question(s) and rule(s) used in the tool; such that the tool responds appropriately when it learns the height of a Residential or Domestic building. Formerly it would not have been possible to make a recommendation that one may protect a building using a BS 9251 system if it were, say 22m in height but if the change were to go ahead it may become possible to do so. If a more complex implementation was arrived at, which might seek to obtain considerable quantitative technical information from users (such as, for example some kind of hazard evaluation or survey technique) and match it against detailed requirements of the source documents; then it may be necessary to review both the 'Scope' sections and the remainder of the documents (building on the example of BS 9251 just given it may be that there is some interplay between the requirements given in the Scope section of the document (e.g. the 20 or 30m height limit) and requirements given elsewhere in the document pertaining to fire hazard evaluation and quantification (such height limits may subsequently be modified by the standard if it is discovered there is another reason to do so e.g. unusually high fire load being present). This would be a much more involved process. Initial and on-going interpretation of the source material and the translation of it in to the 'rules' that form the backbone of the system will require consultation with the identified stakeholders (Building Control Officers, Fire Engineers, Architects, Fire and Rescue Services, Organisational risk manager, Project Managers (Design and Build Contractors), Insurance Surveyors and Consultants and expert colleagues) who will all have an interest in ensuring that the derived interpretations are acceptable and workable from their perspectives. This will place a considerable burden upon the upkeep task associated with the tool.

At this stage, the system is to be developed with maintainability and upkeep in mind and this objective will carry forward through the life of the project.

6 CONCLUSIONS AND DISCUSSION

It has been demonstrated in numerous ways that there is a need for the research; consultation with and survey responses obtained from experts found agreement that current fixed firefighting system selection practice are fundamentally deficient. It has been found that having determined the need for fixed firefighting system, the subsequent hazard analysis may be absent or flawed. The next step in specifying a system, linking the hazard (however well it is described) with a suitable fixed firefighting system by way mitigation is then hampered by the absence of any system performance and reliability data; a choice of fixed firefighting system is offered by the market place and for example by BSI selection guide BS 5306-0 (BSI, 2011a). However, this document is merely a list with no specific guidance on, or method for, practitioners to discern the merit or otherwise of each available option in their specific circumstances.

At this stage a prototype fixed firefighting selection system has been developed and used to gather feedback from a closed group of experts. The prototype has proven the concept and also demonstrated that off-the-shelf development environments exist that are suitable for pursuing the development of the tool. Intended as a de-risking step, the prototype has a very limited scope and functionality. The next steps in the project are to develop and release a full ‘beta’ version of the selection tool, capture in-use feedback from a broader group of experts (insurance industry risk surveyors), implement changes as required and to release the first full release of the tool. A further more in-depth audit of available development environments and techniques will be undertaken to guide the process of the future development of the tool. Once the development environment has been determined it will be possible to efficiently begin to fully structure and order the knowledge required to develop the rules and outputs of the tool.

The progress achieved so far demonstrates that the tool has much potential to provide a way for an informed, responsible and independent body to impart aggregated knowledge and experience to the subject area. This may benefit a broad base of users. There is a real opportunity here to contribute to a change for the better in the selection and subsequent performance of fixed firefighting systems. This would result in improved outcomes where fires occur in buildings and equipment protected by fixed firefighting systems. In turn this would mean financial, environmental and societal impact of fire losses was lessened.

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APPENDIX C PAPER 3

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Bird, S. N., Ruikar, K., Bosher, L., Glockling, J. & Bouchlaghem, N. M (2014).

Decision Structuring Method for Selection of Fixed Firefighting Systems: development and lessons learned from case studies.

Proceedings of the 9th International Conference on Risk Analysis and Hazard Mitigation, 4th – 6th June 2014. New Forest, UK.

Abstract

Following a major fire, an historic structure in the UK has been rebuilt to an impressive standard. The fire protection strategy developed as part of the re-build process outlines the six key elements, which all focus on 'life safety' as opposed to 'property protection' ambitions. A 'property protection' approach (more commonly adopted in cases where assets and business continuity are to be protected) usually assures of protection of both life and property, whilst a 'life safety' approach considers a structure sacrificial, once sufficient time has been allowed for safe evacuation. In this case one might expect the protection strategy to place some considerable emphasis upon the need to protect the object itself in the event of another fire. A watermist fixed firefighting system was installed. Such systems are not supported by equivalently rigorous standards, installation and product certifications when compared to the predominant alternative technology; sprinkler systems. The resultant fire risk management and resilience measures were of concern to experts. This case study presents learning opportunities which have potential to inform future risk management strategies and therefore improve decision support.

The aim of this research is to better understand current practice in risk analysis and selection of fixed firefighting systems as part of the fire risk management strategy. Building upon previous work, this paper reports on case studies illustrating aspects of system selection practice and how this experience can contribute to the underpinning knowledge on which to base selection decisions. The paper concludes by considering the likely impact of the development of a Fixed Firefighting System Selection Tool (FFSST).

1 INTRODUCTION

Fixed firefighting systems, combined with appropriate risk assessment and mapping activities are relied upon at a micro scale as risk management measures in support of hazard management and control. Examples of such risk assessment processes include: for buildings; a prescriptive approach: the Department for Communities and Local Government's (DCLG) "The Building Regulations 2010 - Fire Safety, Approved Document B" [1], for buildings; a performance based approach: BSIs code of practice BS 7974 "Application of fire safety engineering principles to the design of buildings" [2]. For machinery BS EN 13478 "Safety of machinery - Fire prevention and protection" [3]. When applied effectively, mitigating measures, which may include fixed firefighting systems, can help to contribute at a macro scale to reduce economic and political vulnerability.

This research is concerned with understanding fixed firefighting system selection practice and seeking ways to optimise outcomes. Previous work [4, 5] has determined that there is a need for an Expert System or Decision Support system to be created to assist users in the complex task of assessing hazard and selecting the most suitable means by which to mitigate the risks posed.

Davenport et al., [6] suggest that "knowledge is neither data nor information". Their work then goes on to explore in some detail the process of combining data or information, through use or manipulation, to form knowledge or expertise which may usefully be applied. King [7] reports that knowledge is often described as "justified personal belief". Further that Knowledge Management (KM) allows organisations develop their knowledge bases and make it available to those who may benefit from it. He states that small increases in knowledge utilisation can yield great benefits. As highlighted in the work of Duan [8], the time of subject domain experts (such as those providing advice on fixed firefighting system specification and selection) is sought after and expensive. The scarcity and disparities in the quality and accessibility of supporting information from the perspective of the lay-person seeking to inform themselves, has been highlighted [4]. A considerable amount of the domain knowledge is tacit. Such tacit knowledge, such as custom and practice, tradition, inherited practice, implied values, and prejudgments is acknowledged to be potentially a crucial part of scientific knowledge [9]. So an Expert System, using primarily captured experience based techniques for providing the basis for building automated solutions [10] and "being suited to tasks where expertise, which is the vast body of task-specific knowledge, is transferred from a human to a computer" [11] appears attractive as a proposition in this application, where information and data requires augmenting to render it more useful and accessible to would-be users.

In pursuing the project aims and objectives (described in section 1.1), it has become apparent that finding usable underpinning data (or knowledge) for some aspects of the work (for example a means to consider the expected likely success rate of one fixed firefighting approach compared to another) can be difficult. A number of examples of fixed firefighting system selection practice of concern have recently come to the attention of the authors. Such

"Lessons learned" activities are recognised [12] as being potentially very useful in improving practices and outcomes. However it is also noted in the same work that there are challenges in the areas of the effort required to gain the benefit and subsequent dissemination and use. Care must be taken to ensure that these recent examples are helpful in building the evidence base upon which the design of the firefighting system selection tool will be based. The events are reported as case studies in this paper, accompanied by commentary on the significant findings or lessons and how this can translate in to useful knowledge to be captured in this research.

1.1 AIM AND OBJECTIVES

The research aim is to investigate the process of selection of fixed firefighting systems and if warranted to develop a means to assist with the decision making process. Previous work [4], [5] has determined that there is a need for the FFSST. It will partially automate the process of fixed firefighting system selection by collecting and analysing relevant data and making recommendations to the user and additionally it should serve as an educational resource by providing information and indirectly by signposting the user to the disparate sources of pre-existing supporting knowledge available to them.

1.2 FIXED FIREFIGHTING SYSTEM SELECTION TOOL (FFSST)

The Expert System or Decision Support system referenced above is referred to as a Fixed Firefighting System Selection Tool (FFSST) in the remainder of this paper.

1.3 FIXED FIREFIGHTING SYSTEMS

The term “Fixed Firefighting System” is in common use in literature as a generic descriptor for any fixed (installed and non-portable) firefighting (with suppression or extinguishing objective) system. Examples of which include the British Standards Institution’s (BSI) standard for “Components for gas extinguishing systems” (multiple parts) [13], DCLGs “Fire safety risk assessment guidance document” [14].

Common causes of fire include electrical equipment malfunction, electrical distribution system malfunction, use of cooking equipment and undertaking hot-works, industrial processes and human actions to name a few [15]. In the built environment as the density, complexity and scale of populations and activity within a building increase, then the potential sources of causes of fire will also increase dramatically in number (electrical equipment and distribution systems are a good example of this). So too might the potential scale and consequence of a fire. Fixed firefighting systems tend to be specified as additional fire protection and resilience measures when various perceived risk and consequence thresholds are breached. They may be installed throughout entire buildings or installed to protect local ‘objects’ (high risk or consequence equipment for example). In the established UK framework (regulations, guidance, custom and practice) for the built environment, fixed firefighting systems are specified or proposed as risk mitigation features under certain circumstances in a number of places. Notably: Approved Document B [1], LPC Design Guide [16], British Standard (BS) 9999 [17], BS 7974 series [2], The Supply of Machinery (Safety) Regulations [18] and the Supply of Machinery (Safety) (Amendment) Regulations [19]. BRE Global’s “Sprinkler systems explained: A guide to the sprinkler installation standards and rules” [20] tells us that sprinkler systems (a type of fixed firefighting system) are installed mostly; to meet legislative requirements, or to achieve risk reduction for business resilience purposes.

1.4 'LIFE SAFETY' & 'PROPERTY PROTECTION' DESIGN OBJECTIVES

Fire risk management practice in the UK has evolved to the point where two clearly distinct protection objectives have emerged, commonly referred to in the sector as 'Life safety' or 'Property protection' [5]. The distinction is perhaps most clearly made in BSIs BS 7974 series "Application of fire safety engineering principles to the design of buildings", part 8 "Property protection, business and mission continuity, and resilience" which states "*Frequently, the contents of a building and the work conducted within it are of considerably greater value than the building itself, either intrinsically because of their monetary or historic or cultural value, or indirectly because of the effects of their loss on business or mission continuity, as can be the case for example in computing suites, archives, many industrial plants and also in educational establishments*" [21., Section 0.1]. The introductory text continues to confirm that the UK national Building Regulations [22] are intended only to go as far as mandating that *life safety* considerations be adequately designed for.

Scotland is proposing regulatory changes in its public consultation [23] that acknowledge a difference between the approaches to protection of life and property and question the extent of the remit of the building regulations, such is the strength of the argument that good levels of property protection are also in the interests of society. "*...Concerns about fire have traditionally centred on life protection rather than asset protection. A primary objective of the building standards system however is to 'further the achievement of sustainable development.' The sustainability of communities could be served by the protection against both deliberate and accidental fires in buildings such as schools that serve as social assets and components of the local economic network....*" [23., Section 2.15.0].

The remainder of this paper outlines the methods used, presents the case studies and key findings, and details the contribution they make to the development of the Fixed Firefighting System Selection Tool.

2 RESEARCH METHODS

The research methods used in preparation of the material reported in this paper have included: literature review (which included regulations, standards, codes of practice and supporting guides), review of related reported case study material (which included fire incident reports, fire engineering design rationales, risk survey reports and independent expert reviewer opinions), consultation and correspondence with experts (who included risk surveyors, insurance industry risk underwriters, fire engineers and fixed firefighting system suppliers). The case studies reported in this paper were used to contribute to the development of the FFSST, as described in subsequent sections of this paper. Owing to commercial sensitivities it has been necessary to preserve a degree of anonymity in some cases.

3 CASE STUDIES

This section considers case studies which serve to illustrate a variety of influences upon fixed firefighting system selections. The specific case studies were selected because they were contemporaneous to the research, sufficient material was available to make useful deductions and contributions to this research and they span a variety of quite disparate issues all of which may be faced when making a fixed firefighting system selection; thus the issues encountered are germane and highly transferable.

3.1 CASE STUDY 1: ACTIVE FIRE PROTECTION OF AN HISTORIC STRUCTURE

The structure, which was generally considered a unique and highly valued cultural relic and an important part of the nation's heritage, suffered a fire. Partly on account of it not being protected by any active firefighting provision, the fire damage was extensive. Subsequently it has been fully restored at very considerable expense. The Fire Protection Association's (FPA – the industrial sponsor of this research) opinion was sought on the fire engineering design and active fire protection measures proposed to help protect an historic structure. In the ensuing review process, the opportunity arose to review the instructions of the commissioning body (the 'owner' of the structure), the adopted fire engineering design and the design of the active fire protection system. As part of the review, consultations were held with subject matter experts from the Insurance sector. The review concluded that the protection objectives have been incorrectly identified. Considering the impact of the different objectives BSIs Published Document PD 7974-8 states "Although life safety is of utmost importance, a building design which focuses exclusively on life safety might not adequately protect property and business continuity resulting in a building, or plant, with diminished resilience to the effects of fire" [24., Clause 0.2.]. Assumptions based upon this incorrect identification of the protection objective were carried through to the design of the mitigating features. Finally, variability in the availability, reliability and maintainability of different fixed firefighting systems [5] had not been understood and consequently overlooked.

Key learning outcomes of this case study for this research: identification of protection objectives is complex but critical step. Seeking to ascertain the correct objective should be part of the selection process. There may be opportunities in this research to highlight some of the difficulties commonly encountered in this step. The potential disparity in likely performance of different types of systems should also be considered and highlighted in the system selection process.

3.2 CASE STUDY 2: FIRE AND RISK MANAGEMENT JOURNAL (FRM) ARTICLE

An article appeared in a sector trade journal, which is published by the FPA. Typical subscribers to this journal include similar groups of people as have been identified previously in the research as being potentially responsible for making decisions when it comes to firefighting system selection. The article was authored on behalf of the trade association representing a particular type of fixed firefighting system. Whilst the article presents some interesting ideas, subject matter experts at the FPA agreed that aspects of the article appeared unbalanced, which could lead to readers being misinformed. The article exhibited bias in that, for example, no mention of the most obvious alternative choice (sprinkler systems) for the given risk was made. Some of the claims made may be overstating the capability and maturity of the technology. For example by suggesting the technology should be installed to "recognised standards" and then citing "British Standards DD 8458-1: 2010: Fixed fire protection systems. Residential and domestic watermist systems. Code of practice for design and installation and DD 8489-1: 2011: Fixed fire protection systems. Industrial and commercial watermist systems Code of practice". This is misleading because these documents [25, 26] are not Standards (the front covers explicitly state "This publication is not to be regarded as a British Standard"). This is important because compliance with appropriate national or international standards is often regarded as a de-facto means to demonstrate fitness for purpose "*Where conformity assessment depends on the measurement of the parameters of* *performance of a product or process, measurements or test results should be traceable to national or international measurement standards*" [27., p. 5.].

Such material may be a factor contributing to the acceptance of systems in situations such as that highlighted in the previous case study; where, on balance, experts would consider the application to be unsuitable.

Key learning outcomes of this case study for this research: As in the previous case study, the potential disparity in likely performance of different types of systems should be considered and highlighted in the system selection process. The issue also highlights the scarcity of the comparative evidence on system availability, reliability and maintainability required in order to do so. Thus reinforcing the need to develop a means to evaluate the anticipated availability, reliability and maintainability as part of this research.

3.3 CASE STUDY 3: PROTECTION OF A HIGH RISK PIECE OF INDUSTRIAL EQUIPMENT

The FPA was again asked for its opinion on the suitability of fixed firefighting system designs intended to protect a high risk piece of industrial equipment (in this case a computer numerically controlled (CNC) cutting machine). The machine was a high value piece of equipment in itself, but the perhaps more significant factor was the vulnerability of a process of a much higher value upon the equipment. If the machine was damaged or out of service for any considerable period, the commercial consequential losses (such as loss of orders and breach of contracts) could be of the order of tens of millions of pounds.

The equipment incorporated significant quantities of oil, used as a lubricant and coolant. In close proximity to this were potential sources of ignition (heat from the friction arising in the process and sparks from the cutting operation). Experts internal and external to the FPA were consulted and a review of standards and literature was undertaken. The findings were that whilst there is some published guidance it is somewhat short on delivering what it sets out to.

BS EN 13478 – "Safety of machinery — Fire prevention and protection" [28]. This standard invites the user to undertake hazard evaluations as per the methods of EN 1050 [29] and EN 292-1 [28] and cross refers to a number of specific clauses within EN 292-1 [28]. On doing so, if the machine is considered not to be "*safe*" [28, Figure 4.] then it is suggested "*the user make improvements, considering the following points in order*" [28, clause 5.]. However the referenced EN 292-1 [28] is withdrawn, replaced by BS EN ISO 12100-1 "Safety of machinery. Basic concepts, general principles for design. Basic terminology, methodology" [9], which is also withdrawn, replaced by BS EN ISO 12100 "Safety of machinery. General principles for design. Risk assessment and risk reduction" [30]. In the case of BS EN 13218 "Machine tools - Safety – Stationary grinding machines" its stated scope is to "*...specify the technical safety requirements and/or protective measures to be adopted by persons undertaking the design, construction and supply of stationary grinding machines ...".* At clause 5.8 "*Measures against fire and explosion hazards*" it states "*...Such measures may include: Fire extinguishing devices, Pressure relief devices* ...". The use of the word 'may' (instead of 'shall') renders it ambiguous as to whether fire extinguishing devices are required or not.

Key learning outcomes of this case study for this research: Both sets of cited guidance contain significant areas of subjectivity and inconsistency; with further difficulties in application being encountered due to obsolescence of referenced documents. These problems were encountered in areas that could make a critical difference to how and to what design fire protection measures were implemented and are considered a real problem to practitioners seeking to apply the guidance. FPA are aware of instances when the design of fixed firefighting systems has been compromised and it is considered that better guidance could have helped to avoid such compromises. At this time, no more definitive standardised guidance on the protection of such risks was identified, therefore it is considered there is a gap in the base of underpinning knowledge relating to essential principles of the design of fixed firefighting protection for high risk and consequence objects such as the one considered in this case.

4 IMPLICATIONS FOR THE FFSST DEVELOPMENT

The positioning of the learning outcomes from the case studies is within the development of the FFSST is illustrated in Figure 1.

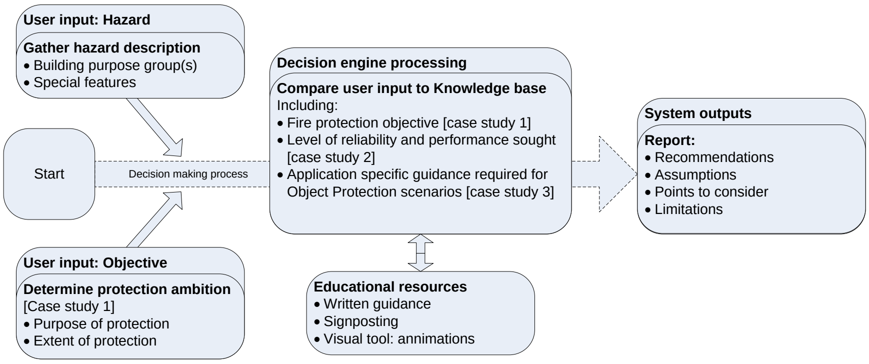

Figure 1: Overview of FFSST architecture incorporating case study lessons

It is intended that improvements in the observed position from the three case studies can be made in the following ways: Seeking to ascertain the correct fire protection objective is a critical (but complex) step and should form part of the fixed firefighting system selection process. It will be possible to construct the FFSST such that early in the process, the tool asks the user what the protection objective is. It will be necessary to accompany this question with education material giving advice on the differences and importance of this point to outcomes. This could be accomplished by explanatory text, illustrations and possibly even animations.

The absence of and need for performance (reliability) data relating to different types of firefighting systems, or alternative to this, an adequate means to anticipate what the approximate level of reliability might be is considered a more complex problem and will be the subject of further work in this research.

When considering knowledge gaps in guidance for the design of fire protection for high risk individual pieces of equipment, it is proposed that incremental improvements can be made by filling some of the gaps identified in section 3.3. For example the disjointed structure of the existing information (in the referenced British and European Standards) could be improved by consolidating and enhancing the advice offered and making the advice accessible via the FFSST. Again, further work will be required to develop and structure this portion of 'knowledge' within the tool. A starting point would be to consider the overarching intent of the British and European Standards, graphically represented in figure 2.

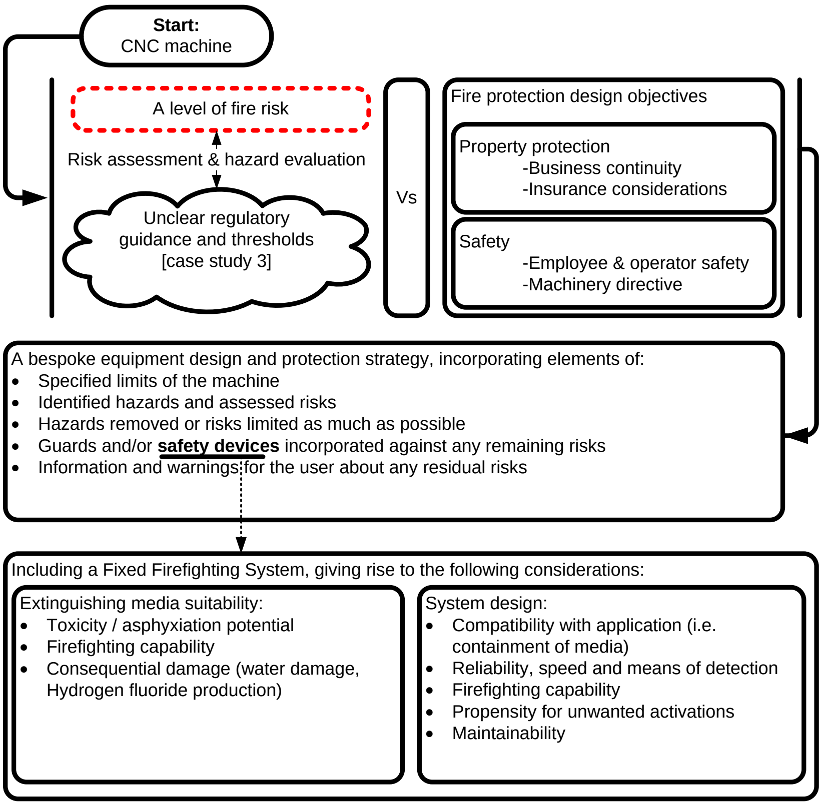

Figure 2: Possible FFSST implementation model for object protection scenarios

5 CONCLUSIONS

The case studies reported in this paper illustrate the importance of correctly identifying fire protection objectives in order for the outcome of the subsequent fire protection measures design process to stand the best chance of delivering the most suitable solution. They also highlight examples of the potential misinformation being propagated by some factions of the fire protection industry, the incomplete support afforded to users of fixed firefighting systems in the form of the relevant European regulations and associated guidance and the lack of useable expected performance data. Areas that are particularly problematic are risk assessment and lack of consistent methods of risk mapping, giving rise to inconsistent levels of risk management, hazard prevention, management and control. However, in identifying these problems and sources of literature, and through the continuation of this research, using the methods outlined in this paper and previously reported [4] and [5], it will be possible to systematically derive improvements in the areas of identified shortcomings, through filling knowledge gaps and enshrining the knowledge in the decision support system and/or through creating educational resources (accessed through the decision support system) in order to tackle frequently misunderstood aspects. King notes that even small increases in knowledge utilisation will yield great benefits [7]. This work has the potential to deliver considerable increased in knowledge.

The next steps in the research will be to: complete the development of a methodology to consider the likely availability, reliability and maintainability of different types of fixed firefighting systems, to complete the development of the first release of the FFSST and to evaluate its performance.

These steps will help to fulfil the objectives of the research; to evidence the need for and deliver a decision support and educational tool (the proposed FFSST) intended to improve levels of safety and security. Ultimately this is to help achieve improved levels of business continuity and resilience and at the macro scale contributing to reduced political and economic vulnerability.

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APPENDIX D TECHNICAL OUTPUT 1

Full reference

Bird, S. N. (2014)

TB234 Protection of High Hazard Storage (HHS) configurations.

LPC Rules for Automatic Sprinkler Installations - Incorporating BS EN 12845. Moreton-in-Marsh, UK: The Fire Protection Association.

Abstract

The identified need for the work of "TB234 - Protection of High Hazard Storage (HHS) configurations)" in connection with this research was recorded in (Bird et al., 2012). Subsequently this 47 page technical supplement has been authored (with input from a small sub-committee of experts by a series of meetings). It was extensively peer-reviewed by experts from the fire protection industry and recently published. It now forms part of the widely used firefighting system standard "LPC Rules for Automatic Sprinkler Installations - Incorporating BS EN 12845" (FPA, 2014b). It also contains much material which forms an ideal information/education/standard resource which has been signposted to in relevant circumstances from the FFSST.

It has also been submitted to CEN (European Standardisation Committee) for consideration for adoption in future editions of EN 12845 (the British and European Sprinkler Standard).

Fire Protection Association
Special Projects Group

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3rd September 2014

Verification of authorship

Dear Dr Ruikar,

Please accept this letter as confirmation that Simon Bird, EngD Research Engineer acted as the lead author in relation to the following publications, which form an integral part of his EngD research:

BIRD, S. N., GLOCKLING, J. & STEPHENS, J., 2011. *IQ1: Water Mist Questionnaire: Building Protection*, Moreton in Marsh, Gloucestershire, UK, The Fire Protection Association.

BIRD, S. N., GLOCKLING, J. & STEPHENS, J., 2011. *IQ2: Water Mist Questionnaire: Object Protection*, Moreton in Marsh, Gloucestershire, UK, The Fire Protection Association.

BIRD, S. N. 2014. *TB234 Protection of High Hazard Storage (HHS) configurations. LPC Rules for Automatic Sprinkler Installations - Incorporating BS EN 12845*. Moreton-in-Marsh, UK: The Fire Protection Association.

Consistent with our quality assurance procedures, such publications are drafted and prepared by the named author(s), subjected to a thorough peer review process by panels of relevant industry experts and upon completion published by the Fire Protection Association.

Yours sincerely,

Dr J. D. L Glockling
Technical Director, The Fire Protection Association

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TECHNICAL BULLETIN 234: 2014: 1

Protection of High Hazard Storage (HHS) configurations

Replaces or supplements: 6.3.2, Table 2, 7.2, Table 4 , Table 5, 11.1.3, 11.2 to 11.4.1.1, 12.5, 13.4.4, Annex G.5 and Annex G.7.
Implementation date: The requirements of this Technical Bulletin shall be applied to all orders placed after 31 May 2014. Where all stakeholders agree, it may be used immediately.

TB234.1 INTRODUCTION

This Technical Bulletin specifies the requirements for the protection of various High Hazard Storage configurations using a Control Mode Density Area (or CMDA) approach.

Technical Bulletin TB235[1] specifies requirements for the Control Mode Specific Application (CMSA) approach (similar to the approach known as Early Suppression Fast Response (ESFR)) for the protection of high hazard storage risks. Of the design approaches TB234 and TB235, whichever is selected should be followed in its entirety.

Technical Bulletin TB234 or TB235 should be applied where the hazard classification is equal to or greater than HHS1. These TBs are not applicable to occupational health (OH) risks including permitted amounts of storage, in such cases see BS EN 12845 clause 6.2.2 and other relevant clauses. These TBs are not applicable to High Hazard Process risks.

Design details are given in the section TB234.4 entitled 'Design Characteristics' in relation to the following commonly observed design challenges:

- sprinkler head selection;
- ceiling clearance;
- areas protected by ceiling level sprinklers only;
- areas protected by ceiling level and intermediate level in-rack sprinklers;
- housekeeping;
- dry and alternate systems;
- solid or slatted shelves;
- bracketing and pipework supports;
- mezzanines, platforms and ducts;
- flues;
- oversize flues;
- ceiling slope;
- ceiling clearance for goods stored above the uppermost level of intermediate level in-rack sprinklers;
- protection of rack-ends;
- areas of differing design density;
- protection of structural steel work;

[1] Intended for future publication, to update TB209.

TB234

- 'incidental' storage;
- idle pallets (wooden pallets and plastic pallets);
- block separation and aisle widths;
- bulkheads;
- baffles and water shields;
- ventilation – smoke vents;
- ventilation – forced and HVLS (high volume low speed);
- flexible pipes and joints to intermediate level in-rack sprinkler arrays;
- number of intermediate level in-rack sprinkler heads per valve set (replaces BS EN 11.1.3 and is identical to relevant part of TB229.3.8);
- detailed example of sprinkler head locations;
- sprinkler guards (identical to BS EN clause 14.6);
- dimensions and sprinkler head locations (replaces BS EN 12.5);
- sprinkler head obstructions;
- pre-calculated systems.

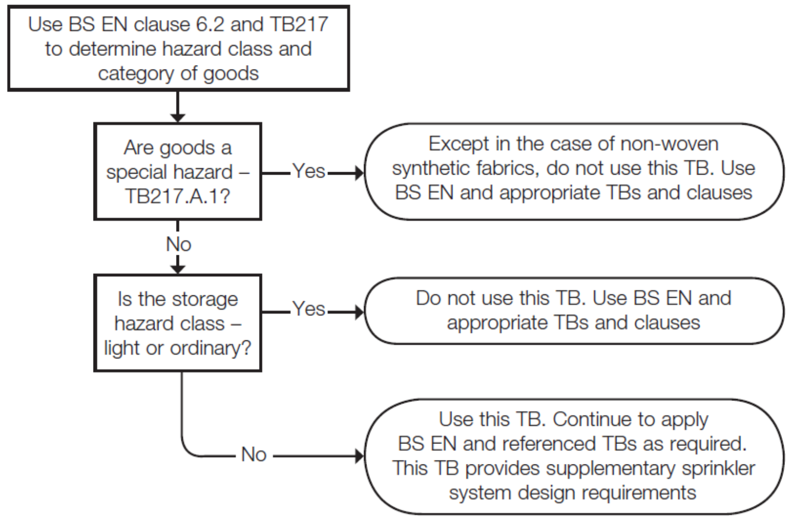
This Technical Bulletin specifies the protection design requirements for the following storage configurations:

- free standing or block storage;
- single and double row beam pallet racking configurations;
- multiple row rack storage;
- double deep pallet racking;
- drive in, flow through and push back racking;
- post pallets – single and multiple rows;
- cantilever racking (long items);
- solid or slatted shelving configurations;
- solid or slatted shelves 1m or less deep (aisle to aisle);
- solid or slatted shelves of greater than 1m and no more than 2,8m deep (aisle to aisle);
- solid or slatted shelves greater than 3,2m deep (aisle to aisle);
- carpet storage;
- non-woven synthetic fabric storage.

TB234.2 HOW TO DETERMINE WHETHER THIS TB APPLIES

Determine the storage category of the stored goods. This process needs to be completed for each type or area of storage within the premises. See Figure TB234.F1.

Figure TB234.F1: Determine whether this TB applies



COMMENTARY AND RECOMMENDATIONS ON TB234.2

Where no equivalent examples are given, appropriate full scale fire test evidence must be sought. Where the available fire test evidence is not applicable, it may be necessary to undertake appropriate full scale fire testing to ensure design adequacy.

TB234.3 DEFINITIONS

Aisle – the space between racks of storage, often used to provide access to the storage.

Note: Aisles less than 600mm wide are to be considered as flues for the purposes of this document.

Bulkhead – a solid and continuous fire-resisting partition made from material meeting at least the rating Euroclass A1 or A2 of BS EN 13501 Part 1.

Ceiling clearance – the distance from the top of the storage block (measured from the maximum allowable height of the block to the ceiling sprinkler deflectors). See TB234.4.2, Figure TB234.F2.

Horizontal support – the support provided to stored units. This may be anything providing the means of support: beams, shelf, slats, rails, runners, floor, hanger, etc. Lower unit(s) of stored goods may also provide support to units stored above but are excluded from this definition.

Note: According to the geometry and nature of stored units there may as a result be any number of units high per horizontal support, within the constraints of the requirements of this document.

Incidental storage – ad-hoc storage such as work in progress in manufacturing, assembly or process areas, which may not otherwise be considered as HHS risk.

Longitudinal flue – clear vertical space through stored goods orientated parallel to the normal loading aisle, which readily permits rapid rise of hot gases through convection and water to penetrate (see TB234.4.7).

Pallet load – one single pallet load of goods.

Special hazard – see TB217.A.1 and TB234.5.7.2 as appropriate.

Storage category – a classification system (I, II, III, IV) used to express the fire hazard of stored goods, which considers material combustibility, packing and storage configuration.

Transverse flue – a clear vertical space through stored goods orientated perpendicular to the normal loading aisle, which readily permits rapid rise of hot gases through convection and water to penetrate (see TB234.4.7).

COMMENTARY AND RECOMMENDATIONS ON THE TERM "TIER"

The term "tier" is widely used in an attempt to describe "levels" of storage. However as this term is incompletely defined and owing to the changing nature of stored goods it is now considered a redundant term. Instead, the design concepts in this document which would previously have made use of the word tier are now described in terms of vertical distances, horizontal supports and in some cases limitations upon the stored goods.

TB234.4 DESIGN CHARACTERISTICS

This section specifies various requirements for design of sprinkler protection systems for HHS occupancies.

COMMENTARY AND RECOMMENDATIONS ON TB234.4

This section is intended to provide clarification and illustration of design issues that have commonly been found to cause difficulties in sprinkler protection design.

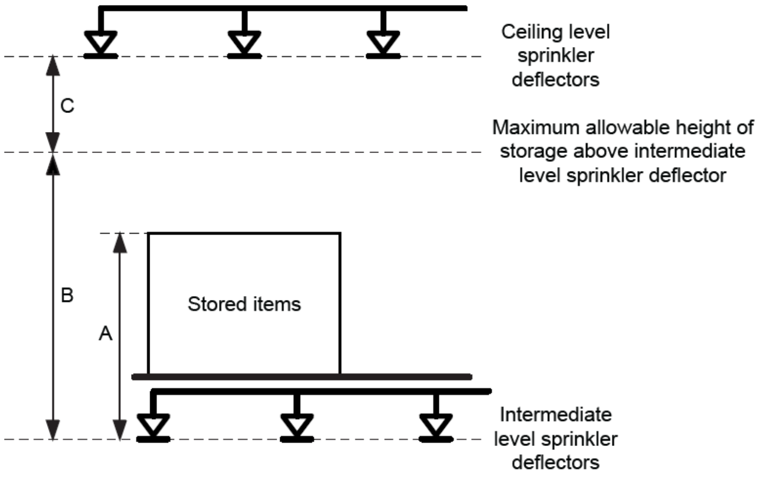
TB234.4.1 Sprinkler head selection

Sprinklers shall be selected in accordance with Table TB207.T1.

TB234.4.2 Ceiling clearance

Ceiling clearance is to be measured from the top of the maximum allowed storage height to the ceiling sprinkler deflectors. See Figure TB234.F2 for an illustration showing how to measure ceiling clearance where ceiling and intermediate sprinklers are used or Figure TB234.F3 where ceiling only sprinklers are used.

Figure TB234.F2: Illustration of 'ceiling clearance' (dimension 'C')

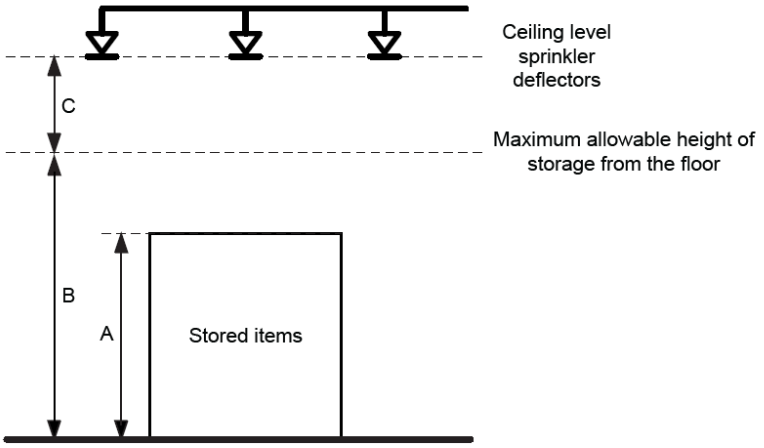


Legend
'A' - Actual height of storage above the uppermost level of intermediate level sprinkler deflectors
'B' - Allowable height of storage above the uppermost level of intermediate level sprinkler deflectors
'C' - Ceiling clearance (distance from maximum allowable height of storage to ceiling level sprinkler deflectors above)

TB234.4.2.1 *Areas protected by ceiling level sprinklers only*

Permissible ceiling clearances are specified in each of the sections in TB234.5 detailing sprinkler protection for the given storage configurations and in no case shall exceed 6,0m.

Figure TB234.F3: Illustration of 'ceiling clearance' (dimension 'C')



Legend
'A' - Actual height of storage from the floor
'B' - Allowable height of storage from the floor
'C' - Ceiling clearance (distance from maximum allowable height of storage to ceiling level sprinkler deflectors above)

Where ceiling clearance exceeds the permitted distance, one of the following mitigating measures shall be taken:

- use of suitable rack storage with intermediate level in-rack sprinklers (and with a row of intermediate level in-rack sprinklers directly above the top level of racked storage);
- a non-combustible false ceiling or mezzanine made from material meeting at least the rating Euroclass A1 or A2 of BS EN 13501 Part 1 shall be installed above the storage with sprinkler protection above and below, to reduce the effective ceiling clearance. Ceiling strength to be sufficient to withstand a 50N/m^2 updraft.

TB234.4.3 **Housekeeping**

COMMENTARY AND RECOMMENDATIONS ON TB234.4.3

Good housekeeping of warehouse and storage facilities is essential to ensuring the fire risk does not significantly alter and therefore possibly render the fire suppression system design unsuitable.

Experience has shown that problems commonly occur in respect of:

- ad-hoc storage at, or near, the ends of aisles;
- changes to storage configuration (eg changes in storage levels within racks or parts of rack that may leave existing sprinklers exposed to impact damage or obstructed by the stored goods);
- changes to the nature of stored goods;
- changes to lighting configurations;
- battery chargers at or near storage.

Further guidance is given in RC18: *Recommendations for fire safety in warehouses* (RISCAuthority, 2013).

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TB234.4.4 Dry and alternate systems

Dry and alternate systems (alternate systems are no longer permitted in new installations to the LPC Rules) should be avoided. Should it nonetheless be necessary to install a system that can operate in the dry mode at roof level, the area of operation should be increased by 25%.

Intermediate level in-rack sprinklers shall always be installed in the wet mode.

> COMMENTARY AND RECOMMENDATIONS ON TB234.4.4
>
> As an alternative to installing a dry system, a type B pre-action system may be used.

TB234.4.5 Bracketing and pipework supports

See BS EN clause 17.2.

TB234.4.6 Mezzanines, platforms and ducts

See BS EN clause 12.4.10.

TB234.4.7 Flues

The requirements for flues vary by storage configuration. See each relevant Storage Configuration section in TB234.5.

For free standing or block storage configurations type ST1 (TB234.5.1) there are no requirements specified regarding the minimum size and horizontal distance between flue spaces for this type of storage; however, arrange storage such that flue spaces that are provided are not blocked from water penetration [reference FM DS 8-9 (June 2011), clause 2.2.3]. See also TB234.4.8.

TB234.4.8 Oversize flues

Where flue widths exceed 600mm between storage racks (ST4) or shelving (ST15 or ST16) storage arrangements then each rack or arrangement shall be treated as a single row and protected accordingly with its own intermediate level in-rack sprinkler protection.

See also TB234.4.7.

TB234.4.9 Ceiling slope

Ceiling slopes shall not exceed 10° (17,6%) gradient.

> COMMENTARY AND RECOMMENDATIONS ON TB234.4.8
>
> In installations where the specified slope is exceeded, the following alternative solutions may be considered for use:
>
> - Intermediate level in-rack sprinklers protection including protection above the uppermost level of storage shall be used;
> - The impact upon the area of operation of the sprinkler system shall be taken in to consideration and provision for the area adjusted accordingly.
>
> The insurer (and authority, if applicable) shall be consulted upon the acceptability of the proposed design solution on a case-by-case basis.

TB234.4.10 Protection of rack-ends

Extension and modifications (such as picking and distribution (P&D) stations) shall be protected as per the regime used to protect the rack.

TB234.4.11 **Areas of differing design density**

Where different ceiling or roof protection design densities are used in the same compartment (ie attributable to different hazard characteristics beneath), the most onerous density shall overhang the actual hazard boundary by one sprinkler pitch (extend beyond the actual change in hazard boundary).

In undertaking the hydraulic calculations, the designer shall always ensure that all potential assumed maximum areas of operation (AMAOs) are within the performance capabilities of the water supplies.

TB234.4.12 **Protection of structural steel work**

COMMENTARY AND RECOMMENDATION ON TB234.4.12

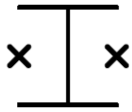
In addition to the obligatory statutory requirements to guard against structural collapse, the following guidance is offered: Where columns are sited within storage piles and are not within a sprinkler protected flue, structural columns of less than 2 hours' fire resistance, amongst the storage, should have provision for cooling sprays from small orifice narrow angle sealed sprayers.

There shall be one sprayer located on each side of the column at the level of the top of the storage with lower opposed pairs of sprayers, at intervals not exceeding 4,5m, to the base of the column. Where there are obstructions to water downflow, sprayers shall be located immediately below each obstruction.

The sprayers shall be directed to wet the surface area of the structural member (with water impinging on any column web) at a rate of 10mm/min related to the surface area of the structure over a 4,5m length.

Figure TB234.F4 illustrates two sprinkler heads protecting a vertical I-beam.

Figure TB234.F4: Vertical structural I-beam protected by two sprayers



The demand for water for column protection is to be added to the appropriate AMAO.

TB234.4.13 **'Incidental' storage**

Where 'incidental' storage occurs due to a production process or building use, the storage risk presented shall also be subject to the hazard assessment as specified by BS EN Clause 6.2.

Requirements for storage of idle pallets are given in TB234.4.14 and TB215.

COMMENTARY AND RECOMMENDATION ON TB234.4.13

Where various quantities and configurations of storage occur, all cases should be considered and the design should be sufficient to cater for the worst-case scenario.

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TB234.4.14 **Idle pallets**

TB234.4.14.1 ***For wooden pallets:***

In High Hazard protected risks, the freestanding storage of idle pallets shall meet all of the following criteria:

- limited to blocks not exceeding 2 x 2 pallets and 1,6m high irrespective of the density of water provided;
- not be stored within 5m of combustible walls (walls that cannot satisfy BS EN 13501 Part 1 Euroclass A1 or A2 with >2 hour fire rating);

- no other pallet stacks or stored goods shall be within 5m (including freestanding or racked stored goods and other blocks of freestanding pallets).

Where these limitations cannot be complied with, TB215 shall be applied in full.

COMMENTARY AND RECOMMENDATIONS ON TB234.4.14.1

1.Idle pallets stored in almost any quantity present a very severe fire risk. Where they are present or likely to be present the fire insurer should always be notified. Where dispensation from the requirements of TB234.4.14 is required, this should be at the discretion of the fire insurer and should be agreed in writing, including the limitations of such deviations.

2. This TB is not applicable to OH protected risks, but in such cases idle pallet storage shall be confined to single stack blocks not exceeding 1,2m high. A clear space of 1,5m should be maintained between the pallets and any process or combustible wall. No other pallet stacks or storage shall be within 5m. Where these limitations cannot be met or are exceeded, TB215 shall be applied in full.

TB234.4.14.2 *For plastic pallets:*

For plastic pallets stored in any quantity, TB215 shall always be applied in full.

COMMENTARY AND RECOMMENDATIONS ON TB234.4.14.2

Plastic pallets can present a considerable fire hazard. Where unavoidable, plastic pallet storage (eg work in progress stack) should be confined to single stack blocks not exceeding 1,0m high. A clear space of 1,5m should be maintained between the pallets and any process or combustible wall. No other pallet stacks or storage shall be within 5m. Where these limitations cannot be met or are exceeded, TB215 shall be applied in full.

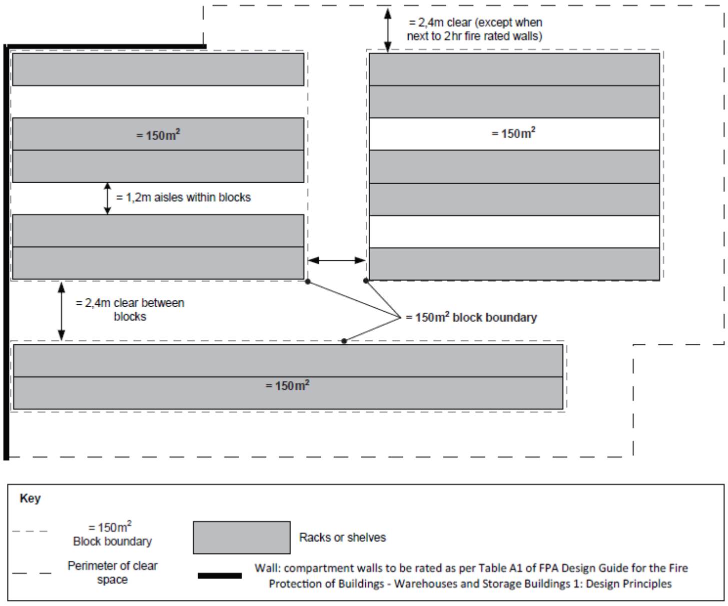
TB234.4.15 **Block separation and aisle widths**

See the requirements of the relevant section in TB234.5.

For ST4, ST15 and ST16 without intermediate level in-rack sprinkler protection, storage shall be limited as shown in Figure TB234.F5:

- storage blocks shall be limited to ≤150m² (including aisles within blocks);
- aisles within blocks shall be ≥1,2m;
- there shall be ≥2,4m clear space between and around blocks, except to non-combustible (BS EN 13501 Part 1 Euroclass A1 or A2) >2 hour fire-rated walls.

Figure TB234.F5: Example of block size, aisle width and clear space requirements



COMMENTARY AND RECOMMENDATIONS ON TB234.4.15

Experience has shown floor markings can complement good management of a facility and help promote good practice in maintaining required aisle widths.

TB234.4.16 Bulkheads

Where bulkheads are required as part of the in-rack protection regime, they shall be fire resisting and meet at least BS EN 13501 Part 1 Euroclass A1 or A2.

TB234.4.17 Baffles and water shields

TB234.4.17.1 Water shields

Sprinklers installed in racks, or under perforated shelves, platforms, floors or similar locations, where water from a higher sprinkler or sprinklers may cause wetting close to the bulb or fusible element, shall be fitted with a metal water shield with a diameter of between 75mm and 150mm.

Water shields on upright sprinklers shall not be attached directly to the deflector or yoke (except as part of an approved sprinkler assembly), and any bracket supports shall be designed so as to minimise obstruction to the sprinkler water distribution.

COMMENTARY AND RECOMMENDATION ON TB234.4.17.1

The water shields referred to here are intended to perform the function of a water shield, not a heat collector. See TB229.3.12 for more information.

TB234.4.17.2 *Baffles*

COMMENTARY AND RECOMMENDATIONS ON TB234.4.17.2

The baffles referred to in BS EN clause 12.3 are intended to perform the function of a water shield, not a heat collector. Studies (US Nuclear Research Council, 2002) have shown that rather than promote their operation as intended, heat collectors may delay or prevent the operation of sprinkler heads. If in special cases baffles are proposed as heat collecting devices, then appropriate testing should be undertaken to prove that there is no detriment to sprinkler head sensitivity and response time.

TB234.4.18 Ventilation – smoke vents

Where installed, smoke vents shall be implemented in a way such that they do not adversely impact upon the capability of the sprinkler system.

COMMENTARY AND RECOMMENDATIONS ON TB234.4.18

Experience has shown this can be best achieved by either:

- manual control of smoke vent operation (for activation by Fire and Rescue Service); or
- where systems are automatic, an appropriate activation time delay, triggered by the sprinkler system operation (where this option is exercised careful consideration needs to be given to the life safety implications – there will be an uncertain time delay from ignition to sprinkler activation in addition to any time delay between sprinkler activation and smoke vent opening). The authority should be consulted.

TB234.4.19 Ventilation – forced and HVLS (high volume low speed)

Forced ventilation shall be shut down immediately upon sprinkler or fire alarm detection (whichever occurs first). The effect of shutting down forced ventilation systems shall be considered by means of a risk assessment process (for example upon: accumulation of toxic gases, dusts, accumulation of explosive materials, availability of oxygen, etc).

HVLS fans should be centred between four sprinkler heads.

COMMENTARY AND RECOMMENDATIONS ON TB234.4.19

Forced ventilation systems can have a detrimental effect upon fire protection from sprinkler systems in a number of ways, for example: by moving hot gases, encouraging horizontal fire spread, ventilating a fire and adversely effecting sprinkler distribution patterns.

Where a risk assessment reveals that there could be life safety implications arising from de-activating such systems, agreement of the system implementation should be sought from insurers and any other relevant authorities.

TB234.4.20 Flexible pipes and joints to intermediate level in-rack sprinkler arrays

Where relative movement is likely to occur between different sections of pipework within the sprinkler system, eg in the case of certain types of racking, a flexible section or joint capable of accommodating the expected movement shall be fitted, in accordance with the requirements of BS EN clause 17.1.4.

Flexible connectors as defined in TB227.2.4 shall not be used.

TB234.4.21 Number of sprinkler heads per valve set (replaces BS EN 11.1.3 and relevant parts of TB229.3.8)

The maximum area controlled by a single wet alarm valve, including any sprinklers in a subsidiary extension, shall not exceed that shown in Table TB234.T1.

Table TB234.T1: Maximum size of wet pipe and pre-action installations

Sprinkler head location	Limit per valve set
HHS ceiling sprinklers	9,000m^2
Intermediate level in-rack sprinklers	2,000 heads

TB234.4.22 Detailed example of sprinkler head locations

See Figure TB234.F6, Figure TB234.F7 and Figure TB234.F8 for examples of locations to site intermediate level in-rack sprinklers heads in rack storage.

TB234.4.23 Sprinkler guards (identical to BS EN clause 14.6)

When sprinklers, other than ceiling or flush sprinklers, are installed in a position at risk of accidental mechanical damage, they shall be fitted with a suitable metal guard.

TB234.4.24 Dimensions and sprinkler head locations (replaces BS EN 12.5)

The specific requirements of applicable sections of this document for each type of storage shall be followed.

Whenever any rack or structural steelwork is likely to interfere significantly with the water discharge from the sprinklers, additional sprinklers shall be provided and taken into account in the flow calculation.

It shall be ensured that water from intermediate level in-rack sprinklers can penetrate the goods stored.

The minimum distance between a sprinkler head deflector and the underside of horizontal support for the level above shall be 25mm. Sprinkler heads and range pipes shall be located such that they are protected from mechanical damage by being behind pallet support beams. Sprinkler heads shall be centred in clear transverse flues and there shall be a clear space above stored goods of at least 150mm to the sprinkler deflector (see Figure TB234.F6).

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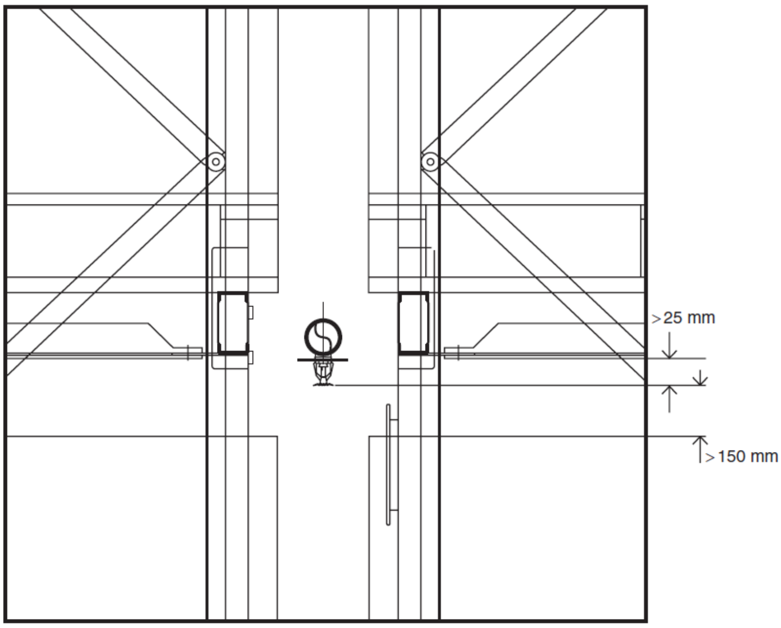
Figure TB234.F6: Detailed view of sprinkler head alignment with respect to storage system arrangement



See Figure TB234.F7. The 'A' sprinkler head shall be located in the flue(s). Sprinkler heads shall be 25mm clear of the racking upright. The 'B' sprinkler head is to be centred to clear the transverse flue.

Figure TB234.F7: Detailed view of sprinkler head alignment with respect to storage system arrangement

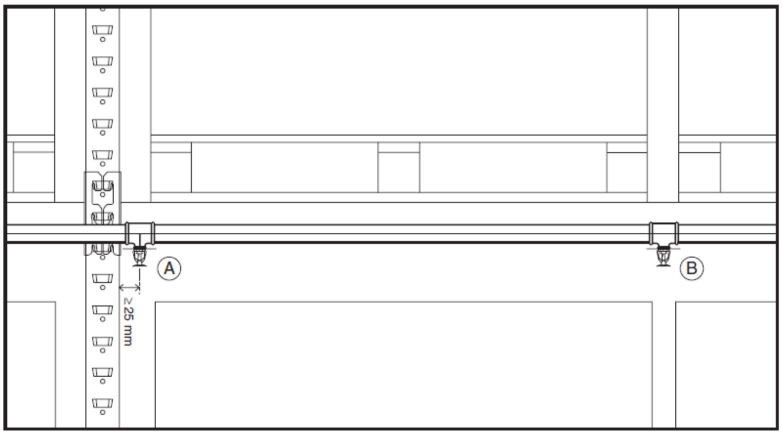


Figure TB234.F8 shows an end elevation detail. Sprinkler heads shall be sited at the rear face (away from normal loading side) of a single row rack. The head shall be at least 75mm away from the rack upright support. Where mesh is used, the head shall be sited inside the mesh. The minimum distance between a sprinkler head deflector and the underside of horizontal support for the level above shall be 25mm. There shall be a clear space above stored goods of at least 150mm to the sprinkler deflector.

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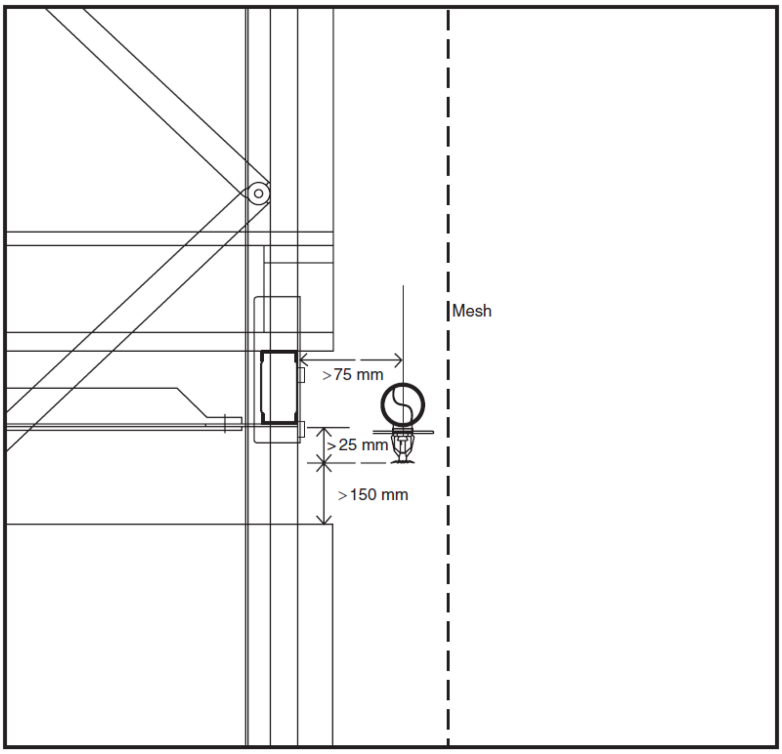
Figure TB234.F8: Detailed view of sprinkler head alignment with respect to storage system arrangement



TB234.4.25 **Sprinkler head obstructions**

Obstructions that will cause significant disruption or shadowing to the sprinkler head discharge shall be avoided. Where unavoidable, it may be necessary to install additional sprinkler heads.

TB234.4.26 **Pre-calculated systems**

Pre-calculated systems shall not be used for high hazard storage risks.

TB234.5 EXAMPLE STORAGE CONFIGURATIONS (Replaces BS EN 6.3.2)

The storage configuration shall be classified as follows:

- ST1: free standing or block stacking (see TB234.5.1);
- ST2: post pallets in single rows, with aisles not less than 2,4m wide (see TB234.5.2);
- ST3: post pallets in multiple (including double) rows (see TB234.5.2);
- ST4: palletised rack (beam pallet racking) (see TB234.5.3);
- ST8: Multiple row palletised racking (beam pallet and flow through racking) (see TB234.5.4 or TB234.5.5);
- ST15: lower-challenge shelving configurations (see TB234.5.6);
- ST16: higher-challenge shelving configurations (see TB234.5.6);
- ST10: Horizontal carpet storage racks (see TB234.5.7).

Free standing or block storage (ST1)

Note: For each storage method, there are specific limitations to storage heights depending on the type and design of sprinkler systems – see remainder of this TB and reference BS EN parts.

COMMENTARY AND RECOMMENDATIONS ON TB234.5

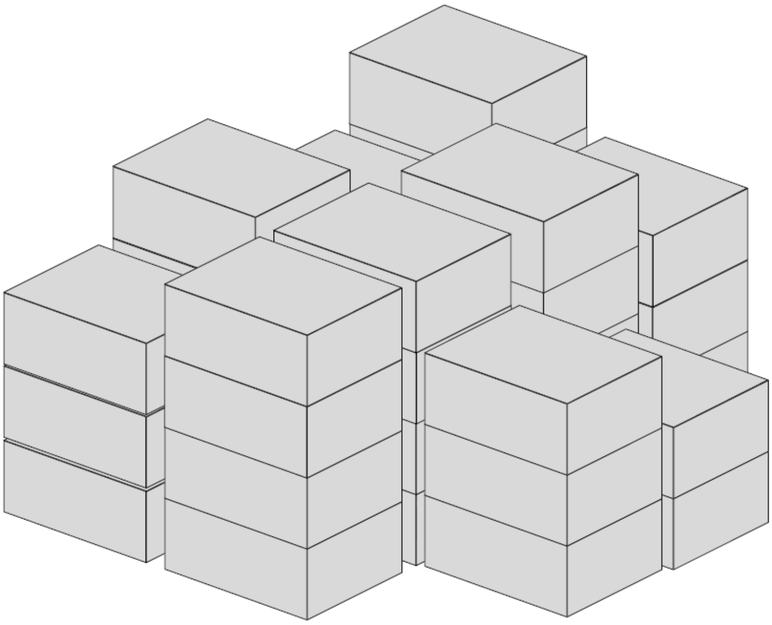
BS EN Storage classifications ST5 and ST6 are replaced in this Technical Bulletin by classes denoted as ST15 and ST16. The features of ST15 and ST16 are best described by the requirements outlined in section TB234.5.6. These new classes have some similarities and some differences when compared to ST5 and ST6. Care should be taken to avoid confusion between the old and the new classes.

TB234.5.1 Free standing or block storage (ST1)

TB234.5.1.1 Scope

This section applies to free standing or block storage. Figure TB234.F9 shows typical examples of this type of storage arrangement.

Figure TB234.F9: Example illustration of free standing or block storage (ST1) configuration



TB234.5.1.2 Requirements (replaces ST1 section of BS EN table 2):

- storage shall be confined to blocks not exceeding 150m² in a plan area for category I,II, III and IV goods;
- storage blocks shall be separated by a continuous clear space of at least 2,4m wide around the perimeter of the block;
- intermediate level in-rack sprinklers are not appropriate for this type of storage;
- where clearance to the ceiling from the maximum design height of the stored goods exceeds 4m one of the following mitigating features shall be provided:

Free standing or block storage (ST1)

- a non-combustible false ceiling or mezzanine above the block storage with sprinkler protection above and below (see TB234.4.2); or
- install racking with appropriate intermediate level in-rack sprinkler protection;

- consider suitability of ESFR protection approach (see TB209);
- sprinklers shall be selected in accordance with Table TB207.T1;
- Table TB234.T2 specifies storage height limits for each category of goods, the required design density and the area of operation.

Table TB234.T2: Design criteria for ST1 HHS with roof or ceiling protection only (replaces ST1 section of BS EN Table 4)

Storage configuration	Maximum permitted storage height (Note 1) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m^2)
	Category 1	Category 2	Category 3	Category 4		
ST1	5,3	4,1	2,9	1,6	7,5	
	6,5	5,0	3,5	2,0	10,0	
	7,6	5,9	4,1	2,3	12,5	260
		6,7	4,7	2,7	15,0	
		7,5	5,2	3,0	17,5	
			5,7	3,3	20,0	
			6,3	3,6	22,5	
			6,7	3,8	25,0	300
			7,2	4,1	27,5	
				4,4	30,0	

Note 1: The vertical distance from the floor to the sprinkler deflectors, minus 1m, or the highest applicable value shown in the table, whichever is the lower.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

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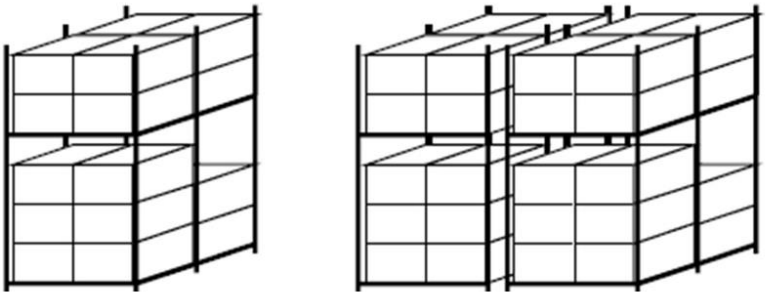
TB234.5.2 Post pallets – Single and Multiple rows (ST2 and ST3)

TB234.5.2.1 Scope

Figure TB234.F10: Example illustration of single and multiple row post pallet racking configurations (ST2 and ST3)



TB234.5.2.2 Requirements (replaces ST2 and ST3 section of BS EN table 2):

- for ST2 (single row configurations), for category I,II, III and IV goods, aisles between rows shall not be less than 2,4m wide;
- for ST3 (double or multiple row configurations), for category I,II, III and IV goods, storage shall be confined to blocks not exceeding 150m^2 in plan area. Blocks shall be separated by aisles not less than 2,4m wide;
- intermediate level in-rack sprinklers are not required;
- where clearance to the ceiling from the maximum design height of the normally stored goods exceeds 4m one of the following mitigating features shall be provided:
    - a non-combustible false ceiling or mezzanine above the block storage with sprinkler protection above and below; or
    - install racking with appropriate intermediate level in-rack sprinkler protection;
- consider suitability of ESFR protection approach (see TB209);
- Table TB234.T3 specifies storage height limits for each category of goods, the required design density and the area of operation for wet, dry and pre-action systems.

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Post pallets – Single & Multiple rows (ST2 & ST3)

Table TB234.T3 Maximum permitted storage heights, design density and area of operations for roof or ceiling only protection for ST2 and ST3 (replaces ST2 and ST3 section of BS EN Table 4)

Storage configuration	Maximum permitted storage height (Note 1) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m^2)
	Category 1	Category 2	Category 3	Category 4		
ST2	4,7	3,4	2,2	1,6	7,5	260
	5,7	4,2	2,6	2,0	10,0	
	6,8	5,0	3,2	2,3	12,5	
		5,6	3,7	2,7	15,0	
		6,0	4,1	3,0	17,5	
			4,4	3,3	20,0	300
			4,8	3,6	22,5	
			5,3	3,8	25,0	
			5,6	4,1	27,5	
			6,0	4,4	30,0	
ST3	4,7	3,4	2,2	1,6	7,5	260
	5,7	4,2	2,6	2,0	10,0	
		5,0	3,2	2,3	12,5	
				2,7	15,0	
				3,0	17,5	

Note 1: The vertical distance from the floor to the sprinkler deflectors, minus 1m, or the highest applicable value shown in the table, whichever is the lower.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

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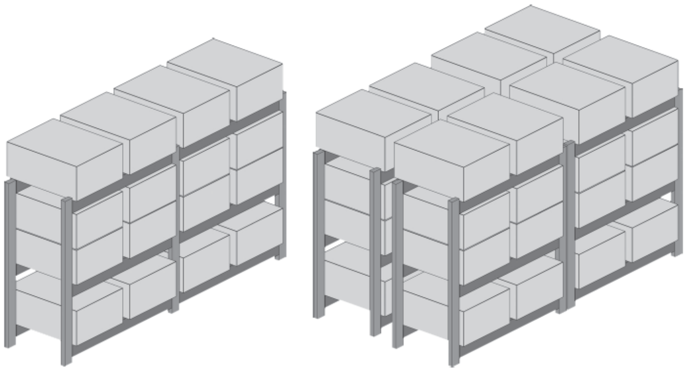
TB234.5.3 Beam Pallet Racking storage configurations (ST 4)

TB234.5.3.1 Scope

This section applies to double or single row racking. Figure TB234.F11 shows typical examples of this type of storage arrangement.

Figure TB234.F11: Example illustration of single and double row beam pallet racking configurations (ST4)



TB234.5.3.2 Requirements (replaces ST4 section of BS EN table 2):

TB234.5.3.2.1 Ceiling only protection

Ceiling only protection may be used where all of the following are complied with:

- the storage height limits, design density and area of operations given in Table TB234.T4, and;
- storage blocks shall be limited to 150m² plan area. Blocks shall be separated by a continuous clear space of at least 2,4m wide around the perimeter of the block (see TB234.4.15); and
- aisle between rows of racking shall be ≥1,2m wide (see TB234.4.15); and
- ceiling clearance ≤6,0m (see TB234.4.2.1); and
- longitudinal flues are not required but may be provided; and
- transverse flues shall be provided:
  - at maximum horizontal spacings of 1,4m when their width is at least 75mm but less than 150mm and/or their vertical alignment cannot be maintained;
  - at maximum horizontal spacings of 2,7m when their width is at least 150mm and they are maintained clear, aligned and throughout the full height of the rack.

Where these requirements cannot be met, see section TB234.5.3.2.2.

COMMENTARY AND RECOMMENDATIONS ON TB234.5.3

Where aisle widths between rows of racking are >1,2m but <2,4m wide, use of intermediate level in-rack sprinklers is recommended.

Beam Pallet Racking storage configurations (ST 4)

Table TB234.T4 Maximum permitted storage heights, design density and area of operations for roof or ceiling only protection (replaces ST4 sections of BS EN Table 4)

Storage configuration	Maximum permitted storage height (Note 1) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m^2)
	Category 1	Category 2	Category 3	Category 4		
ST4	4,7	3,4	2,2	1,6	7,5	260
	5,7	4,2	2,6	2,0	10,0	
	6,8	5,0	3,2	2,3	12,5	
		5,6	3,7	2,7	15,0	
		6,0	4,1	3,0	17,5	
			4,4	3,3	20,0	300
			4,8	3,6	22,5	
			5,3	3,8	25,0	
			5,6	4,1	27,5	
			6,0	4,4	30,0	

Note 1: The vertical distance from the floor to the sprinkler deflectors, minus 1m, or the highest applicable value shown in the table, whichever is the lower.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

TB234.5.3.2.2 With intermediate level in-rack sprinkler protection

Where the requirements of TB234.5.3.2.1 cannot be met, intermediate level in-rack sprinklers are required in addition to ceiling sprinklers and all of the following shall be complied with:

- storage height limits, design density and area of operations as given in Table TB234.T5;
- sprinklers and storage shall be configured as shown in Figure TB234.F12.

Table TB234.T5 Design criteria for roof or ceiling sprinklers with intermediate level in-rack sprinklers (replaces ST4 sections of BS EN Table 5)

Storage configuration	Maximum permitted storage height above the top level of in-rack protection (Notes 1,3) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m^2)
	Category 1	Category 2	Category 3	Category 4		
ST4	3,5	3,4	2,2	1,6	7,5	260
			2,6	2,0	10,0	
			3,2	2,3	12,5	
			3,5	2,7	15,0	

Note 1: Flues shall continue uninterrupted through the storage above the top level of intermediate level in-rack sprinkler protection.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling clearance of goods above the top level of intermediate level in-rack sprinklers must not exceed 6,0m. See TB234.4.2.

Note 4: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

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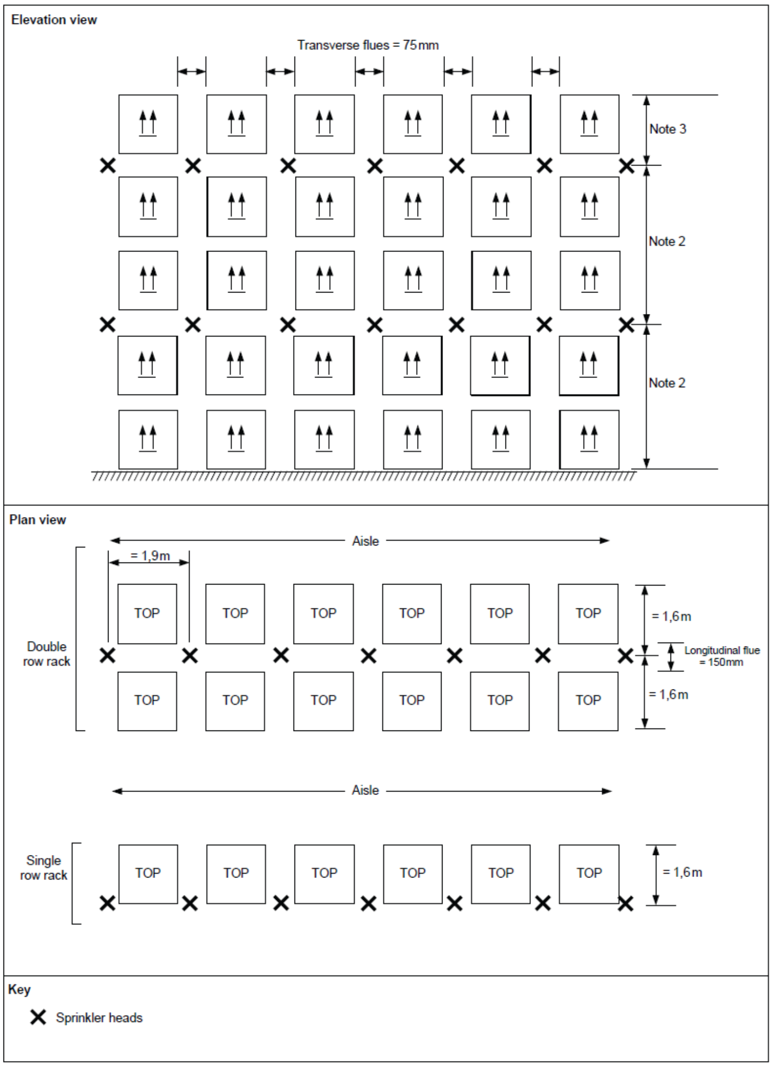
Beam Pallet Racking storage configurations (ST 4)

Figure TB234.F12: Key fire protection features of ceiling and intermediate level in-rack sprinkler protected Single or Double row pallet racking, category I to IV goods.



Notes:

1. Required flues shall be maintained throughout the height of the rack:
   a) Transverse flues are required and shall be at least 75mm wide;
   b) Longitudinal flues are required and shall be at least 150mm wide.
2. Maximum vertical distance to intermediate level in-rack sprinklers from floor (or from the horizontal support at the level of intermediate level in-rack sprinklers protection below) is 3,5m or two horizontal supports, whichever is the lesser. Horizontal spacing not to exceed 1,9m and; vertical spacing x horizontal spacing is not to exceed 4,9m^2.

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Beam Pallet Racking storage configurations (ST 4)

3. Goods stored above the highest level of intermediate level in-rack sprinklers shall not exceed the applicable height given in Table TB234.T5 or one stored unit, whichever is the lesser.
4. In-rack sprinklers are to be sited at flue intersections.
5. For single row racks, the sprinkler heads shall be located at the rear reference to the normal loading aisle (as opposed to on the face) of the rack.

TB234.5.3.3 ***Hydraulics (replaces 7.2.3)***

Where more than 50 intermediate level in-rack sprinklers are installed in the racks, they shall not be fed from the same control valve set as the roof or ceiling sprinklers. Where intermediate in-rack sprinkler heads are supplied from the roof valve set, the control valve set shall be not less than 100mm diameter.

In-rack sprinklers and the associated ceiling sprinklers shall always be fully calculated (see TB231.2.1).

Calculation of the maximum installation pressure demand based on the hydraulically most unfavourable location

Where the hydraulically most unfavourable AMAO includes both roof or ceiling level sprinklers and intermediate level in-rack sprinklers the hydraulic system pressure and flow requirements on which the water supply performance is established, as outlined in TB210, shall be determined by the hydraulically balanced and simultaneous operation of:

a) the roof or ceiling level sprinklers located within the AMAO (as defined in BS EN 12845 Clause 13.4) over the in-rack or shelf storage area; plus

b) any non-rack intermediate or supplementary sprinklers located within the AMAO in a) above; plus

c) three sprinklers operating simultaneously on each level of in-rack sprinklers, up to a maximum of three levels. Where rack aisles are 2,4m or more in width only one rack need be assumed to be involved. Where rack aisles are less than 2,4m but greater than or equal to 1,2m in width, two racks shall be assumed to be involved. Where rack aisles are less than 1,2m in width, three racks shall be assumed to be involved.

In order to verify the water supply performance will satisfy the maximum installation pressure demand for the most unfavourable AMAO consisting of a), b) and c) above, it will be necessary to demonstrate all roof or ceiling level sprinkler AMAOs and all in-rack or shelf sprinklers AMAOs likely to be in simultaneous operation have been considered.

Calculation of the maximum flow demand based on the hydraulically most favourable location

Where the hydraulically most favourable AMAO includes both roof or ceiling level sprinklers and intermediate level in-rack sprinklers a hydraulic analysis of the simultaneous operation of the following sprinklers shall be carried out to determine the maximum flow rate the water supplies need to cater for:

a) the roof or ceiling level sprinklers located within the AMAO (as defined in BS EN 12845 Clause 13.4) over the in-rack or shelf storage area; plus

b) any non-rack intermediate or supplementary sprinklers falling within the AMAO in a) above; plus

c) three sprinklers operating simultaneously on each level of in-rack sprinklers, up to a maximum of three levels. Where rack aisles are 2,4m or more in width only one rack need be assumed to be involved. Where rack aisles are less than 2,4m but greater than or equal to 1,2m in width, two racks shall be assumed to be involved. Where rack aisles are less than 1,2m in width, three racks shall be assumed to be involved.

In order to verify that the water supply performance and capacity will satisfy the maximum flow demand for the most favourable AMAO consisting of a), b) and c) above, it will be necessary to demonstrate all hydraulically most favourable roof or ceiling level sprinkler AMAOs and all hydraulically most favourable in-rack or shelf sprinklers AMAOs likely to be in simultaneous operation have been considered.

The highest flow requirement (Q_{max}) shall be taken at the point of intersection of the pressure-flow demand characteristic of the most favourable area of operation and the water supply pressure-flow characteristic with the suction source at its normal level. This highest flow value discharging for a period of 90 minutes shall determine the effective capacity of the water storage tank.

Note: It is not necessary to assume simultaneous operation of more than three rows of sprinklers in the vertical plane nor more than three rows of sprinklers in the horizontal plane.

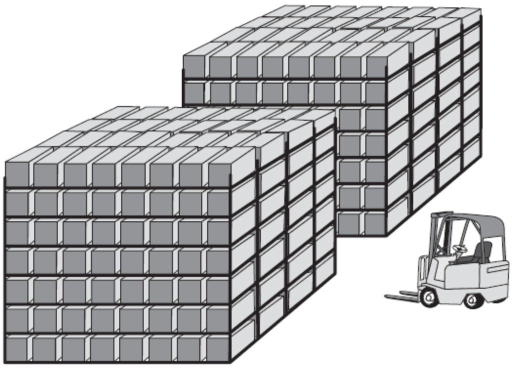
Note: The minimum pressure at any operating sprinkler is 1,0 bar for K115 in-rack sprinklers (see TB229.3.9).

TB234.5.4 Double deep pallet racking (ST8)

TB234.5.4.1 Scope

This section applies to racking arranged such that pallets can be stored four-deep with three longitudinal flues. Pallets are typically loaded from aisles by trucks with extending forks. Flues are required (as specified further on in the section and depending on the configuration). Figure TB234.F13 shows typical examples of this type of storage arrangement.

Figure TB234.F13: Example illustration of multiple row rack storage – double deep pallet racking



TB234.5.4.2 Requirements

TB234.5.4.2.1 Ceiling only protection

Ceiling only protection may be used where all of the following are complied with:

- the storage height limits, design density and area of operations given in Table TB234.T6, and;
- storage blocks shall be limited to 150m² plan area. Blocks shall be separated by continuous clear space of no less than 2,4m wide around the perimeter the block, and;
- ceiling clearance ≤6,0m; and
- full height clear longitudinal flues of at least 150mm wide are to be provided every pallet load (eg three per double deep rack);
- full height clear transvers flues of at least 75mm wide are to be provided at a maximum of every 1,9m.

Where these requirements cannot be met, see section TB234.5.4.2.2.

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Double deep pallet racking (ST8)

Table TB234.T6 Maximum permitted storage heights, design density and area of operations for ceiling only protection for double deep racking (categories I to IV)

Storage configuration	Maximum permitted storage height above the top level of in-rack protection (Notes 1) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m^2)
	Category 1	Category 2	Category 3	Category 4		
ST8	4,7	3,4	2,2	1,6	7,5	260
	5,7	4,2	2,6	2,0	10,0	
		5,0	3,2	2,3	12,5	
				2,7	15,0	
				3,0	17,5	

Note 1: The vertical distance from the floor to the sprinkler deflectors, minus 1m, or the highest applicable value shown in the table, whichever is the lower.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling clearance of goods above the top level of intermediate level in-rack sprinklers must not exceed 6,0m. See TB234.4.2.

Note 4: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

TB234.5.4.2.2 With intermediate level in-rack sprinkler protection

Where the requirements of TB234.5.4.2.1 cannot be met, intermediate level in-rack sprinklers are required in addition to ceiling sprinklers and all of the following shall be complied with:

- storage height limits, design density and area of operations are given in Table TB234.T7;
- sprinklers and storage shall be configured as shown in Figure TB234.F14.

Table TB234.T7 Design criteria for roof or ceiling sprinklers with intermediate in-rack sprinklers (no equivalent EN clause)

Storage configuration	Maximum permitted storage height above the top level of in-rack protection (Notes 1, 3) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m^2)
	Category 1	Category 2	Category 3	Category 4		
ST8	3,5	3,4	2,2	1,6	7,5	260
			2,6	2,0	10,0	
			3,2	2,3	12,5	
				2,7	15,0	

Note 1: Flues shall continue uninterrupted through the storage above the top level of intermediate level in-rack sprinkler protection.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling clearance of goods above the top level of intermediate level in-rack sprinkler protection must not exceed 6,0m. See TB234.4.2.

Note 4: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

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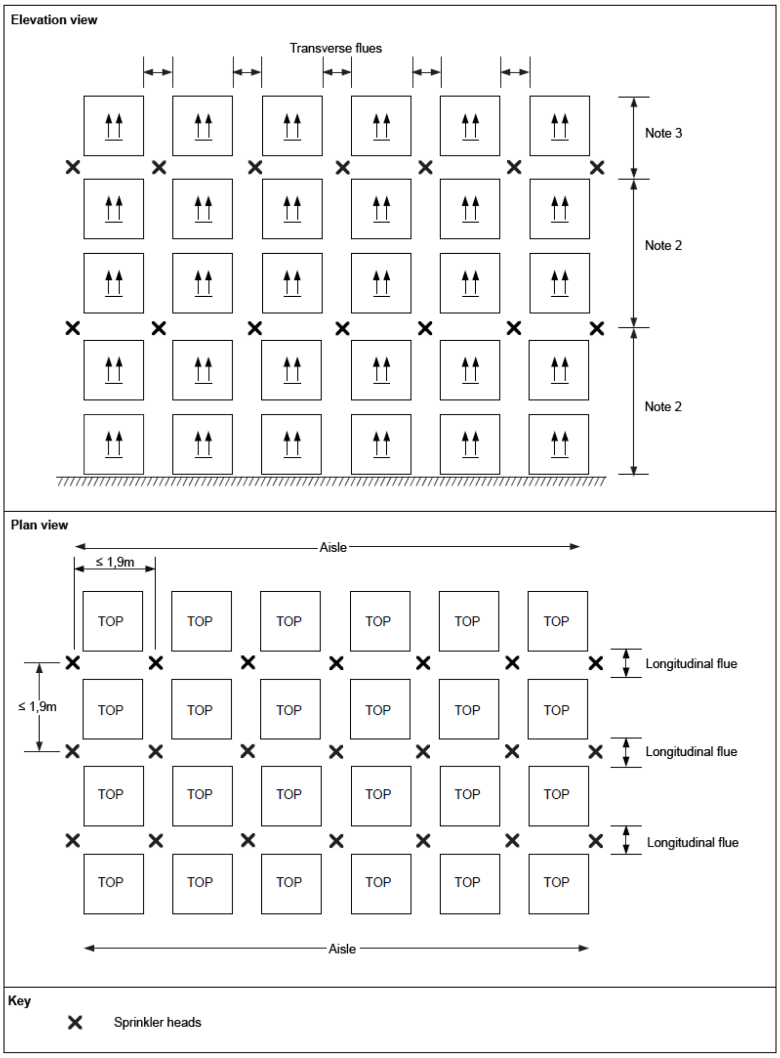
Double deep pallet racking (ST8)

Figure TB234.F14: Key fire protection features of ceiling and intermediate level in-rack sprinkler protected double-deep pallet racking, category I to IV



Notes:

1. Required flues shall be maintained throughout the height of the rack:
   a) transverse flues are required and shall be at least 75mm wide;
   b) longitudinal flues are required and shall be at least 150mm wide.
2. The maximum vertical distance to intermediate level in-rack sprinklers from the floor (or from the horizontal support at the level of intermediate level in-rack sprinkler protection below) is 3,5m or two horizontal supports, whichever is the lesser. Horizontal spacing not to exceed 1,9m and; vertical spacing x horizontal spacing is not to exceed 4,9m^2.

3. Goods stored above the highest level of intermediate level in-rack sprinklers shall not exceed the applicable height given in Table TB234.T7 or one stored unit, whichever is the lesser.
4. Intermediate level in-rack sprinklers to be sited at flue intersections. Consideration shall be given to the location of sprinklers with respect to the possibility of impact damage.
5. Repeat pattern for any additional levels of storage.
6. Where ceiling clearance ≥6,0m intermediate level in-rack sprinklers shall be installed above the uppermost level of stored goods.

TB234.5.4.3 Hydraulics (replaces 7.2.3)

Where more than 50 intermediate level in-rack sprinklers are installed in the racks, they shall not be fed from the same control valve set as the roof or ceiling sprinklers. The control valve set shall be not less than 100mm diameter.

Intermediate level in-rack sprinklers and the associated ceiling sprinklers shall always be fully calculated (see TB231.2.1).

Calculation of the maximum installation pressure demand based on the hydraulically most unfavourable location

Where the hydraulically most unfavourable AMAO includes both roof or ceiling level sprinklers and intermediate level in-rack or shelf sprinklers the hydraulic system pressure and flow requirements on which the water supply performance is established, as outlined in TB210, shall be determined by the hydraulically balanced and simultaneous operation of:

a) the roof or ceiling level sprinklers located within the AMAO (as defined in BS EN 12845 Clause 13.4) over the in-rack or shelf storage area; plus

b) any non-rack intermediate or supplementary sprinklers located within the AMAO in a) above; plus

c) three sprinklers are operating simultaneously on each level of in-rack sprinklers, up to a maximum of three levels. Three rows of sprinklers shall be assumed to be involved. Maximum of 27 heads.

In order to verify that the water supply performance will satisfy the maximum installation pressure demand for the most unfavourable AMAO consisting of a), b) and c) above, it will be necessary to demonstrate all roof or ceiling level sprinkler AMAOs and all in-rack or shelf sprinklers AMAOs likely to be in simultaneous operation have been considered.

Calculation of the maximum flow demand based on the hydraulically most favourable location

Where the hydraulically most favourable AMAO includes both roof or ceiling level sprinklers and intermediate level in-rack sprinklers a hydraulic analysis of the simultaneous operation of the following sprinklers shall be carried out to determine the maximum flow rate the water supplies need to cater for:

a) the roof or ceiling level sprinklers located within the AMAO (as defined in BS EN 12845 Clause 13.4) over the in-rack or shelf storage area; plus

b) any non-rack intermediate or supplementary sprinklers falling within the AMAO in a) above; plus

c) three sprinklers are operating simultaneously on each level of in-rack sprinklers, up to a maximum of three levels. Three rows of sprinklers shall be assumed to be involved. Maximum of 27 heads.

Double deep pallet racking (ST8)

In order to verify the water supply performance and capacity will satisfy the maximum flow demand for the most favourable AMAO consisting of a), b) and c) above, it will be necessary to demonstrate all hydraulically most favourable roof or ceiling level sprinkler AMAOs and all hydraulically most favourable in-rack or shelf sprinklers AMAOs likely to be in simultaneous operation have been considered.

The highest flow requirement (Q_{max}) shall be taken at the point of intersection of the pressure-flow demand characteristic of the most favourable area of operation and the water supply pressure-flow characteristic with the suction source at its normal level. This highest flow value discharging for a period of 90 minutes shall determine the effective capacity of the water storage tank.

Note: It is not necessary to assume simultaneous operation of more than three rows of sprinklers in the vertical plane nor more than three rows of sprinklers in the horizontal plane.

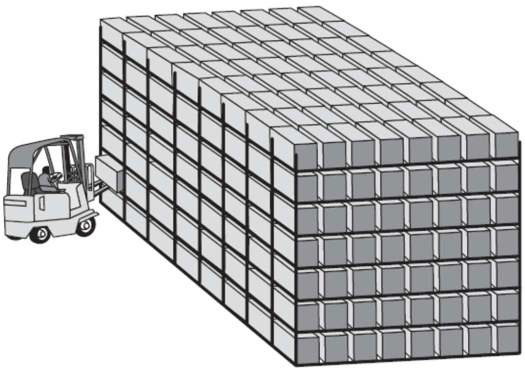
Note: The minimum pressure at any operating sprinkler is 1,0 bar for K115 intermediate level in-rack sprinklers (see TB229.3.9).

TB234.5.5 Multiple row rack storage – 'drive in', 'flow through' and 'push back' racking (ST8)

TB234.5.5.1 Scope

This section applies to 'drive in', 'flow through' and 'push back' racking. These racking types are typically arranged such that units of stored goods are abutted together. Flues are required (as specified further on in the section and depending on the configuration). Figure TB234.F15 shows typical examples of this type of storage arrangement.

Figure TB234.F15: Example illustration of multiple row rack storage – 'drive in', 'flow through' and 'push back' racking



TB234.5.5.2 Requirements

TB234.5.5.2.1 Ceiling only protection

Ceiling only protection may be used where all of the following are complied with:

- the storage height limits, design density and area of operations given in Table TB234.T8; and
- storage blocks shall be limited to 150m² plan area. Blocks shall be separated by a continuous clear space of at least 2,4m wide around the perimeter of the block; and
- ceiling clearance ≤6,0m; and
- full height clear longitudinal flues of at least 150mm wide are to be provided at a maximum of every 4,8m; and
- full height clear transverse flues of at least 75mm wide are to be provided at a maximum of every 1,9m.

Where these requirements cannot be met, see section TB234.5.5.2.2.

Multiple row rack storage – 'drive in', 'flow through' and 'push back' racking (ST8)

Table TB234.T8 Maximum permitted storage heights, design density and area of operations for ceiling only protection for multiple row racking (categories I to IV)

Storage configuration	Maximum permitted storage height above the top level of in-rack protection (Note 1) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m^2)
	Category 1	Category 2	Category 3	Category 4		
ST8	4,7	3,4	2,2	1,6	7,5	260
	5,7	4,2	2,6	2,0	10,0	
		5,0	3,2	2,3	12,5	
				2,7	15,0	
				3,0	17,5	

Note 1: The vertical distance from the floor to the sprinkler deflectors, minus 1m, or the highest applicable value shown in the table, whichever is the lower.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

TB234.5.5.2.2 With intermediate level in-rack sprinklers protection

Where the requirements of TB234.5.5.2.1 cannot be met, intermediate level in-rack sprinklers are required in addition to ceiling sprinklers and all of the following shall be complied with:

- Table TB234.T9; and
- Figure TB234.F16 or Figure TB234.F17 (as appropriate).

Table TB234.T9 Design criteria for ceiling sprinklers with intermediate level intermediate level in-rack sprinklers for multiple row racking (categories I to IV)

Storage configuration	Maximum permitted storage height above the top level of intermediate level in-rack sprinkler protection (Notes 1,3) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m^2)
	Category 1	Category 2	Category 3	Category 4		
ST8	3,5	3,4	2,2	1,6	7,5	260
			2,6	2,0	10,0	
			3,2	2,3	12,5	
				2,7	15,0	

Note 1: Flues shall continue uninterrupted through the storage above the top level of intermediate level in-rack sprinkler protection.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Maximum of one unit of stored goods high.

Note 4: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

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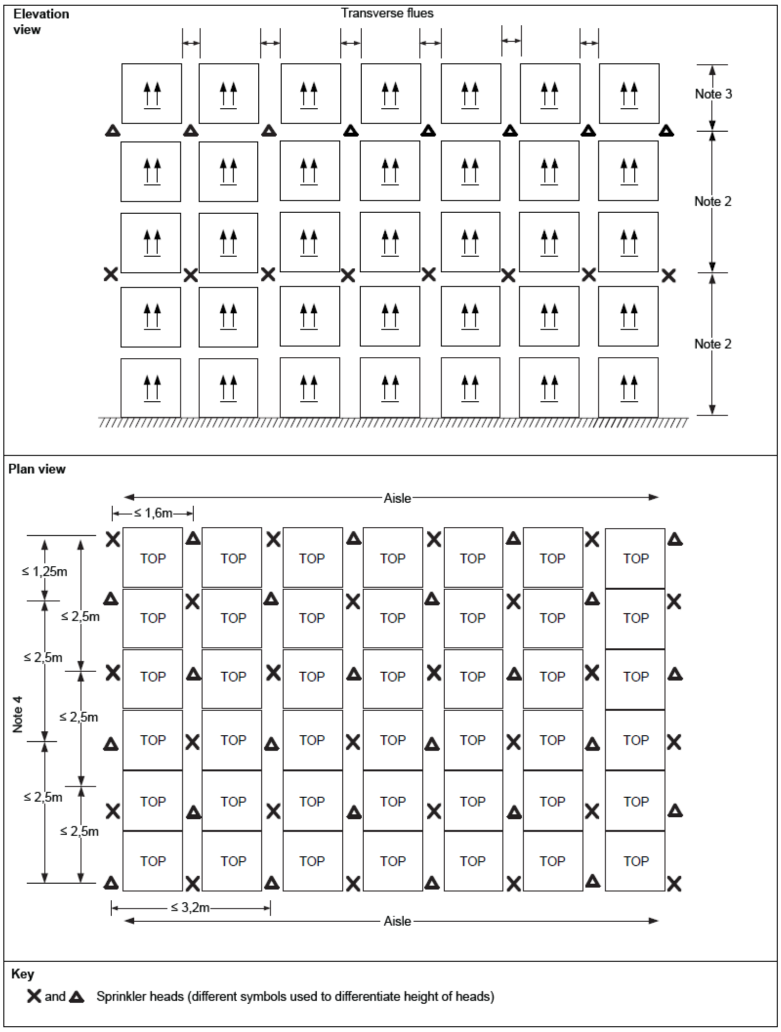
Multiple row rack storage – 'drive in', 'flow through' and 'push back' racking (ST8)

Figure TB234.F16: Key fire protection features of ceiling and intermediate level in-rack sprinkler protected 'drive in', 'flow through' and 'push back' racking, category I, II and III



Notes:

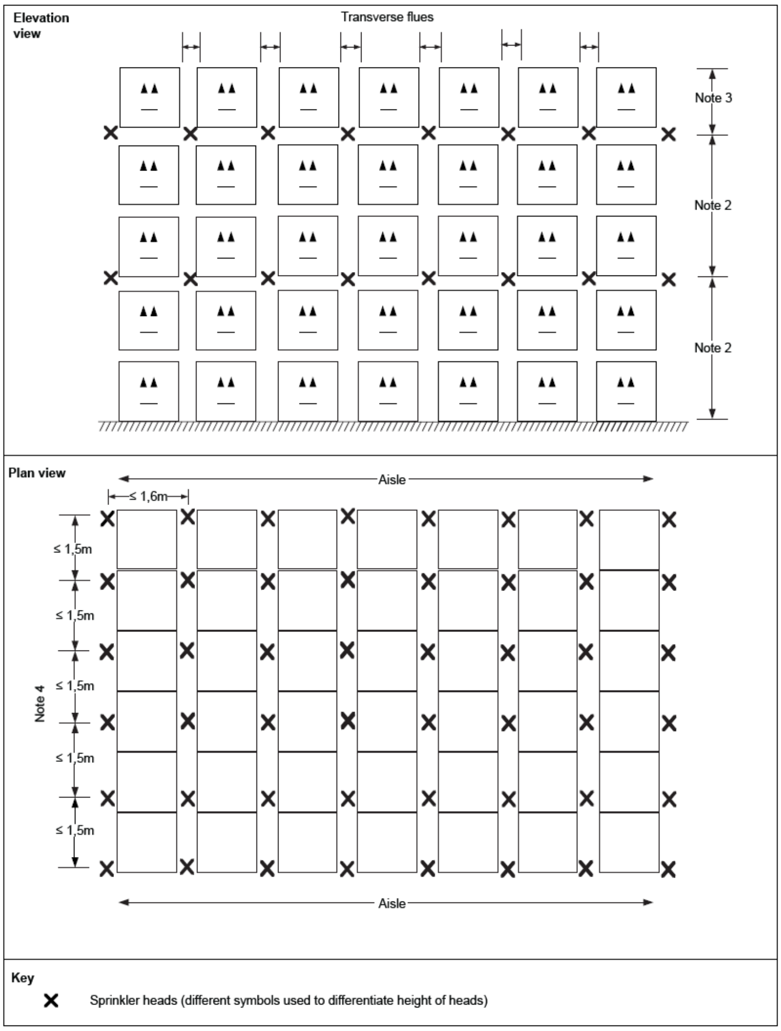
1. Required flues shall be maintained throughout the height of the rack.
   a) transverse flues are required every 1,6m and shall be at least 75mm wide;
   b) longitudinal flues are not required however if they are provided they shall be at least 75mm wide, except: they are not required for the storage level located directly above intermediate level in-rack sprinklers, or when intermediate level in-rack sprinklers are provided at every level.

Multiple row rack storage – 'drive in', 'flow through' and 'push back' racking (ST8)

2. The maximum vertical distance to intermediate level in-rack sprinklers from the floor (or from the horizontal support at the level of intermediate level in-rack sprinkler protection below) is 3,5m or two horizontal supports, whichever is the lesser. The maximum horizontal intermediate level in-rack sprinkler head spacing is 3,2m in longitudinal flue orientation and 2,5m perpendicular to longitudinal flues.
3. Goods stored above highest level of intermediate level in-rack sprinklers shall not exceed the applicable height given in Table TB234.T9 or one stored unit, whichever is the lesser.
4. In rack sprinklers must be aligned with the transverse flue and should be aligned with the longitudinal flue where it may arise. Consideration shall be given to the location of sprinklers on loading faces with respect to impact damage.
5. Sprinklers are to be located such that all four faces of the racks are directly protected.
6. Repeat staggered pattern for any additional levels of storage.
7. Where the clearance between the top of stored goods and ceiling sprinklers >6,0m, intermediate level in-rack sprinklers shall be installed above the uppermost level of stored goods.

Multiple row rack storage – 'drive in', 'flow through' and 'push back' racking (ST8)

Figure TB234.F17: Key fire protection features of ceiling and intermediate level in-rack sprinkler protected 'drive in', 'flow through' and 'push back' racking, category IV



Notes:

1. Required flues shall be maintained throughout the height of the rack:
   a) transverse flues are required every 1,6m and shall be at least 75mm wide;
   b) longitudinal flues are not required however if they are provided shall be at least 75mm wide, except: they are not required for the storage level located directly above intermediate level in-rack sprinklers, or when intermediate level in-rack sprinklers are provided at every level.

Multiple row rack storage – 'drive in', 'flow through' and 'push back' racking (ST8)

2. The maximum vertical distance to intermediate level in-rack sprinklers from the floor (or from the horizontal support at the level of intermediate level in-rack sprinkler protection below) is 3,5m or two horizontal supports, whichever is the lesser. Maximum horizontal intermediate level in-rack sprinkler head spacing is 1,6m in longitudinal flue orientation and 1,5m perpendicular to longitudinal flues.
3. Goods stored above highest level of intermediate level in-rack sprinklers shall not exceed the applicable height given in Table TB234.T9 or one stored unit, whichever is the lesser.
4. Intermediate level in-rack sprinklers must be aligned with transverse flue and should be aligned with the longitudinal flue where it may arise. Consideration shall be given to the location of sprinklers on loading faces with respect to impact damage.
5. Sprinklers are to be located such that all four faces of the racks are directly protected.
6. Intermediate level in-rack sprinklers must be aligned with transverse flue and should be aligned with the longitudinal flue where it may arise.
7. Repeat pattern for any additional levels of storage.
8. Where ceiling clearance ≥6,0m intermediate level in-rack sprinklers shall be installed above the uppermost level of stored goods.

TB234.5.5.3 *Hydraulics (replaces 7.2.3)*

Where more than 50 intermediate level in-rack sprinklers are installed in the racks, they shall not be fed from the same control valve set as the roof or ceiling sprinklers. The control valve set shall be not less than 100mm diameter.

Intermediate level in-rack sprinklers and the associated ceiling sprinklers shall always be fully calculated (see TB231.2.1).

Calculation of the maximum installation pressure demand based on the hydraulically most unfavourable location

Where the hydraulically most unfavourable AMAO includes both roof or ceiling level sprinklers and intermediate level in-rack or shelf sprinklers the hydraulic system pressure and flow requirements on which the water supply performance is established, as outlined in TB210, shall be determined by the hydraulically balanced and simultaneous operation of:

a) the roof or ceiling level sprinklers located within the AMAO (as defined in BS EN 12845 Clause 13.4) over the in-rack or shelf storage area; plus
b) any non-rack intermediate or supplementary sprinklers located within the AMAO in a) above; plus
c) three sprinklers are operating simultaneously on each level of in-rack sprinklers, up to a maximum of three levels. Three rows of sprinklers shall be assumed to be involved. Maximum of 27 heads.

In order to verify that the water supply performance will satisfy the maximum installation pressure demand for the most unfavourable AMAO consisting of a), b) and c) above, it will be necessary to demonstrate all roof or ceiling level sprinkler AMAOs and all in-rack or shelf sprinklers AMAOs likely to be in simultaneous operation have been considered.

Calculation of the maximum flow demand based on the hydraulically most favourable location

Where the hydraulically most favourable AMAO includes both roof or ceiling level sprinklers and intermediate level in-rack sprinklers a hydraulic analysis of the simultaneous operation of the following sprinklers shall be carried out to determine the maximum flow rate the water supplies need to cater for:

Multiple row rack storage – 'drive in', 'flow through' and 'push back' racking (ST8)

a) the roof or ceiling level sprinklers located within the AMAO (as defined in BS EN 12845 Clause 13.4) over the in-rack or shelf storage area; plus

b) any non-rack intermediate or supplementary sprinklers falling within the AMAO in a) above; plus

c) three sprinklers are operating simultaneously on each level of in-rack sprinklers, up to a maximum of three levels. Three rows of sprinklers shall be assumed to be involved. Maximum of 27 heads.

In order to verify that the water supply performance and capacity will satisfy the maximum flow demand for the most favourable AMAO consisting of a), b) and c) above, it will be necessary to demonstrate all hydraulically most favourable roof or ceiling level sprinkler AMAOs and all hydraulically most favourable in-rack or shelf sprinklers AMAOs likely to be in simultaneous operation have been considered.

The highest flow requirement (Q_{max}) shall be taken at the point of intersection of the pressure-flow demand characteristic of the most favourable area of operation and the water supply pressure-flow characteristic with the suction source at its normal level. This highest flow value discharging for a period of 90 minutes shall determine the effective capacity of the water storage tank.

Note: It is not necessary to assume simultaneous operation of more than three rows of sprinklers in the vertical plane or more than three rows of sprinklers in the horizontal plane.

Note: The minimum pressure at any operating sprinkler is 1,0 bar for K115 intermediate level in-rack sprinklers (see TB229.3.9).

TB234.5.6 Solid or slatted shelving (ST15 and ST16)

TB234.5.6.1 Scope

This section specifies the requirements for protecting various types of shelf storage configuration. This includes affixed: solid shelves, slatted shelves, grated shelves (<70% open) or other types of shelving located within storage racks.

Note: where all of the following apply:

- flues can be provided and maintained and storage can conform to TB234.5.2 (ST4); and
- shelf area (bounded by full width flues) ≤2,0m²; and
- shelves are fixed in place.

The requirements of TB234.5.2 (ST4) may be applied in place of the requirements of this section.

Multiple row rack configurations with abutted storage need not be protected as solid shelves provided they meet the following conditions:

- there are no solid or slatted shelves in the racks; and
- pallet loads are butted only in one direction; and
- pallet loads are not wider than 1,6m; and
- clear transverse flues (≥75mm) are provided on each side of rows of butted pallets; and
- clear longitudinal flues (≥150mm) are provided a maximum of 4,8m horizontally when ceiling only protection is used.

Where the requirements of TB234.5.6.2 or TB234.5.6.3 cannot be achieved, the insurer (and authority, if applicable) shall be consulted upon the acceptability of the proposed design solution on a case-by-case basis.

COMMENTARY AND RECOMMENDATIONS ON TB234.5.6

Shelf depth shall be measured from the exposed longitudinal face to the opposing exposed longitudinal face (aisle to aisle). Longitudinal flues up to 600mm that may exist shall be included in the measurement.

Solid, mesh, slatted or grated shelves, and/or objects placed on them (eg stored goods) forming solid horizontal barriers in storage racks can obstruct the path of rising hot gases required to activate sprinklers, promote horizontal fire spread and adversely impact the ability of water to penetrate the rack vertically.

Maintaining the minimum requirements specified in TB234.5.6 helps ensure sprinkler water can reach all surfaces of the protected commodity and disrupts horizontal fire spread.

When goods are abutted together such that they form a solid barrier and obstruct flues identified as essential elsewhere in this Technical Bulletin, the effect upon the fire protection is the same as if a solid shelf were present, hence the requirement to protect as a solid shelf risk if this is the case. Similarly, if slatted shelves combined with the goods upon them obstruct flues the result is the same.

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Solid or slatted shelving (ST15 & ST16)

TB234.5.6.2 *Storage class "ST15"*

TB234.5.6.2.1 *Requirements*

Ceiling only protection may be used where one (or more) of the storage configuration characteristics is satisfied:

- shelves, with or without flue spaces are no deeper than 0,8m (aisle to aisle); or
- storage is solely of open fronted, 5 sided, metal construction bin box storage regardless of shelf depth; or
- shelves, without flue spaces are no deeper than 1,2m (aisle to aisle) and storage blocks are limited to plan areas of 150m² with 2,4m wide breaks to surrounding blocks (see TB234.4.15).

And the following sprinkler installation design conditions are met:

- Storage height limits, design density and area of operations given in Table TB234.T10 are complied with; and
- Ceiling clearances above the maximum normal height of stored goods ≤6,0m.

Note: Open top bin-box storage arrangements are considered a special case and not covered by this document. In such cases, the insurer (and authority, if applicable) shall be consulted upon the acceptability of the proposed design solution on a case-by-case basis.

Table TB234.T10 ST15 maximum permitted storage heights, design density and area of operations for roof or ceiling only protection (replaces ST5 section of BS EN table 4)

Storage configuration	Maximum permitted storage height (Note 1) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m²)
	Category 1	Category 2	Category 3	Category 4		
ST15	4,7	3,4	2,2	1,6	7,5	260
	5,7	4,2	2,6	2,0	10,0	
		5,0	3,2	2,3	12,5	
				2,7	15,0	
				3,0	17,5	

Note 1: The vertical distance from the floor to the sprinkler deflectors, minus 1m, or the highest applicable value shown in the table, whichever is the lower.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

TB234.5.6.3 *Storage class "ST16"*

TB234.5.6.3.1 *Requirements*

Intermediate level in-rack sprinkler protection in accordance with the requirements of this section is required where one (or more) of the following storage configuration characteristics exists:

- shelves, with or without flue spaces are > 0,8m to ≤3,2m deep (aisle to aisle); or
- the storage height limits specified for are TB234.5.6.2.1 exceeded; or
- ceiling clearances above the maximum normal height of stored goods exceed 6,0m.

Solid or slatted shelving (ST15 & ST16)

The following sprinkler installation design conditions shall be met:

- transverse flues shall be at least 150mm wide and occur at least every 3,2m; and
- intermediate level in-rack sprinkler horizontal spacing not to exceed 1,9m and where possible be coincident with flues; and
- ceiling sprinklers shall be installed to meet the criteria for storage height limits, design density and area of operations specified in Table TB234.T11; and
- intermediate level in-rack sprinkler shall be installed at every levels and storage shall be configured as shown in Figure TB234.F15.

COMMENTARY AND RECOMMENDATIONS ON TB234.5.6.3.1

An allowable exception is the case where handpicking shelves are present and the shelves are too close together to sprinkler protect at every level. In which case intermediate level in-rack sprinklers shall be installed in handpicking parts of the shelving at maximum vertical spacing of 2,0m irrespective of the number of shelves.

If transverse flues cannot be implemented, the insurer (and authority, if applicable) shall be consulted upon the acceptability of the proposed design solution on a case-by-case basis. Vertical bulkheads (BS EN 13501 Part 1 Euroclass A1 or A2) a maximum of 3,2m apart and aisle width 1,2m or greater may be a suitable alternative.

Table TB234.T11 ST16 – Design criteria for roof or ceiling sprinklers with intermediate level in-rack sprinklers and maximum permitted storage heights above the top level of intermediate level in-rack sprinkler protection (replaces ST6 section of BS EN table 5)

Storage configuration	Maximum permitted storage height above the top level of intermediate level in-rack sprinkler protection (Notes 1,3) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m²)
	Category 1	Category 2	Category 3	Category 4		
ST15	2,0	2,0	2,0	1,6	7,5	260
				2,0	10,0	
					12,5	
					15,0	

Note 1: Flues shall continue uninterrupted through the storage above the top level of intermediate level in-rack sprinkler protection.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling clearance of goods above the top level of intermediate level in-rack sprinkler protection must not exceed 6,0m. See TB234.4.2.

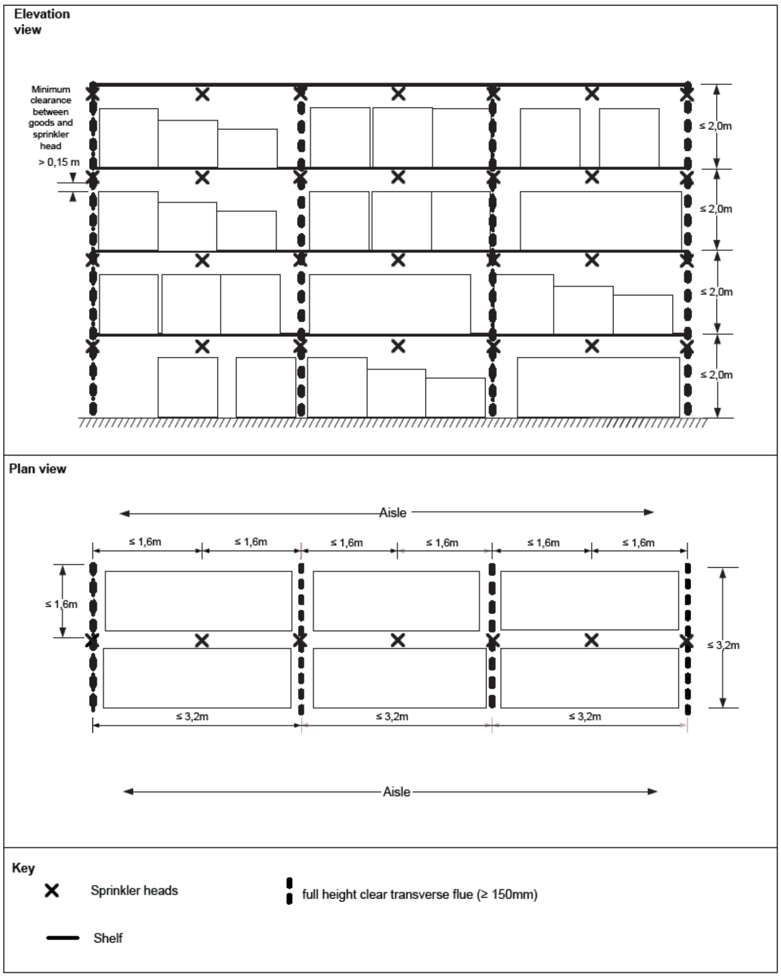
Note 4: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

TB234

TECHNICAL BULLETIN 234: 2014: 1

Solid or slatted shelving (ST15 & ST16)

Figure TB234.F18: Key fire protection features of ST16 shelving, category I to IV goods.



Notes:

1. Intermediate level in-rack sprinklers are required as shown.
2. Required flues shall be maintained throughout the height of the rack:
   a) transverse flues (≥150mm) required every 3,2m or less. Intermediate level in-rack sprinklers shall be aligned with transverse flues, where they exist;
   b) longitudinal flues are not required in this configuration.
3. Intermediate level in-rack sprinklers shall be installed below every shelf level.
4. Where goods are stored above highest level of intermediate level in-rack sprinklers, the height of those goods shall not exceed the applicable height given in Table TB234.T11 or one stored unit, whichever is the lesser.
5. The configuration may be repeated to achieve unlimited storage height.

TB234.5.6.3.1.1 Hydraulic design criteria

Where more than 50 intermediate level in-rack sprinklers are installed in the racks, they shall not be fed from the same control valve set as the roof or ceiling sprinklers. The control valve set shall be not less than 100mm diameter.

Intermediate level in-rack sprinklers and the associated ceiling sprinklers shall always be fully calculated (see TB231.2.1).

Calculation of the maximum installation pressure demand based on the hydraulically most unfavourable location

Where the hydraulically most unfavourable AMAO includes both roof or ceiling level sprinklers and intermediate level in-rack or shelf sprinklers the hydraulic system pressure and flow requirements on which the water supply performance is established, as outlined in TB210, shall be determined by the hydraulically balanced and simultaneous operation of:

a) the roof or ceiling level sprinklers located within the AMAO (as defined in BS EN 12845 Clause 13.4) over the in-rack or shelf storage area; plus

b) any non-rack intermediate or supplementary sprinklers located within the AMAO in a) above; plus

c) all in-rack or shelf sprinklers assumed to be in operation. Assume the number heads = 3 per level x 3 levels x 1,2 or 3 racks (3 sprinklers are operating simultaneously at the most hydraulically remote position on each level of in-rack sprinklers, up to a maximum of three levels. Where rack aisles are 2,4m or more in width only one rack need be assumed to be involved. Where rack aisles are less than 2,4m but greater than or equal to 1,2m in width, two racks shall be assumed to be involved. Where rack aisles are less than 1,2m in width, three racks shall be assumed to be involved.). Maximum of 27 heads.

In order to verify that the water supply performance will satisfy the maximum installation pressure demand for the most unfavourable AMAO consisting of a), b) and c) above, it will be necessary to demonstrate all roof or ceiling level sprinkler AMAOs and all in-rack or shelf sprinklers AMAOs likely to be in simultaneous operation have been considered.

Calculation of the maximum flow demand based on the hydraulically most favourable location

Where the hydraulically most favourable AMAO includes both roof or ceiling level sprinklers and intermediate level in-rack sprinklers a hydraulic analysis of the simultaneous operation of the following sprinklers shall be carried out to determine the maximum flow rate the water supplies need to cater for:

a) the roof or ceiling level sprinklers located within the AMAO (as defined in BS EN 12845 Clause 13.4) over the in-rack or shelf storage area; plus

b) any non-rack intermediate or supplementary sprinklers falling within the AMAO in a) above; plus

c) all in-rack or shelf sprinklers assumed to be in operation. Assume the number heads = 3 per level x 3 levels x 1,2 or 3 racks (3 sprinklers are operating simultaneously at the most hydraulically remote position on each level of in-rack sprinklers, up to a maximum of three levels. Where rack aisles are 2,4m or more in width only one rack need be assumed to be involved. Where rack aisles are less than 2,4m but greater than or equal to 1,2m in width, two racks shall be assumed to be involved. Where rack aisles are less than 1,2m in width, three racks shall be assumed to be involved.). Maximum of 27 heads.

In order to verify that the water supply performance and capacity will satisfy the maximum flow demand for the most favourable AMAO consisting of a), b) and c) above, it will be necessary to demonstrate all hydraulically most favourable roof or ceiling level sprinkler AMAOs and all hydraulically most favourable in-rack or shelf sprinklers AMAOs likely to be in simultaneous operation have been considered.

Solid or slatted shelving (ST15 & ST16)

The highest flow requirement (Q_{max}) shall be taken at the point of intersection of the pressure-flow demand characteristic of the most favourable area of operation and the water supply pressure-flow characteristic with the suction source at its normal level. This highest flow value discharging for a period of 90 minutes shall determine the effective capacity of the water storage tank.

Note: The minimum pressure at any operating sprinkler is 1,0 bar for K115 intermediate level in-rack sprinklers (see TB229.3.9).

TB234.5.7 **Special Hazards**

This section gives requirements for frequently encountered specific types of storage.

TB234.5.7.1 *Carpet storage (ST10)*

TB234.5.7.1.1 *Requirements:*

Intermediate level in-rack sprinklers are required and the following are to be complied with:

- continuous full height vertical fire-resisting transverse bulkheads (BS EN 13501 Part 1 Euroclass A1 or A2) or transverse flues ≥150mm wide and clear the full height of the rack shall be provided (maximum longitudinal spacing to be 3,2m);
- the storage height limits, design density and area of operations given in Table TB234.T12;
- storage shall be configured as shown in Figure TB234.F19;
- aisles are expected to be >>2,4m due to space required to load and unload rolls.

Table TB234.T12 Design criteria for roof or ceiling sprinklers with intermediate level in-rack sprinklers and maximum permitted storage heights above the top level of intermediate level in-rack sprinkler protection (no equivalent BS EN clause)

Storage configuration	Maximum permitted storage height above the top level of intermediate level in-rack sprinkler protection (Note 1) (m)				Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m^2)
	Category 1	Category 2	Category 3	Category 4		
ST15	Not applicable		1,6	Not applicable	7,5	260
			2,1		10,0	
			2,7		12,5	

Note 1: Flues shall continue uninterrupted through the storage above the top level of intermediate level in-rack sprinkler protection.

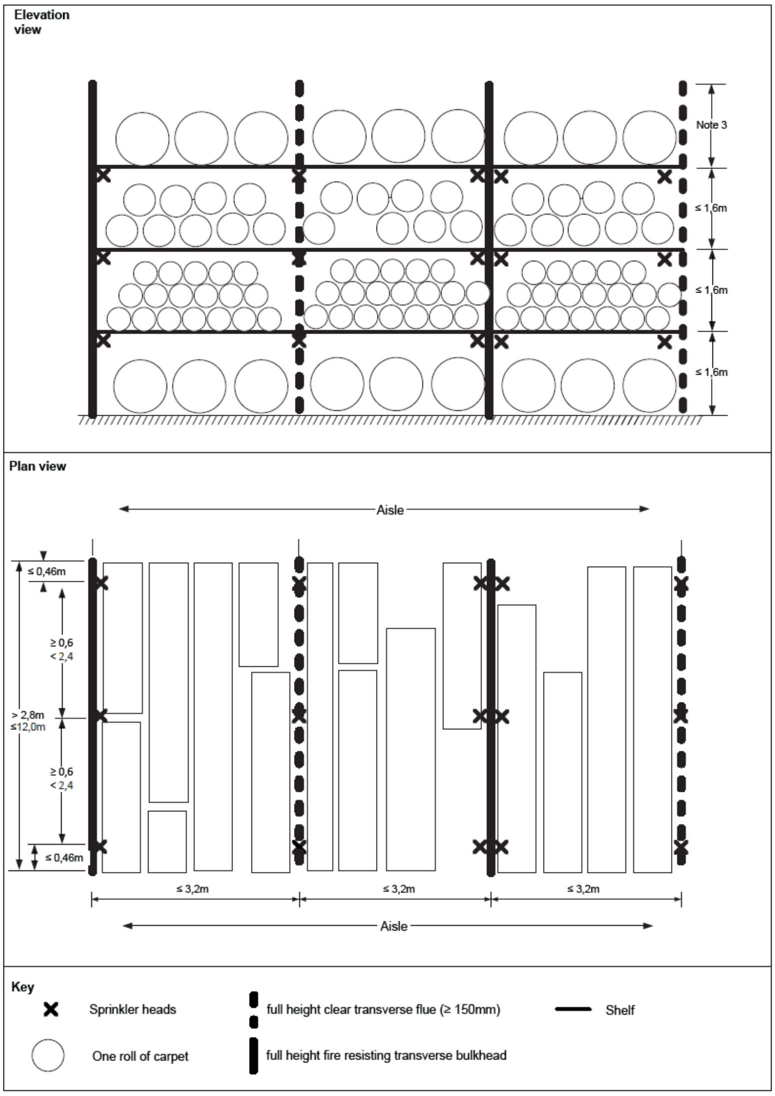
Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

TB234

Special Hazards, Carpet storage

Figure TB234.F19: Key fire protection features of carpet stores, showing full height bulkheads (optional) and sprinklers at every level (required).



Notes:

1. Intermediate level in-rack sprinklers are required and shall be installed at every level. Two or more rows of sprinklers will be required per shelf (depending on depth of shelf and spacing of sprinklers in the transverse axis, see required sprinkler head spacings in the figure).
2. Required flues and bulkheads shall be maintained throughout the height of the rack:
   a) transverse flues (≥150mm) or fire-resisting bulkheads are required every 3,2m apart or less. Sprinklers shall be aligned with transverse flues, where they exist. Sprinklers shall be offset from transverse bulkheads as shown;

b) longitudinal flues (≥150mm) or fire-resisting bulkheads are required where back to back (double row) racks are used. Where longitudinal flues exist, sprinklers shall be located within the flue and co-incident with any transverse flue intersections.

3. Carpet stored above highest level of intermediate level in-rack sprinklers shall not exceed the applicable height given in Table TB234.T12 or one roll high, whichever is the lesser.

4. Intermediate level in-rack sprinklers shall be installed above the uppermost level of carpet unless the top of the racking is fully open (free from shelves, slats or other obstructions) and ceiling clearance ≤6,0m.

5. The configuration may be repeated to achieve unlimited storage height.

TB234.5.7.1.2 *Hydraulics*

Where more than 50 intermediate level in-rack sprinklers are installed in the racks, they shall not be fed from the same control valve set as the roof or ceiling sprinklers. The control valve set shall be not less than 100mm diameter.

Intermediate level in-rack sprinklers and the associated ceiling sprinklers shall always be fully calculated (see TB231.2.1).

Calculation of the maximum installation pressure demand based on the hydraulically most unfavourable location

Where the hydraulically most unfavourable AMAO includes both roof or ceiling level sprinklers and intermediate level in-rack or shelf sprinklers the hydraulic system pressure and flow requirements on which the water supply performance is established, as outlined in TB210, shall be determined by the hydraulically balanced and simultaneous operation of:

a) the roof or ceiling level sprinklers located within the AMAO (as defined in BS EN 12845 Clause 13.4) over the in-rack or shelf storage area; plus

b) any non-rack intermediate or supplementary sprinklers located within the AMAO in a) above; plus

c) all in-rack or shelf sprinklers assumed to be in operation. Assume that number heads = 3 x *l* x *n* (see C&R on TB234.5.7.1).

where n is the number of rows of sprinkler heads per shelf.

- in a single row rack; or
- in a double row rack, where racks are back to back

and, l is the number of levels assumed to be operating up to a maximum of 3.

In order to verify that the water supply performance will satisfy the maximum installation pressure demand for the most unfavourable AMAO consisting of a), b) and c) above, it will be necessary to demonstrate all roof or ceiling level sprinkler AMAOs and all in-rack or shelf sprinklers AMAOs likely to be in simultaneous operation have been considered.

Calculation of the maximum flow demand based on the hydraulically most favourable location

Where the hydraulically most favourable AMAO includes both roof or ceiling level sprinklers and intermediate level in-rack sprinklers an hydraulic analysis of the simultaneous operation of the following sprinklers shall be carried out to determine the maximum flow rate the water supplies need to cater for:

a) the roof or ceiling level sprinklers located within the AMAO (as defined in BS EN 12845 Clause 13.4) over the in-rack or shelf storage area; plus

b) any non-rack intermediate or supplementary sprinklers falling within the AMAO in a) above; plus

c) all in-rack or shelf sprinklers assumed to be in operation.
Number heads = 3 x *l* x *n* (see C&R on TB234.5.7.1).

Where:

n is the number of rows of sprinkler heads per shelf:

- in a single row rack; or
- in a double row rack, where racks are back to back;

and

l is the number of levels assumed to be operating up to a maximum of 3.

In order to verify that the water supply performance and capacity will satisfy the maximum flow demand for the most favourable AMAO consisting of a), b) and c) above, it will be necessary to demonstrate all hydraulically most favourable roof or ceiling level sprinkler AMAOs and all hydraulically most favourable in-rack or shelf sprinklers AMAOs likely to be in simultaneous operation have been considered.

The highest flow requirement (Q_{max}) shall be taken at the point of intersection of the pressure-flow demand characteristic of the most favourable area of operation and the water supply pressure-flow characteristic with the suction source at its normal level. This highest flow value discharging for a period of 90 minutes shall determine the effective capacity of the water storage tank.

Note: The minimum pressure at any operating sprinkler is 1,0 bar for K115 intermediate level in-rack sprinklers (see TB229.3.9).

COMMENTARY AND RECOMMENDATIONS ON TB234.5.7.1

Number heads = 3 x *l* x *n* is derived from the following assumptions:

l = the number of levels up to a maximum of 3 levels (*l*) operating

3 heads per level operating

n is the number of rows of sprinkler heads per shelf:

- in a single row rack; or
- in a double row rack, where racks are back to back.

Aisles >>2,4m are expected to facilitate handling of goods stored in the carpet storage configuration.

No maximum number of heads is set as the number of heads is determined by the value of '*n*'.

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Special Hazards, Carpet storage

TB234.5.7.2 Non-woven synthetic fabric (replaces BS EN Annex G.7)

TB234.5.7.2.1 Non-woven synthetic fabric – free standing storage

Ceiling only protection may be used where all of the following are complied with:

- the limits for storage height, design density and area of operations are given in Table TB234.T13; and
- storage blocks shall be limited to 150m² plan area. Blocks shall be separated by continuous clear space of no less than 2,4m wide around the perimeter the block; and
- where clearance to the ceiling from the maximum design height of the normally stored goods exceeds 4m one of the following mitigating features shall be provided;
- a non-combustible false ceiling or mezzanine above the block storage with sprinkler protection above and below; or
- suitable storage racking shall be installed, with the addition of intermediate level in-rack sprinkler protection. See TB234.5.7.2.2.

Table TB234.T13 Non-woven synthetic fabric: Design criteria for roof or ceiling protection only

Storage configuration	Maximum permitted storage height (Note 1) (m)	Design density (mm/min)	Area of operation (wet or pre-action system) (Note 2) (m²)
ST1	1,6	10,0	260
	2,0	12,5	
	2,3	15,0	
	2,7	17,5	
	3,0	20,0	
	3,3	22,5	300
	3,6	25,0	
	3,8	27,5	
	4,1	30,0	

Note 1: The vertical distance from the floor to the sprinkler deflectors, minus 1m, or the highest applicable value shown in the table, whichever is the lower.

Note 2: See TB234.4.4. If despite this it is necessary to install a dry system, the area of operation should be increased by 25%.

Note 3: Ceiling slopes shall not exceed 10° (17,6%) gradient – see TB234.4.9.

TB234.5.7.2.2 Non-woven synthetic fabric – rack storage

For palletised rolls stored in single or double row racks, treat as Category IV goods and refer to section TB234.5.3.2.2 for requirements.

For non-palletised rolls or other storage configurations of fabric, no requirements are specified in this document. The insurer (and authority, if applicable) shall be consulted upon the acceptability of the proposed design solution on a case-by-case basis.

TB234

TB234.6 REFERENCED DOCUMENTS

BS EN 13501+A1 (2009) Part 1: *Fire classification of construction products and building elements. Classification using test data from reaction to fire tests*. London, UK: BSI.

FPA Design Guide for the Fire Protection of Buildings – Warehouses and Storage Buildings 1: Design Principles, FPA, 2008

LPC Rules for Automatic Sprinkler Systems 2009 incorporating BS EN 12845

LPC Rules for Automatic Sprinkler Systems incorporating BS 5306-2

FM Global, Property Loss Prevention Data Sheets 8-9 (July 2011)

FM Global, Property Loss Prevention Data Sheets 8-1 (May 2004)

FM Global, Property Loss Prevention Data Sheets 2-0 (April 2011)

APPENDIX E TECHNICAL OUTPUT 2

Full reference

Bird, S. N., STEPHENS, J. & J. GLOCKLING. (2011).

IQ1: Water Mist Questionnaire: Building Protection.

The Fire Protection Association. Moreton in Marsh, Gloucestershire, UK,

Abstract

IQ1 interactive "Water Mist Questionnaire: Building Protection" is a questionnaire that was developed to allow a more detailed 'audit' and investigation of the suitability of proposed firefighting systems. It seeks to gather information on design, quality and anticipated performance of water mist systems. It was peer reviewed by a panel of insurance risk managers (subject matter experts) and has been published since 2011. Since its publication it has been well used and feedback received is that it is extremely useful. It is now additionally made available as a resource for users from within the FFSST.

Fire Protection Association
Special Projects Group

Dr. K. Ruikar
Senior Lecturer
School of Civil and Building Engineering
Loughborough University
Loughborough
Leicestershire
LE11 3TU

3rd September 2014

Verification of authorship

Dear Dr Ruikar,

Please accept this letter as confirmation that Simon Bird, EngD Research Engineer acted as the lead author in relation to the following publications, which form an integral part of his EngD research:

BIRD, S. N., GLOCKLING, J. & STEPHENS, J., 2011. *IQ1: Water Mist Questionnaire: Building Protection*, Moreton in Marsh, Gloucestershire, UK, The Fire Protection Association.

BIRD, S. N., GLOCKLING, J. & STEPHENS, J., 2011. *IQ2: Water Mist Questionnaire: Object Protection*, Moreton in Marsh, Gloucestershire, UK, The Fire Protection Association.

BIRD, S. N. 2014. *TB234 Protection of High Hazard Storage (HHS) configurations. LPC Rules for Automatic Sprinkler Installations - Incorporating BS EN 12845*. Moreton-in-Marsh, UK: The Fire Protection Association.

Consistent with our quality assurance procedures, such publications are drafted and prepared by the named author(s), subjected to a thorough peer review process by panels of relevant industry experts and upon completion published by the Fire Protection Association.

Yours sincerely,

Dr J. D. L Glockling
Technical Director, The Fire Protection Association

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Water Mist is a form of active fire protection that, like all extinguishing technologies, can be effective in the protection of certain, but not all, risks.

In the absence of a published British Standard or European Standard with scope relevant to the protection of buildings or contents with this type of system[1], the questions herein are intended to elicit information that could be useful in providing evidence of the "equivalence" of such systems to alternatives where published and recognised national standards do exist.

If requested to do so, please complete one of these forms for each building to be protected by water mist system(s). This form is to be used to capture and record some of the data required to support a claim of "equivalence" and to provide evidence of sound engineering practice. Do not use this form for local application systems (a separate form is available for these systems).

[1] DD (Draft for Development) documents issued by BSI (British Standards Institution) are not to be regarded as British Standards. TS (Technical Specifications) issued by CEN (European Committee for Standardisation) are not to be regarded as European Standards.

Form: IQ 1

Version 1.2 November 2011

RISCAuthority

Water Mist Questionnaire: Building Protection

To be completed at the design and proposal stage of suppression system planning

Issued by: Ins. Co./Trade Ass/AHJ name in here

NOTE:

Completion of this form neither guarantees system performance nor system acceptance by Ins. Co. / Trade Ass / AHJ.

Dear Reader,

Re: RISCAuthority Suppression System Questionnaire Series

RISCAuthority is an insurance-funded initiative whose remit includes ensuring the highest levels of quality in the protection of the insured estate. In the field of fire suppression, a plethora of options exist and whilst many may be potentially capable of mitigating the identified risk they will each be supported to varying degrees by standards and certification schemes depending on their pedigree, novelty to the market place and design intent.

Part of RISCAuthority's remit is to promote new technologies in applications where they may make the greatest contribution to business and property protection and ensure that, irrespective of the technology deployed, at least the same level of rigour is achieved in determining the performance requirements; analysis of the risk; and the choice of the suppression technology, appropriate to the hazard.

This RISCAuthority Suppression System Questionnaire "*Water Mist Questionnaire: Building Protection*" is one of a developing series that will eventually cover various types of suppression systems that are not adequately covered by comprehensive standards and appropriate third party certification. It is designed to aid the purchaser of the system and their insurer to ensure that all elements pertinent to the selection, performance, design, delivery and upkeep of the system have been addressed.

It is anticipated that use of this Questionnaire will be an interim measure pending the development of comprehensive installation and component standards alongside component and installation certification schemes.

Whilst the questionnaire is comprehensive its content has been influenced by real shortcomings frequently experienced by insurers in the selection and deployment of building protection systems, some of which have resulted in very large losses.

RISCAuthority, in releasing IQ1 for water mist building protection, recognises that water mist may have the potential to make a contribution to the protection of buildings and may be an appropriate choice for certain hazards.

Regards,

Dr James LD Glockling

Technical Director Fire Protection Association

Director RISCAuthority

RISCAuthority

IMPORTANT NOTICE

This document has been developed through the RISCAuthority and published by the Fire Protection Association (FPA). RISCAuthority membership comprises a group of UK insurers that actively supports a number of expert working groups developing and promulgating best practice for the protection of people, property, business and the environment from loss due to fire and other risks. The technical expertise for this document has been provided by the Technical Directorate of the FPA, external consultants, and experts from the insurance industry who together form the various RISCAuthority Working Groups. Although produced with insurer input it does not (and is not intended to) represent a pan-insurer perspective. Individual insurance companies will have their own requirements which may be different from or not reflected in the content of this document.

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Water Mist Questionnaire - Building Protection

1. Full address(s) of risk(s) to be protected:

2. Roles and responsibilities

2a. Entity responsible for the design of the water mist system

Company or organisation's name

Lead designer's name and job title

Company or organisation's address

3. Entity responsible for the installation of the water mist system (if different to question 2a above)

Company or organisation's name

Responsible person's name and job title

Company or organisation's address

4. Description of the water supply, including details of any energy sources required, storage systems, and means to pressurise the water:

Water source: (please select)
- Town main
- Stored water
- Stored water relying on town main infill

Stored water volume (if applicable): dm^3

Town main infill rate (if applicable): dm^3/min

Water supply pressure at commencement of discharge: Bar

Water supply pressure at end of effective discharge*: Bar

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* Pressure at end of effective discharge - The minimum pressure below which the least hydraulically favourable nozzle will no longer supply extinguishing media at a rate that will meet the performance objective as outlined in Question 13; as proven by supporting experimental fire tests detailed in Question 22.

Provide details of any required energy source for water supplies:

Where electrical power supplies are used, reference (drawing number, title, date, issue number) the circuit diagrams provided which identify sources, interdependencies and all isolation means:

---

5. Name and address of the water mist component supplier(s):

---

6. Water mist component details for critical and key components:

Component (make/model):	Approval details:
Pumps:	
Water storage cisterns or vessels:	
Additives:	
Compressed gas supplies:	
Valves:	
Actuators:	
Nozzles (including details of the effective operating pressure range of the nozzle):	
Fire detection means:	
Alarms:	

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Pipework and fitting (include details of materials of construction):

Pipe fixings:

Other components critical to system function:

7. Extent of protection

7a. Is the property fully protected by water mist? Yes ○ No ○

7b. Are <u>all</u> roof, ceiling and floor voids fully protected? Yes ○ No ○

If the answer to either question is "No", give details of the unprotected spaces at Question 10h.

8. If there are any unprotected parts of the property, who has taken the responsibility for the decision not to protect these parts?

9. What is the intended use(s) of the building? (eg, school, factory, warehouse, shop(s), offices, mixed use (specify), etc):

10. In the following sections, please give details of the occupancy of each room or compartment within the property including any unprotected parts (eg school class room, office, computer room, atria, laboratory, storeroom, stockrooms or cupboard etc).

Individual room or enclosure description:

Room dimensions (W x D x H) in m

Protected by water mist Yes ○ No ○ Protected by other active suppression systems Yes ○ No ○

Individual room or enclosure description:

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Room dimensions (W x D x H) in m

Protected by water mist Yes ◯ No ◯ Protected by other active suppression systems Yes ◯ No ◯

ADD ANOTHER ROOM OR COMPARTMENT - (Remove)

a. Identify rooms with storage giving details of the materials, including any packaging, to be stored and the size of the room and contents. If storage is 'unknown' or 'uncontrolled' please list as such and state what assumptions have been made in respect of this in determining protection requirements. Also provide details of storage height and storage method:

b. Identify the room that has the largest quantity of combustible materials:

c. Identify the largest room or compartment volume:

dimensions (W x D x H) in m and Volume in m^3

d. Identify the room or compartment with the highest ceiling:

dimensions (W x D x H) in m

e. Which room or compartment has the largest number of water mist nozzles and how many nozzles are there within the identified room or compartment?

Cross refer to separate sheets or drawings if necessary. If used record the document number, title, issue number and date here:

f. List and give brief details of all other rooms protected by water mist as specified in Question 10:

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g. Identify any rooms protected by other active fire suppression systems as specified in Question 10, giving details of protection provided:

h. Identify any areas, room or voids (including ceiling voids and floor spaces) within the protected property without any form of active protection as specified in Question 10. Include justification for doing so:

11a. Provide details of ventilation systems (including smoke ventilation) present in water mist protected rooms or compartments. Will any ventilation system be operational during water mist system operation? Give details of any interlock controls:

11b. Possible natural ventilation sources. Provide details of doors, windows, shutters, other openings, and controls upon their use:

12. Is any process equipment or machinery being protected by water mist or within the protected space? Yes ◯ No ◯

If, 'yes', provide a full description and describe any interlocks provided to stop processes, fuel supplies, ventilation, conveyors, rotating machinery or similar features:

13. What is the performance objective for the water mist system?

Fire control ☐ Fire extinguishment ☐ Fire suppression ☐

Note: If the objectives differ in different compartments make this clear:

14. What is the largest number of water mist nozzles that are assumed to be operating within the property during a fire (assuming a single ignition source)?

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Explain how this number has been arrived at if the number of nozzles in any room or compartment exceeds the number assumed to be operating:

---

15. What is the duration of effective water discharge for the assumed maximum number of nozzles operating? For pumped systems this might be determined by the size of water supply. For gas pressurised systems this might be the time from actuation until the pressure at the hydraulically least favourable nozzle falls below the pressure at which the system is proven by fire testing (Question 22) to fulfil its performance objective (Question 13):

16a. System activation. Does the system use thermally activated nozzles (i.e. locally operated fusible element type nozzles) as one of its means of system activation? Yes ◯ No ◯

16b. Does the system rely on automatic activation by any means other than direct local operation of heads exposed to heat? Yes ◯ No ◯

16c. Can the system be manually operated? Yes ◯ No ◯

16d. If 'yes' to 16a or 16b, provide full details of the control and activation system including the RTI of the detection device:

---

17. Identify the nozzles at the most and least hydraulically favourable locations from the water supplies and describe their liquid extinguishing media delivery rate during the discharge period in litres per minute For pumped systems a single figure may be supplied for each nozzle. For gas propelled systems the flow profile for each nozzle is required over the effective discharge period:

---

18. Are any trade-offs / compensatory features proposed as a result of the presence of the system? If so, provide full details. Where part of a fire engineered solution please provide details of the fire strategy:

---

19. Provide details of building construction and fire protecting separation. Include details of fire resisting separation between protected and unprotected spaces if present:

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RISCAuthority

20. Which specification(s) is the system designed to?

21. Who is the provider of the installed system third party certification? (eg Lloyds, LPCB, Warrington, VdS, FM etc):

22. Fire test evidence - please provide the accredited third party test report(s) that demonstrate the system performance in a representative scenario for all parts of the water mist protected property, with reference to system operating parameters, scale, the risk protected, obstructions, ceiling height, detection method, detection performance and system performance objective (List here by: issuing body, title, date, report number. Please provide copies of reports separately):

23. Will the installed system require a written scheme of examination to comply with the pressure system regulations 2000? Yes ◯ No ◯

23a. If 'yes' to Question 23, has the system users'/owners' responsible person been made aware of their responsibilities? Yes ◯ No ◯

23b. If 'yes' to Question 23a, provide details of the competent person(s) certifying the written scheme of examination and undertaking any identified examinations before the system is first used:

Notes: The Pressure Systems Safety Regulations 2000 came into force on 21 February 2000. Users and owners of pressure systems are required to demonstrate that they know the safe operating limits, principally pressure and temperature, of their pressure systems, and that the systems are safe under those conditions. They need to ensure that a suitable written scheme of examination is in place before the system is operated. They also need to ensure that the pressure system is actually examined in accordance with the written scheme of examination. A written scheme of examination is a document containing information about selected items of plant or equipment which form a pressure system, operate under pressure and contain a `relevant fluid'. The term relevant fluid is defined in the Regulations and covers compressed or liquefied gas, including air, at a pressure greater than 0.5 bar (approximately 7 psi).

For further information see:

HSE, 2009. *Safety of pressure systems - Pressure Systems Safety Regulations 2000 - Approved Code of Practice.* 4th edn. London, UK: HSE.

HSE, 2002. *Guide INDG178 - Written schemes of examination - Pressure Systems Safety Regulations 2000.* 2nd edn. Suffolk: HSE Books.

HMSO, 2000. *The Pressure Systems Safety Regulations SI 2000/128.* London, UK: Great Britain.

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24. Details of all drawings, calculations and documents supplied with this questionnaire which have not already been referenced in previous questions above, or that contain additional parts that require consideration:

25. Declaration

I am authorised to represent the company identified below (25d) making this submission. I have supplied full and accurate information as required by this form.

25a. Name

25b. Signature

25c. Date

25d. Representing (company name)

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Annex A: Minimum supporting documentation which must be supplied with the completed questionnaire.

At least the documentation identified in A1 to A7 shall be provided with this questionnaire. Any drawings shall be at a scale of not less that 100:1:

A.1 A general specification for the system;

A.2 A block plan of the premises showing:

a) Fire compartments;
b) The installation and the occupancy of the protected space;
c) The extent of the protection, with details of any unprotected areas or volumes;
d) A cross-section of the full height of the building showing the height of the highest nozzle above datum;
e) Location and rating of fire boundaries.

A.3 General details of the water supplies, which if dependent on a town main at the time of operation shall include pressure and flow data, with the date and time of the test and a plan of the site;

A.4 A description of the essential features of the water mist system with descriptions of key components;

A.5 A statement, declaring whether the system requires a written scheme of examination, complying with the pressure systems regulations 2000 or not;

A.6 Fire test evidence of system performance pertinent to the described risk;

A.7 Design and operation manual for the watermist system;

The following documentation shall be provided to support the questionnaire as part of the design process.

A.6 A summary schedule, which shall include the following:

a) the name of the project;
b) drawing and document references including issue number, issue dates and titles;
c) the installation type(s);
d) control valve(s) details, including nominal diameter, and reference number(s)
e) the number of nozzles controlled by each control valve; and
f) the height of highest nozzle controlled by each control valve.

A.7 Layout drawings of the water mist installation(s); the drawings shall include:

a) the north point indication;
b) the level of protection provided for each hazard or occupancy;
c) constructional details of floors, ceilings, roofs, exterior walls separating protected and non-protected areas ;
d) location of nozzles relative to structural features, particularly those which effect the performance of water mist or which may give rise to shielded fires;
e) the location and dimensions of concealed floor, roof and ceiling voids;
f) indication of obstructions such as trunking, stagings, light fittings, heaters, suspended open cell ceilings which may adversely influence performance;
g) water mist nozzles, their fire detecting means and their operating set point;

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h) location and type of control valve sets;
i) flow alarms, sounders and alarm panel;
j) pressure switches;
k) locations and sizes of any subsidiary stop valves;
l) the drainage slope of the pipework;
m) the locations of all drain and test valves;
n) pipework and pipe fitting specifications and materials;
o) a key to the symbols used on drawings; and
p) a schedule of water mist nozzles, their fire detection means and the areas they protect.

A.8 Pipework design

Calculations shall be provided which determine the pipe sizes to be used; the information shall be provided either on purpose designed worksheets or as a computer print-out. The following information shall be provided:

a) the calculation method or computer programme name;
b) the date of the data provided;
c) the internal diameter of all pipes ;
e) the location and dimensions of concealed floor, roof and ceiling voids;
f) indication of obstructions such as trunking, stagings, light fittings, heaters, suspended open cell ceilings which may adversely influence performance;
g) water mist nozzles, their fire detecting means and their operating set point;
h) location and type of control valve sets;
i) flow alarms, sounders and alarm panel;
j) pressure switches;
k) locations and sizes of any subsidiary stop valves;
l) the drainage slope of the pipework;
m) the locations of all drain and test valves;
n) a key to the symbols used on drawings.
o) a schedule of water mist nozzles, their fire detection means and the areas they protect.

A.9 Water supply drawings

The drawings shall show the water supplies and the pipework up to the control valves. The position of any stop valves, non-return valves, pressure reducing or controlling devices, water meters and any connections for other services shall be shown.

APPENDIX F PAPER 4 (UNPUBLISHED)

Full reference (unpublished draft currently under review with Automation in Construction Journal)

Bird, S. N., Ruikar, K., Bosher, L., and Glockling, J. (2014).

Fixed Firefighting System Selection: Towards improved decision making.

Abstract

Fixed firefighting systems are an essential fire safety tool. In the UK and Europe over recent decades regulatory changes have been successful in creating an environment in which more innovation can take place. Increased numbers of fixed firefighting system types are now available. However, these systems offer levels of performance (and therefore safety) with considerable variance.

In response, a Fixed Firefighting System Selection Tool has been developed to complement the current regulatory framework and optimise selections. The tool incorporates logic, rules and fire safety educational resources to aid the system selection process. Evaluation of the tool has been undertaken using qualitative inputs from a range of key experts. The evaluation findings indicate that the Tool: is an innovative approach to promoting good fire safety designs, efficiently provides useful fire safety education to users and the supporting resources which consider firefighting system benefit are helpful.

1 INTRODUCTION

Fixed Firefighting Systems (FFS) are an essential hazard mitigation tool, particularly in potentially high financial and/or risk consequence scenarios. Previous research [1-3] has explored and reported the background to the FFS selection problem; historically, the choice of fixed firefighting system type has been somewhat limited by prescriptive regulatory requirements, or in non-regulatory circumstances (such as risk management initiatives or obtaining favourable insurance terms) practice that had to some extent perhaps become de facto. For instance, cases of sprinkler systems being a widely adopted solution, with a number of other solutions (for example: gaseous, powder, wet chemical and water mist) being available for circumstances where sprinkler systems were considered unsuitable. However, in the United Kingdom (UK) and Europe over recent decades regulatory changes have been successful in opening up markets and in a number of areas creating an environment in which more innovation can take place. It appears that consequently an increased number of types of fixed firefighting systems are now available to the user, also with increasingly overlapping ambitions in terms of scope of application. Not all systems now offered are equally mature in terms of; cost, supporting knowledge, experience and overall performance. Case studies [3] have demonstrated that understanding of performance and limitations (suitability, cost, benefit and in-service reliability) may not be widely appreciated. Experts are observing increasing numbers of what they consider to be poor fixed firefighting system choices and/or fire outcomes when such systems are called upon to fight fire, which is a cause of concern [1,3].

In order to provide better guidance upon the selection of FFS a Tool has been developed (Fixed Firefighting System Selection Tool or FFSST), which makes system recommendations to users and gives them access to various information resources intended to be of potential interest to their specific circumstances. This paper summarises the tool’s development and presents the key findings and implications from the evaluation of the Tool by fire risk management experts.

1.1 BACKGROUND TO FIXED FIREFIGHTING SYSTEM DESIGN

It is generally considered that good quality standards are desirable supporting resources in the field of fixed firefighting system design. “Conformity assessment and accreditation, along with standards are important parts of the nation’s quality infrastructure” [4]. BSI define a Standard as a “document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context” [5]. The LPC Design Guide states that all fire protection products shall be certified by an accredited body [6].

There are many factors to consider when seeking to design and install a fixed firefighting system; these are systems that might have the capability to autonomously activate and discharge significant quantities of firefighting media. Often this media (which may be water, gas or other chemical) can in itself be damaging or harmful (although it should be less harmful than the effects of fire would reasonably have otherwise been). Therefore systems must actuate only in quite specific circumstances, often some considerable time after the original design and installation task was performed. Maintenance is usually recommended but there is widespread anecdotal knowledge in the industry that maintenance is often poorly undertaken or not undertaken at all. These are some examples of factors that contributing to a situation where good quality guidance can be very helpful in seeking to address these issues. Standards (and guides) aim to fulfil the function of capturing and documenting experience and knowledge to improve and uphold outcomes. One of the important objectives of this work is therefore to seek to improve the guidance available to the user. It should seek to be more comprehensive, free from bias towards one technology compared to another and in a form which renders easy access. In order to provide better guidance upon the selection of FFS the FFSST was based upon the following broad selection problem areas (as derived through discussions with a range of experts throughout the project): Suitability, Cost-Benefit and Reliability.

1.2 SUITABILITY

There are a variety of sources of knowledge guiding system specifiers on the basic suitability of system for numerous applications. These include regulations, guidance and standards many of which are reported in previous work [1-3]. However, such guidance tends to be quite limited. Most of these documents are dealing with broad regulatory matters (encompassing many aspects of a building; not just fire safety) or intended to deal with one specific FFS technology only. From these types of documents, the most useful type of information found to be available is that typically found in the 'Scope' section of documents, where the intended application of a technology is given. Other limitations upon the use of the technology can be found peppered throughout some of the documents. Some of this information can be used to derive underpinning 'rules' for use in the FFSST. None of these sources deal in any detail with the issue of selecting FFS where a choice of types is available.

1.3 COST AND BENEFIT

Cost-Benefit Analysis (CBA) as a systematic technique used to consider in detail the desirability of a particular project or programme [7]. CBA is recognised as a technique that the principles of which can be applied to any problem [8]. The authors found that seeking to apply the general principles of optimised CBA as a guiding philosophy in considering this selection problem was useful. Doing so appeared to establish a strong link between the research direction and benefit the outcomes might deliver to the user. In this subject area, the ‘costs’ might include: system purchase and installation costs, cost of ongoing maintenance, negative aspects of having a system (such as unwanted activations and media discharge) and perhaps opportunity cost (what else could have been purchased instead [9], life for example other fire prevention or safety measures). The ‘benefits’ might be described as ‘firefighting performance’ or ‘the consequence of damage arising from fire without a fixed firefighting system compared to the same fire with a firefighting system’. However different systems have different ambitions; for example to ‘suppress’ fires, to ‘control’ fires [10], to ‘extinguish’ [11] fires or to ‘prevent’ [12] fires. Then one should consider that fixed firefighting systems, like any system are not 100% reliable, so in some instances will fail to deliver some or all of potential benefit. It would be reasonable to expect different FFS, comprising very different sets of components and design philosophies to have different levels of reliability. It may also be reasonable to expect different FFS to have different levels of reliability when they are used to protect different scenarios too.

Depending upon what is being protected, it is expected that each of these factors would have a material effect on the ‘benefit’ (and perhaps the ‘cost’) of a FFS. Detailed CBA study of fixed firefighting system performance appears to be in its relative infancy (recent examples of such work have been published by BRE [13] and CEBR [14]). Such work confirms the complexity of properly investigating CBA in this area even with very confined parameters. Quantitative investigation of such matters, whilst being important was therefore identified as being necessarily out of scope of this research. Instead, it was decided that the tool must provide a means by which users may identify these issues so that they make their own investigations if they so wish (examples are given in section 2.4 "supporting media" of this paper). Further it should become a recommendation arising from this research that this aspect is inseparable from any detailed selection exercise; data on 'benefit' or 'reliability' would be a useful asset to further such investigations.

1.4 RELIABILITY

FFS reliability, or the quality of being reliable "able to be trusted, predictable or dependable" [15] has emerged as an important aspect (because of its link to 'benefit' discussed in the preceding section) to be considered in the selection of a FFS. Literature review [16-22] has yielded only a limited amount of reliability data but has been useful in forming an appreciation of what constitutes and contributes to 'reliability' in the context of this selection problem. In turn this has been useful in the development of supporting informative resources (examples are given in section 2.4 "supporting media" of this paper).

2 DEVELOPMENT OF THE TOOL – AN OVERVIEW

Initially, an in-depth review was undertaken to identify potentially suitable development environments or techniques. However, this exercise highlighted that no suitable (generic) solutions could be identified by merely reviewing existing tools and the research or industrial literature. The decision was therefore taken by the project team to seek external expertise on the software development side of the project.

In order to consult with software experts, a specification was developed. Frappier, et al. [23, p. preface] suggest that "A specification method is a sequence of activities leading to the development of a produce called a specification". They then go on to state that typically several system characteristics may be specified; Functional requirements (input-output behaviours), Efficiency requirements (addressing execution time considerations) and implementation requirements (programming language to use, targeted hardware and software platforms). Alagar and Periyasamy [24] refers to the concept of a Software Requirements Document (SRD) as an essential tool in taking an abstract idea for a piece of software through to development; the route through stages of software development are shown in Figure 1.

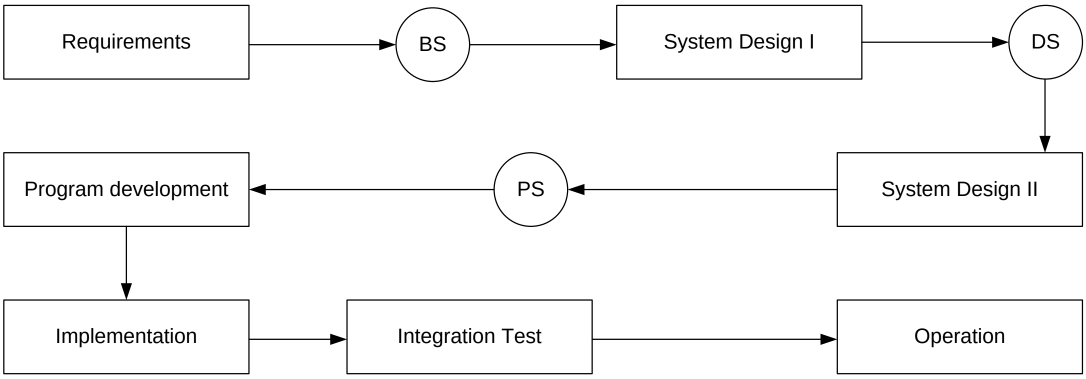

Figure 1 - A simple life-cycle model with specification phases [24]

Three levels of specification are shown; 'BS' Behavioural specification, 'DS' Design specification and 'PS' Production specification. The idea being that an incremental approach is used to improve and add to the specification at each level. Whilst this model bears some resemblance to the steps followed in this research, some of the general principals were observed (such as developing a BS and partial development of a DS) in order to obtain some of the benefits (suitability of end product, efficient use of resource) of utilising a specification approach.

The FFSST sets out to ask the user a series of questions to elicit the required knowledge to make recommendations and signpost users to tailored relevant material that may be useful to them in making their FFS selection. Recommendations are in the form of 'Green' meaning this particular technology type is likely to be a good choice, 'Amber' meaning it might be suitable and 'Red' meaning it is unlikely to be suitable. The process concludes with a report being produced, recording the recommendation to the user in relation to each system type.

Each recommendation will be accompanied by any relevant application notes and links to other relevant resources. These resources may be in a various media formats (i.e. documents, animations, videos, pictures). Figure 2 depicts an overview of the desired FFSST architecture, presented graphically in a style inspired by the work of Ruikar, et al. [25] in developing an e-readiness assessment application architecture and Giarratano [26] and Nilsson [27] in their efforts to describe the main elements of earlier expert systems.

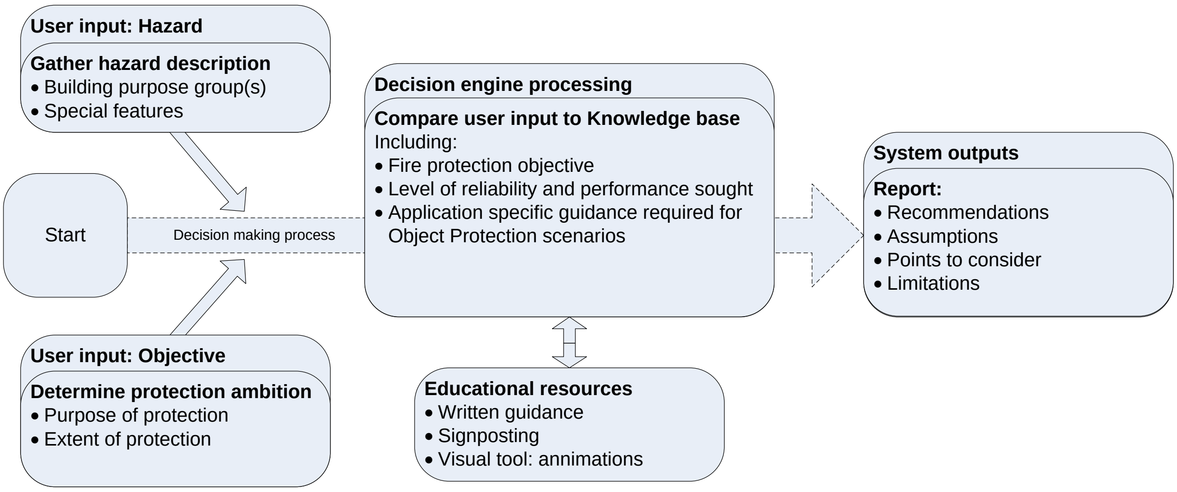

Figure 2 - Overview of derived FFSST architecture.

Having considered the recommendations received from expert, it was decided to select XpertRule's "Knowledge Builder" software. This software can automate business decisions and deliver intelligent user interfaces [28]. The software is highly customisable and the first step in developing a decision support application is usually to tailor the package to suit the specifics of the problem.

2.1 LOGIC AND RULES (FORMING THE TOOL)

Previous work [1-3] has established that underpinning knowledge is available which is suitable for use as rules to guide the selection process or information to accompany recommendations arising from the process. The development environment and process adopted facilitated development on the fly (without the need for detailed pre-planning). This was to avoid the need to attempt to list and inter-relate all the knowledge (rules, decision trees and supporting resources); a task which was considered beyond the scope of the project. As such the derived (and customised) development environment is both the software FFSST compiler and the record of the identified knowledge. An explanation of the method of development follows.

2.2 TOOL DEVELOPMENT METHOD

A framework of rules is established as Attributes. An attribute is essentially a question with two or more answers. Attributes (or questions) may be relevant to one or more FFS technologies.

A *Tree* is created for each FFS technology. FFS technologies are grouped by the most relevant design and installation standard applicable in UK. This was found to be a convenient (and most fully-formed pre-existing) way to demark one technology from another. Horizontal ‘Trees’ are used to structure together ‘Attributes’ and serve to structure the knowledge elicitation process in relation to the suitability of each FFS technology in the users circumstances. It was found that an efficient way to develop each tree was to consider it to be an elimination process, for example by adopting the stance of asking “when is this technology not suitable?” (and what do I need to ask to find that out early in the process?). Figure 3 shows one of simpler decision trees in the development environment.

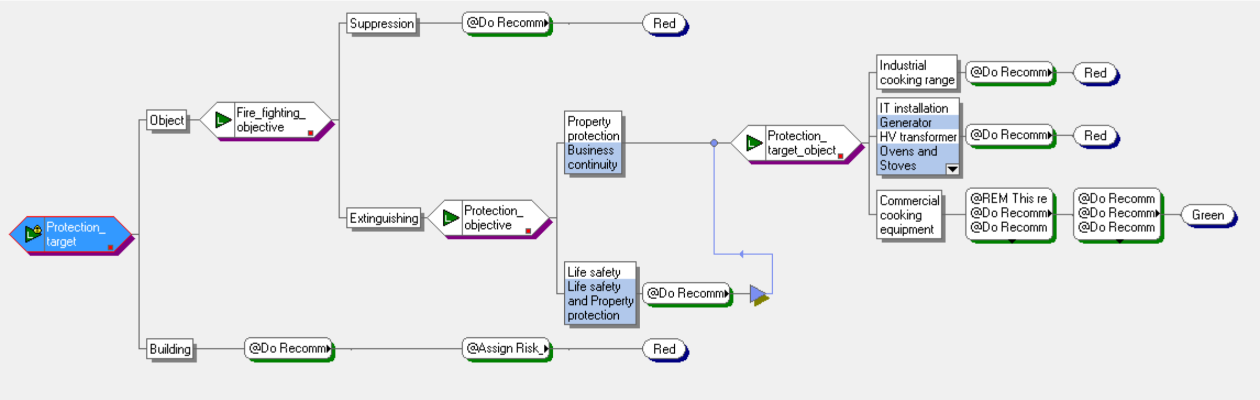

Figure 3 - Example decision tree – for “LPS 1223 - Fixed Fire Extinguishing Systems for Catering Equipment”

Depending upon how the user responds to questions, each tree will be traversed and the software will record a recommendation (red, amber or green) in relation to that tree (which is the recommendation in relation to one particular technology type). As the user progresses through the tree (via a Graphical User Interface (GUI) having an altogether different appearance; see Figure 4 for an example) additional information may be provided to them intended to help make the meaning of questions clear or illustrate various points.

This method of development was found to offer the following advantages:

- Where attributes (or questions) are shared between trees, for efficiency, the user will only be asked that question once.
- In structuring trees from attributes, it is possible to minimise the number of questions put to the user by asking the most impactful (usually the most used) questions first. Thus irrelevant branches of trees may be closed off (and those questions not asked).

Having said that the development environment is both the software FFSST compiler and the record of the identified knowledge, it is necessary to undertake a reverse-engineering exercise in order to extract the assembled rules and knowledge to document the elements that come together to form one tree. An example of such an exercise is presented in Table 1.

Table 1 – ‘Rules’ and ‘Knowledge’ tree in LPS 1223 [29]

Attribute	**Question**	**Possible answers**	**Significance**	**Related information to be given to the user**
Protection target	What is the type of protection?	Object	Within scope: proceed to next question	State FFSST limitation: only one object can be considered at a time Expand on what is meant by ‘object’. Give examples. Signpost to: BS EN 13478 “Safety of machinery - Fire prevention and protection” [30] and BS EN ISO 12100 “Safety of machinery - General principles for design - Risk assessment and risk reduction” [31]
		Building	Recommendation: RED	Record note: *‘This FFS technology is not suitable for the protection of whole buildings’*
Firefighting objective	What is the firefighting objective?	Suppression	Acceptable variation to scope: proceed to next question. Note variation.	Record note: ‘*This is an extinguishing technology, so it should exceed your requirement to suppress a fire*’
		Extinguishing	Within scope: proceed to next question	None
Protection objective	What is the protection objective?	Property protection	Within scope: proceed to next question.	None
		Business continuity		
		Life safety	Acceptable variation to scope: proceed to next question. Note variation.	Record note: *'This method of protection is primarily intended to protect an object (cooking equipment) but in doing so may bring life safety benefit'*
		Life safety & property protection		
Protection target object	What is the protection target?	Commercial cooking equipment	Last question. Recommendation: Green	Expanded definition of ‘commercial cooking equipment’. Illustrative figure of such cooking equipment. Signpost to: RC44 “Risk Control - Recommendations for Fire Risk Assessment of Catering Extract Ventilation” [32] and LPS 1223 [29] Make (and record) assumptions: as we know this is a cooking range it is reasonable to expect there to be water and personnel present and that there will not be a sufficiently gas-tight enclosure to render gaseous systems as likely to be feasible. Record notes: various recommendations are made based upon field experience of the use of this type of system. Video: A video animation of an example of this system type in operation is provided
		Industrial cooking equipment	Recommendation: RED	Expanded definition of ‘Industrial cooking equipment’. Illustrative figure of such cooking equipment. Record note: *‘This approach is for Commercial cooking equipment, not Industrial cooking equipment’*
		All others		Expand on what is meant by this object type. Give examples. Record note: *This FFS technology is not suitable for this scenario*

2.3 SIGNPOSTING

As the user advances through the process of answering questions, more becomes known about their circumstances. The derived GUI (see Figure 4 for an example) is capable of responding in a number of ways; question text and selectable answer options change each time a new question must be posed. Help text is dynamic and may include hyperlinks (useful to signpost towards related documents for reading outside the tool, explanatory videos or animations) and images.

Figure 4 - Example of Graphical User Interface (GUI) – displaying 'object' protection scenarios and help text and graphic for 'Commercial cooking equipment'

The signposting is 'dynamic' in that it adapts to the circumstances the user describes and thus seeks to avoid overloading the user with irrelevant material and only refer them to material that is likely to be applicable. If the Tool can be confident that the scenario involves Commercial cooking equipment, it will make available related further reading to the user. For example (as in Figure 4) LPCB's LPS 1223 "Requirements and testing procedures for the

LPCB certification and listing of fixed fire extinguishing systems for catering equipment" [29] and the FPAs additional guidance "RC44 - Fire risk assessment of catering extract ventilation" [32]. This dynamic signposting is believed to be a facet of the work of considerable value in that it efficiently directs the user towards focused and related material.

2.4 SUPPORTING MEDIA

The research has determined that the FFSST has an important role to play in behaving as an educational resource. Therefore, some consideration has been given to learning styles, with the intention of helping to maximise the impact of the tool. According to Coffield, et al. [33] learning styles have been studied for 40 to 50 years with the broad aim of improving educational techniques by understanding how people learn. The work of Coffield, et al. [33] undertakes a comprehensive review of work undertaken in the field. It identifies 3,800 referenced pieces of work in the field. It breaks these down in to 71 models of learning styles. 13 of these are considered 'major models'. Other notable work on learning styles includes that by Fleming [34]. Fleming suggests that people respond differently to different presentations of information. He defines the main modes of presentation as aural (A), printed words (R), visual (V) and kinesthetics (K) using all senses including touch, hearing, smell, taste and sight. Each of the modes is assigned a letter as denoted in brackets. These letters are re-arranged to form the acronym 'VARK' which is now in common use in the field [34]. The area appears to be not without controversy; Bennett [35] cites the work of Coffield, et al. [33] as suggesting that many of identified styles (and he specifically refers to Fleming's 'VARK' model) were not backed up by credible evidence.

However, there does appear to be general agreement that different people do respond differently to different styles of learning stimuli. The opportunity that this presents should be exploited [33]. As the FFSST is intended to benefit a broad range of users perhaps from quite different backgrounds, the intention is to introduce as many learning styles as can reasonable be achieved. The project team have identified opportunities to use the following techniques: An interactive software tool, on-screen descriptive text, graphical information (explanatory pictures, sketches and animations) and system feedback. Supporting media incorporated in the FFSST now includes: help text and pictures within the Tool, links to applicable standards and guidance, animations to illustrate key concepts and video footage to explain the operation of some system types. Some of this material was pre-existing. Some of it has been created specifically to enrich the tool and address perceived problem areas. Examples of informative material developed as part of this research intended to help users understand and contemplate issues such as cost, benefit and reliability (and for incorporation in to the FFSST) include “IQ1: Water Mist Questionnaire: Building Protection” [36] and “IQ2: Water Mist Questionnaire: Object Protection” [37].

3 EVALUATION OF THE FIXED FIREFIGHTING SYSTEM SELECTION TOOL [4]

Evaluation is considered an important step in support of demonstrating the validity and reliability or “the confidence which someone may have in the findings” [p. 263. 38]. Wong

[4] The current version of the tool (version 1.09 at the time of writing) can be accessed freely at the following internet address: http://xpr.riscauthority.co.uk/xraoutput/main.html

[39] lists some of the problems that can occur as a result of defective software (such as the Tool under development as part of this research) including: undesirable outcomes, reduced customer (or user in this case) satisfaction, increased maintenance costs and/or decreased productivity (or usefulness in this case) and profits (or societal benefit in this case). Evaluation is therefore identified as being a critic step in concluding this phase of the research in terms of helping to impart rigor and as a quality assurance step.

3.1 METHODOLOGICAL CONSIDERATIONS

In order to evaluate the research progress, the techniques used are described in the following paragraphs. Then follows a description of how these techniques are to be applied in the case of this research.

Exploratory data analysis in the form of open ended questions. This technique is suitable when numerous and varied responses are expected [40]. Such responses are considered to be likely in the case of this research, given the breadth of scope of the work and necessarily limited extent to which development has been pursued. Although this technique can certainly yield useful feedback analysis of the responses to questions can be rather complicated and it is noted that “it also requires a great skill to accurately report the information” [p. 86. 40]. Naoum [40] then goes on to propose an example method to structure questions and code example responses to such questions. However even this methodology is considered too structured and inflexible given the expected unstructured nature of feedback anticipated. Instead it is considered in this case that the primary practical means of capturing information to support the evaluation will be to use open questions and accept that laborious and informed analysis of the comments will be the only practical method that has been identified. Fellows and Lui appear to acknowledge that action research (the model which this research has strived to follow) is highly context dependant “is neither standardised nor permanent as it is reliant on the project and knowledge and subjectivity / perceptions of the persons involved” [p. 21. 38].

Active design review [41] is an approach that would appear to lend itself to the circumstances. Wong [39] explains the background to the approach is sympathetic to contemporary working life in that reviewers: may be overloaded, may not be intimately familiar with the objective and intricacies of the software (the Tool) design and often do not achieve much progress when expected to work as large review groups. He goes on to outline the three steps of the active review process: 1) the author presents an overview of the artefact (the Tool), 2) Defect detection is facilitated by the author, by means of open ended questions 3) the final step is defect collection where more in-depth review meetings focus on one specific identified problem area at a time. Finally, he records that reviewers are to be selected based upon their expertise. It is therefore expected that this segmented approach allows reviewers to focus on making improvements in small areas with reduced risk of becoming overloaded. It follows that I small improvements can be appropriately re-combined the results can be significant overall progress towards improvement.

Previous work [1,2] has identified the groups who are either expected to benefit directly or indirectly from the Tool (users, benefactors). In order to keep the evaluation activity to a manageable size, a limited number of ‘groups’ considered likely to have well informed opinions from a range of perspective were targeted as evaluators. The parties and the rationale behind the decision to include them in this active design review evaluation process are detailed in the following table.

Table 2 - Evaluator credentials and selection justification		
Individual	**Organisation**	**Justification and expertise**
Senior Risk Manager (22 years related experience)	Insurance provider	As part of any insurers risk management strategy, fixed firefighting systems are one of the risk management tools available to the insurer to help manage their financial exposure in respect of fire losses. Risk Managers are therefore very familiar with numerous fire risk scenarios. Risk Managers are expect to have good awareness of the overall suitability of recommendations from the FFSST in an insurers risk mitigation context.
Risk Manager (18 years related experience)	Insurance provider	
Director (years of experience not disclosed)	Institute of Fire Safety Managers (IFSM)	The IFSM is a professional body of individuals and companies with the objective to raise the awareness of fire safety at a local, national and international level, promoting fire prevention, fire protection and reducing the risk from fire as far as reasonable practicable. Membership includes a broad range of fire safety practitioners and as such it is considered a good route by which to reach a significant group of the target users of the tool. The IFSM should provide good representation on behalf of potential system users, with emphasis on the user experience, whilst using the tool.
Fire Safety and IRMP Advisor (33 years related experience)	FBU (Fire Brigades Union)	FBU have a broad range of experience in the subject area, from field experience (firefighting), fire prevention and fire engineering. They are therefore seen as a stakeholder that may bring several dimensions of experience (that of a first responded to fires, approving authority and fire engineer) to the tool evaluation process.
Secretary General and Director (40 years related experience)	BAFSA (British Automatic Fire Sprinkler Association) and LPC Consultants	BAFSA is a trade association for installers of sprinkler and other fire protection equipment. The Secretary General has extensive industry experience and is recognised as an expert in the field of fixed firefighting system selection and specification. He is therefore considered a source of potentially deep expertise in the underpinning knowledge incorporated into the tool.

3.2 EVALUATION ANALYSIS, DISCUSSION AND FINDINGS

The evaluation was undertaken on version 1.09 of the tool between 7th to 18th July. This section of the paper reports the feedback received and implications for the tool development. Once it had been established that the identified experts wished to participate in the research, informed consent was obtained and they were given access to the FFSST (version 1.09) plus some guidance upon the intention of the evaluation process. The process was:

- Introductory correspondence
- Invitation to provide feedback (either by writing, meeting or telephone interview) based upon interaction with the tool
- Recorded feedback and tracking of actions arising (i.e. completed, to be completed or to be deferred to a future development cycle)
- Optionally, an interview (telephone or face to face) to allow exploration of points in more depth (two of the five participants elected to use this option to supplement their written submissions).

Examples of feedback received are summarised in Table 3. The feedback was analysed and grouped into three categories; validation (or comments in support of the work and progress achieved), critical feedback giving rise to improvements which have been implemented and critical feedback which it is currently impractical to undertake and must be deferred beyond this phase of work.

Table 3 - Feedback received (summarised)
Feedback in support of the work: • *"I would find it a useful tool, especially because it signposts me to the appropriate standards and guidance"* • *"The tool is looking good and beginning to contribute to supporting the needs of the Industrial sponsor"* • *"I found it easy to use, covered my scenarios well. I like the fact that once the input has gone in I get a number of solutions."* • It was reported that the FFSST loaded and operated correctly on various Microsoft Windows and Mac OS machines
Critique of the work and improvement actions arising: • Fault with logic associated with "Gaseous Halocarbon Systems" identified and rectified by alteration to the logic tree (see Figure 5 and Figure 6). • Where possible (where copyrights and permissions permit), the external informative resources were obtained and placed in the 'Assets' folder of the Tools website. From here they can be obtained by the user with a single click (rather than having to register or log-in to view external resources). • Further explanation of 'HV equipment' (voltage thresholds) would be helpful. "IEE wiring regulations" definition added [42]. • Note added to FFSST output to inform user of the possibility of HF production from the use of FK-5-1-12 [43] extinguishant.
Critique of the work and deferred actions arising: • Optimise GUI for multi device use (i.e. tablet devices in addition to personal computers). • Further develop the meaning, explanation of and philosophy behind terms used: property protection, life safety and business continuity. • One glitch with a graphic placeholder was reported, but this could not be replicated. No further action to be taken at this time. • A new detailed case study (a radioactive sterilisation bunker) was offered for consideration and incorporation into the tool. • The tool could seek to take over the function of the design and installation standards that it currently signposts to. The value in doing this would be that errors of interpretation (reported as frequently encountered) could be irradiated or reduced. Whilst this may be a valid ambition, it is significantly different ambition to the scope of this work.

The actions arising classified as feasible to action in the development cycle were addressed. Those to be deferred have been recorded for future action. Illustration of the process of adjusting logic in a decision tree for maintenance purposes or in response to feedback can, for example, be seen in Figure 5 (before adjustment) and Figure 6 (after adjustment). In this situation (the circumstances, or input data, are described in Table 4) the intention is to alter the FFSST recommendation from 'Red' to 'Amber'.

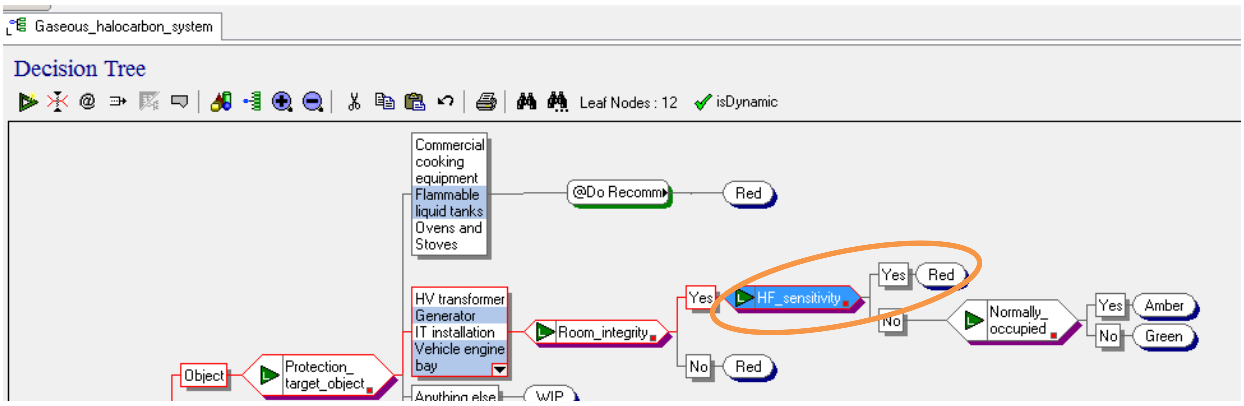

Figure 5: Compiler view (before Modification):

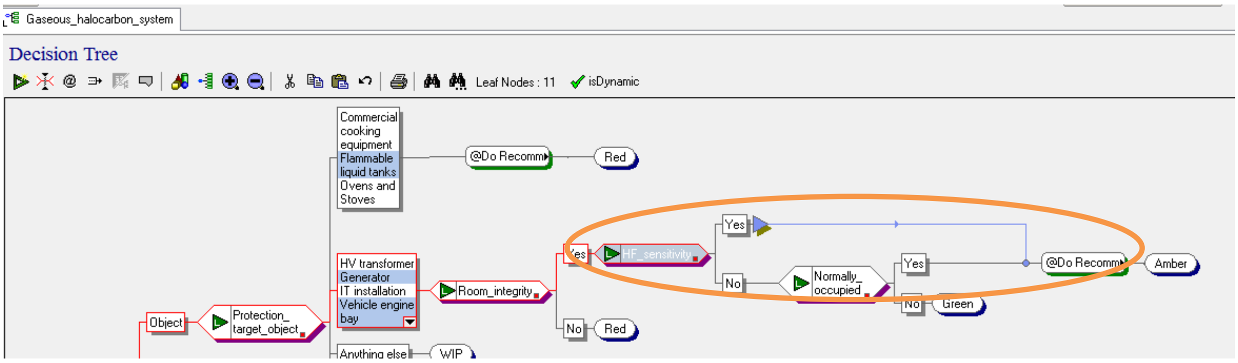

Figure 6: Compiler view (after Modification):

Table 4 - Input-output data capture in fault remediation	
Question	**Response**
What is the type of protection?	Object
What is the protection target?	IT installation
What level of protection are you seeking to achieve?	Property protection
Is the object to be protected in an enclosure with a sufficient level of integrity to maintain the firefighting or prevention media?	Yes
Does the protected space contain anything (such as people or equipment) sensitive to Hydrofluoric acid (HF)?	Yes
Is there any reason why low oxygen levels might not be suitable?	Yes
What is the firefighting objective?	Extinguishing
Is the space to be protected ever occupied by people?	Yes
Are the contents of the building (or equipment to be protected) compatible with water?	No
Are 'deep seated' fires expected?	No

The responses received in the evaluation work have validated that the Tool as developed serves as a useful resource. The preceding example documented in this paper serves to illustrate that it was possible to action some of the feedback received immediately to improve the Tool and demonstrate the process of modification. The evaluation process has also given rise to feedback that can be incorporated into the continuous development cycles associated with the upkeep of such a Tool.

4 CONCLUSIONS AND RECOMMENDATIONS

A tool and supporting resources have been developed which provides users with support in the potentially complex task of selecting a suitable Fixed Firefighting System for their circumstances. The tool incorporates knowledge, rules, logic and a variety of pre-existing and specially created supporting educational and informative resources. The tool has been evaluated at various stages from the initial proof of concept work [1] to the later stage evaluations reported in this paper, which validate the progress achieved to date. The feedback received has been useful in improving the quality and content of the tool and in obtaining confirmation that there is value in the tool and research. This should align well with the objective of the work to contribute to improved outcomes in the event of fire.

The work has revealed the disparity in the maturity of knowledge between system types. It has allowed resources to be created to help to identify (and thus resolve) potential weaknesses of certain FFS technologies.

The tool lends itself well to continue development (and alteration as new resources and knowledge become available). As such it is expected it may prove to act as a catalysis to facilitate further discussion and study of the area of optimum fixed firefighting system selection.

Recommendations arising from this work:

- It is recommended that standards writers should be cognisant of the differing capabilities of fixed firefighting system and alert users to resources (such as the FFSST or other methods of risk and cost-benefit assessment)
- Whilst the outputs of this work represent a considerable improvement upon the information available to users in this subject domain, if it were ever possible to obtain

comparative performance data on different types of FFS in different applications, this could be very useful data.

In summary, this work has been successful in advancing the accessibility of knowledge to users in this selection problem domain. It does so in a refreshing and innovative format. It is believed this format and novelty will encourage uptake and help to maximise the impact of the research; which seeks to achieve improved fire outcomes where FFS is a factor.

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APPENDIX G SURVEY QUESTIONNAIRE AND RESULTS

This survey questionnaire was undertaken in pursuit of objective 1; to review the use of FFS in the fire protection industry.

The questionnaire was open to allow the collection of responses from 17th March 2012 until 20th April 2012. A total of 64 responses were received (65 including one 'test' entry made by the researcher, which has been removed from all further comment and analysis).

1. Have you needed to consider whether an active fire protection system should be provided as part of a projects fire protection means?			
Yes:		100%	64
No [IN WHICH CASE YOUR INPUT INTO THIS QUESTIONNAIRE IS NOT REQUIRED. PLEASE CLOSE THIS WINDOW - THANK YOU]:		0%	1

2. To which of the following age groups (years) do you belong?			
18-27:		0.00%	0
28-37:		10.94%	7
38-47:		34.38%	22
48-58:		28.13%	18
58-68:		25.00%	16
>68:		1.56%	1

3. For approximately how many years has your role involved making or commenting upon the selection of Active Fire Protection Systems?			
0-4:		4.69%	3
5-9:		9.38%	6
10-14:		21.88%	14
15-19:		15.63%	10
20-24:		14.06%	9
>25:		34.38%	22

4. Which of the following best describes your role?			
Building Control Officer:		n/a	3
Fire Engineer:		n/a	27
Architect:		n/a	0
Fire and Rescue Service:		n/a	7
Organisational risk manager:		n/a	5
Project Manager (Design and Build Contractor):		n/a	6
Other *(please specify)*:		n/a	16

Other:

- consultant
- Consultant (to Project Managers and their suppliers, typically)
- Currently Fire Safety Advisor for a Local Council
- Design Engineer
- Fire risk assessor
- fire safety consultant, insurance advisor
- Fire Sprinkler designer
- Insurance - risk engineer

- Insurance Company - Risk engineer
- Insurance Company Risk Engineer
- Insurance Company Risk Manager
- Insurance Risk Consultant
- Insurance risk control / risk management
- Insurance risk engineer
- Insurance surveyor
- Insurance Surveyor
- Insurance Surveyor
- Insurer Risk Consultant
- Managing Director
- manufacturer
- MD - Sprinkler Contractor
- Product manufacturer
- Proposals Engineer for a Major Fire Protection company.
- Qualified fire engineer working in insurance as a risk engineer
- Researcher-adviser fire safety
- Risk Control / Management for an insurance company
- Risk Control Surveyor
- Risk engineering consultant - insurance industry

5. How did you acquire the skills to perform the task of influencing the selection of Active Fire Protection Systems?

On-the-job training / apprenticeship:		n/a	51
Academic qualification(s):		n/a	33
Vocational qualification(s):		n/a	18
Other *(please specify)*:		n/a	8

Other:

- Attendance at CPD events
- Fire Brigade officer
- Fire service
- FM Global training system plus on the job training
- Lean heavily on insurer's skills
- Specific training
- Trained by FM Global (11 years engineering and 2 years underwriting).
- Various training courses and general experience over the years

6. Do you think the proposed Active Fire Protection System Selection Tool will be useful? (Please use the 'other' box if you wish to make a suggestion or provide an expanded answer)

Yes:		85.94%	55
No:		7.81%	5
Other *(please specify)*:		6.25%	4

Other:

- Depends on its effectiveness
- Maybe. It may cause problems by selecting a system that is adequate - but more expensive than an alternative system which is also adequate. Also, there are so many notes and appendices associated with all standards that keeping this tool up to date could be problematic. Will this consider just LPC or will it include FM, NFPA, APSAD, VDS etc..?
- Possibly, but it should not be used as a substitute for experience
- Providing recommendations are always to use third party certified systems. to ensure system is to an industry recognised standard.

7. What type(s) of systems have you recommended?

Aerosol:		n/a	6
Foam:		n/a	42
Gaseous:		n/a	43
Oxygen displacing system:		n/a	13
Powder:		n/a	13
Sprinkler:		n/a	61
water mist:		n/a	41
spray system:		n/a	30
Other *(please specify)*:		n/a	4

Other:

- Deluge, water curtain, water cloud, foam/water sprinklers,
- Survivable Cable. (Passive component of these active systems.)
- Well, when I say powder, I mean cooker hood chemical suppression.
- Wet chemical

8. Would your system choice be accompanied by recommendations to use any particular system specifications?			
Aerosol system to CEN/TR 15276-2:		n/a	2
Foam system to BS EN 13565-2:		n/a	23
Gaseous system (carbon dioxide) to BS 5306 4:		n/a	17
Gaseous system (inert or halocarbon agent) to BS EN 15004-1:		n/a	24
Oxygen displacing system to PAS 95:		n/a	9
Powder system to BS EN 12416-1:		n/a	6
Sprinkler system to BS EN 12845:		n/a	44
Sprinkler system to BS 5306-2:		n/a	26
Sprinkler system to LPC Rules:		n/a	32
Sprinkler system to BS 9251:		n/a	27
Water spray systems and deluge systems to DD CEN/TS 14816:		n/a	14
Water mist system to DD 8458:		n/a	21
Water mist system to DD 8489-1:		n/a	20
Other *(please specify)*:		n/a	20

Other:

- All NFPA codes
- All the above, in that we always look for the BS or EN standard etc appropriate to the type of fire protection being installed / maintained
- Always use third party accredited designer and installer. Use of a system that has an approved British Standard or equivalent.
- At the time, the only water mist standard was NFPA and IMO. Oh, and at the time I did it, I specified DD251 for residential sprinklers. I've also specified FM200 and Inergen systems, but used manufacturers standards (and I think the Inergen systems were, although ADT, actually German- Total Wather, and so probably a DIN or two involved)
- I always look to ensure that NFPA/FM codes are met. This ensures that our insurers accept the installation and give appropriate underwriting credit.
- I would choose the standard that best protects what i need
- LPC and CCV
- NFPA 13, 15, 16
- NFPA 13, NFPA 15, FM Sprinkler rules
- NFPA standards
- NFPA standards and before EN standards came in, the local national standards of the country (BE, FR, DE)
- NFPA,FM
- Sprinkler systems and other active fire suppression systems to FM and NFPA standards
- Sprinkler protection to FM Rules
- Sprinkler systems to NFPA, FM, Vds standards
- Sprinklers - NFPA 13/20 Water spray - NFPA 15 Foam - NFPA 11,16 Mist - NFPA 750
- Subject to the premises involved
- Water mist to NFPA 750 Domestic sprinkler system to BS EN 12259-2 and BS EN 12845 Gaseous extinguishing system to BS ISO 14520, initiated in accordance with BS 7273: Parts 1 and 2
- Water Spray Deluge systems and Foam enhanced sprinkler or deluge systems to relevant NFPA Standard
- wet chemical to LPS 1223

9. Why would you recommend the provision of any active fire protection system?

To satisfy the Building Regulations:		n/a	35
To satisfy the Regulatory Reform (Fire safety) Order:		n/a	23
For Business Continuity purposes:		n/a	44
For Property Protection purposes:		n/a	49
Other *(please specify)*:		n/a	14

Other:

- For life safety protection
- for occupant protection, if justified by the risk analysis, eg where evacuation is difficult like for hospitals, homes of the elderly, prisons., ...
- Insurance Risk acceptance standards
- Insurers requirements (perhaps subtly different from business continuity and property protection?
- life safety
- Life Safety
- Life Safety Increase build flexibilities
- Other statutory requirements including Fire (Scotland) Act 2005, NI Fire regulations, national fire regulations, insurers requirements
- Sub Surface Railway Regulations
- To protect personnel
- To protect the population.
- To satisfy the Fire Scotland Act
- Under the local Licensing laws and the fire precautions laws here in Jersey.
- We install active fire protection primarily for business continuity reasons and to meet local codes in any country that specifies.

10. This question is asked to gauge opinion about various active fire protection system types.			
10.a. Aerosol system to CEN/TR 15276-2 -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	2
Property protection:		n/a	10
No view:		n/a	47
10.b. Foam system to BS EN 13565-2 -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	7
Property protection:		n/a	43
No view:		n/a	15
10.c. Gaseous system (carbon dioxide) to BS 5306 4 -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	1
Property protection:		n/a	41

No view:		n/a	15
10.d. Gaseous system (inert or halocarbon agent) to BS EN 15004-1 -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	15
Property protection:		n/a	43
No view:		n/a	12
10.e. Oxygen displacing system to PAS 95 -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	5
Property protection:		n/a	33
No view:		n/a	22
10.f. Powder system to BS EN 12416-1 -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	3
Property protection:		n/a	25
No view:		n/a	27
10.g. Sprinkler system to BS EN 12845 -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	42
Property protection:		n/a	44
No view:		n/a	4
10.h. Sprinkler system to BS 5306-2 -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	34
Property protection:		n/a	34
No view:		n/a	8

10.i. Sprinkler system to LPC Rules -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	35
Property protection:		n/a	42
No view:		n/a	4
10.j. Sprinkler system to BS 9251 -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	38
Property protection:		n/a	25
No view:		n/a	10
10.k. Water spray systems and deluge systems to DD CEN/TS 14816 -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	5
Property protection:		n/a	39
No view:		n/a	16
10.l. Water mist system to DD 8458 series -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	24
Property protection:		n/a	30
No view:		n/a	13
10.m. Water mist system to DD 8489 series -- Suitable solution for... *(please tick all the apply)*			
Life safety:		n/a	20
Property protection:		n/a	30
No view:		n/a	14

11. In the context of selecting an Active fire protection system, what does "reliability" mean to

you?			
A good likelihood of the system not unduly operating:		n/a	14
A good likelihood of a successful intervention against a fire:		n/a	47
A good likelihood of the system activating when required in a fire:		n/a	44
Other *(please specify)*:		n/a	4

Other:

- A system that requires minimal and cost effective maintenance
- A system with a proven success rate in event of fire, in the type of property proposed
- A system with fault and monitoring control e.g. tampering/frost protection etc.
- A well designed, well understood system appropriate to its usage / location, considered safe to occupants and environments and not causing undue damage or contamination after discharge.

12. Are you aware of any system failures where incorrect system selection played a role in this failure?			
Yes:		39.0%	25
No:		60.9%	39

12.a. If yes, please provide details (if you are at liberty to share)

Other:

- Booker Cash and Carry, OH Group III sprinkler system installed over non protected racking
- Examples when the fire loading has changed on sprinklers and its been greater than the design and the sprinkler system overcome.
- failure to upgrade the system to changing operational conditions : e.g. after changing of the storage method / type of products stored in a warehouse , the sprinkler system was not adapted.
- Gas suppression systems (usually installed in Server rooms) either dismantled, deactivated or switched to manual mode - usually due to misplaced anxiety of occupants as to safety (asphyxiation) if the system were to "accidently" discharge 1 x Water Mist system (High pressure)failure - a pipe coupling failed on discharge. Possibly due to incorrect maintenance - ie pipe was uncoupled by site staff not familiar with importance of correct assembly to remove other components for cleaning and then suppression system not reassembled / re-commissioned correctly.
- I'm not sure I understand what the reference is to "this failure" is. I have experience where

incorrectly specified protection systems have failed to adequately control fire events but this question appears to refer to a specific instance?!

- Inadequate design specification at a drinks canning facility led to recent complete loss of facility (Saudi Arabia).
- Many gas extinguishing systems where enclosure integrity cannot be guaranteed or maintained. Any system that relies on a complex detection, alarm and control system.
- Mist systems installed in schools (kitchens + Gymnasiums)
- no sharing of data, I'm sorry
- Not able to share as the experiences are related to expert witness cases
- Not at liberty to share
- Sprinkler system classified as OHIII unable to correctly control a fire in a HH occupancy.
- The Cadbury Trebor Basset fire at Monkhill
- There have been occasions where CO2 gas suppression has been installed in aviation test bed control rooms. At the time (before me) the strategy was to activate the system out of hours. However, this is totally reliant on operational controls i.e. someone turning the system to automatic when they leave for the evening. When working through the hierarchy of control engineering controls should be considered before operational/management controls. Here is a classic example of where engineering controls inherit a single point of failure - human intervention. The system has now been replaced with Novec 1230.
- Water mist nozzles not extended into the secondary fat tank on a fryer
- Water Mist system in warehouse / production plant
- Watermist failure in Rotherham - not at liberty to share.
- Yes, but you know the same examples as I do!

13. Do you have any other comments in relation to any aspect of the proposed tool or questionnaire?

Responses:

- All solutions have/ could have a role as part of a life safety solution, though some may not be desirable for manned areas e.g. CO_2 - have ticked just Property protection.
- Disappointing that there is no selection category in Section 4 above specifically for Insurance based Risk Engineers. Many have very good experience in these fields, and from a Property protection perspective and Business continuity perspective are very often the key movers for requirements for fixed fire protection in an organisation.
- For all systems the requirements of NFPA are more detailed and acceptable throughout the world. Even sprinkler systems are not as detailed as NFPA although the hydraulic calculations and pump selection can be beneficial
- I feel that the basic idea behind the tool is good but it has been tried many times in the past but with so many variables and changing standards it has proved to be an unreliable route to determine with 100% accuracy the selection of system application. However with improved computer software available it could be another aid in Fire Engineering.
- I have serious concerns about this project - it's not the first of its type and the others failed to adequately address the need for a detailed understanding of system capabilities - look for example at the generalisations in BS 5306 -0 and in particular at the claims for chemical gas systems such as FM 200 which fail to address issues such as fluorine production.
- I would consider this tool should not only help select the best type(s) of fire protection system for the situation, but also enable end-users to select out non-appropriate systems, especially where these may be pushed by less scrupulous installers working with personnel with little or no experience of fire protection systems and their operation characteristics.
- I'm a real novice, learning as I go, so don't appreciate any differences between the different standards of systems in question 10. If it is to be a useful tool, you'll have to make it clear what the different answers mean, and why. There is also probably more than one answer each with pros and cons.
- No
- No.
- Not sure that system selection should be limited to a simple risk, there may be other reasons for selection etc.
- Potentially a good tool, however sometimes a little knowledge is a dangerous thing. If someone is predisposed to recommending a particular system and the tool doesn't rule it out, but states that is a possibility you could end up with that reinforcing their view. Possibly incorrectly.
- The risk assessment to determine whether protection is needed in the first place is essential. This is a very difficult aspect to capture in a single tool due to a wide variation in risk appetite.
- The selection of active fire protection systems should be part of a comprehensive risk evaluation, where the stakeholders (authorities, owners, users of a building) have to define they fire safety goals. The FRAME method I developed is made for that . See www.framemethod.net
- The tool will rely on accurate and consistent input of information. I expect the outcome will require authentication by a third party at least initially over a trial period. The tool must be clear whether it is for life safety, property protection or both outcomes.
- This tool shall be seen as promoting one type of system compared to another, therefore recommendations must be appropriate, and have industry recognised certification, and have third party accreditation available.
- You need to address other key standards used in Fire Protection for example FM Global and NFPA.

Would you be willing to be contacted again to input further in to the development of the Active Fire Protection System Selection Tool? If so please supply contact details, otherwise leave blank:
14.a. Name -- Details
Responses: 37 sets of contact details supplied. **** Redacted for Thesis publication ****

APPENDIX H SOFTWARE SPECIFICATION

Version 4, 8th May 2013

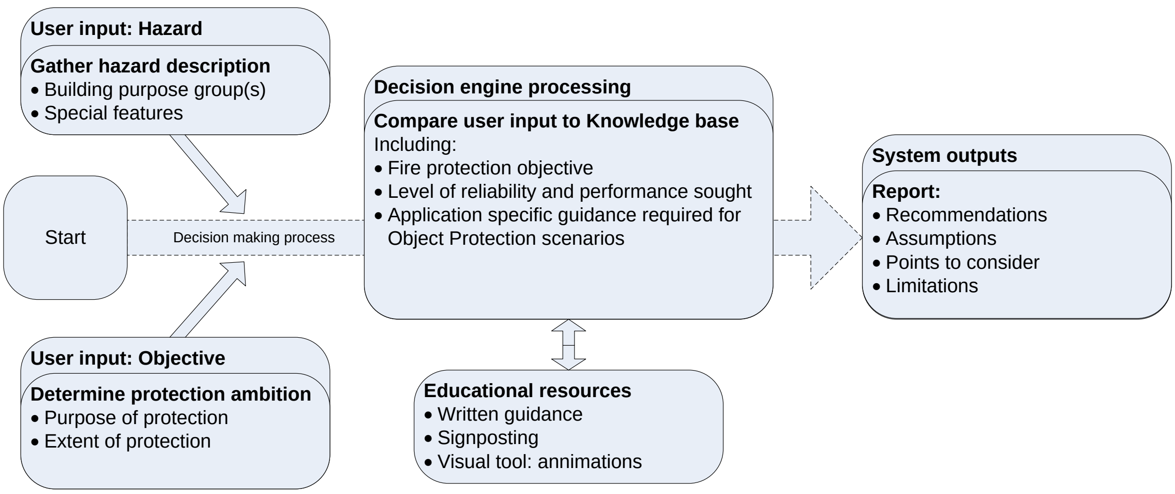
Introduction

A means of developing an Expert System, Knowledge Management or Decision Aiding type system is required. The tool to be developed is to assist users with the potentially complex decision making process of selecting appropriate Fixed Firefighting Systems for their specific circumstances.

Requirements

A development environment or technique to develop the Fixed Firefighting System Selection Tool is sought. The tool should elicit the required knowledge from users to make fully evidenced recommendations. Responses to questions will be matched against a bank of knowledge in order to identify potentially suitable options. A web-based GUI is envisaged for end users. For development and maintenance purposes a visual environment may have advantages.

The approach to development of the tool (the environment or technique) will need to be simple; for use by a non-expert, with minimal initial training requirement after which reasonably rapid development progress will be possible. Alternatively, if no such solution exists, then it may be possible to buy-in a modest amount of expertise to further the ambitions of the project. Ultimately a solution that can be maintained in-house is required.



Inputs

Users will be asked questions from which the tool will build an understanding of their hazard and mitigation requirements. A process of elimination might be used to retain only suitable firefighting system options as potential recommendations to the user (available options are listed in the 'outputs' section). As the user progresses through the question set, some questions will be rendered redundant by preceding questions, in which case, the Tool should not pose such questions in order to make the use of the tool as efficient as possible (e.g. if it has been determined the user is not protecting stored goods, there is no need to determine the hazard classification on the [non-existent] stored goods).

Decision making

It is envisaged that only strict logical operations will be undertaken, based upon the rules derived from Standards, Guides and Custom and Practice (see Questions and Inferences which in some cases show how these rules start to emerge). Confidence and probabilistic techniques are not considered appropriate or necessary at this time.

Outputs

Users will be presented with recommendations on which Fixed Firefighting System(s) best suit their needs. In some cases, recommendations may be ranked. Recommendations will be accompanied by advice which may be relevant and helpful in the scenario. See example reports appended to this document.

System choices

The following system recommendation outputs are predetermined (which will periodically change and be added to or subtracted from):

- Sprinkler system to LPC Rules
- Oxygen displacing system to PAS 95
- Sprinkler system to BS EN 12845
- Aerosol system to CEN/TR 15276-2
- Foam system to BS EN 13565-2
- Gaseous system (carbon dioxide) to BS 5306-4
- Gaseous system (inert or halocarbon) to BS EN 15004-1
- Oxygen displacing system to PAS 95
- Powder system to BS EN 12416-2
- Sprinkler system to BS 5306-2
- Sprinkler system to BS 9251
- Water spray systems and deluge systems to DD CEN/TS 14816
- Water mist system to DD 8458-1
- Water mist system to DD 8489-1

- Water mist system to DD 8489-4
- Water mist system to DD 8489-5
- Water mist system to DD 8489-6
- Water mist system to DD 8489-7
- LPS 1283 Watermist Systems For Use In Commercial Low Hazard Occupancies

Example supplementary recommendations

These system recommendations may be supplemented by further information as appropriate, such as:

- This technology is thought to be rarely the most practical or cost effective solution to protecting this type of risk (consider on-going energy consumption and building management issues)

- Building integrity will need to be sufficient to ensure Oxygen levels can be maintained at the desired level

- Some aspects of this technology are considered immature and unlikely to offer levels of performance (availability, reliability and maintainability) approaching that of those approaches identified as the best system choices. For the following reasons:

  - There are no applicable component standards, dealing with fire protection issues

  - There is no system installation certification scheme (whilst there is a certification scheme of sorts which audits installing companies, this is not the same as a third party System Installation Scheme and cannot be expect to yield such quality and reliability benefits)

  - As disparate proprietary technologies, the repair strategy cannot incorporate the benefits of standard sizing or interchangeable components

  - There has been a lack of independent review of the design, performance and reliability of such systems

  - These systems feature complex control systems and are therefore likely to have inherent reliability issues unlike simpler systems

  - The availability and reliability levels of these systems do not yet benefit from the data collection, analysis and corrective action systems that exist for other more mature approaches to fire protection (such as those specified by full BS documents)
- Appropriate ranges of oxygen index test evidence should be obtained in support of the application
- Third party certified Installers and system components should be used
- The authorities having jurisdiction, along with the other stakeholders should be consulted on the design and specification.
- Maintenance should be applied as required