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DEVELOPMENT OF A FIXED FIREFIGHTING SYSTEM SELECTION TOOL FOR IMPROVED OUTCOMES

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SUMMARY: *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.

KEYWORDS: *decision support, fixed firefighting system selection, fire, suppression system*

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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 Fig. 1).

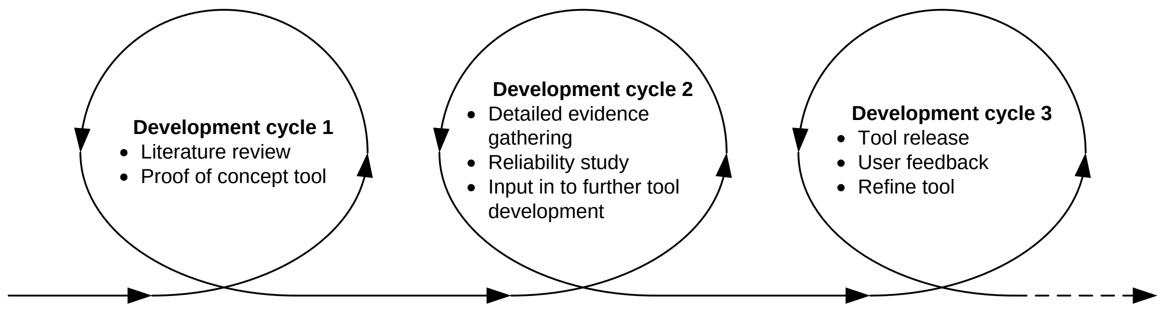

Fig. 1 – Adaptation of "Action Research interacting spiral" (Stringer, 2007)

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.

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).

3.1. FACTORS INFLUENCING CURRENT SELECTION PRACTICE

Many of the factors influencing fixed firefighting selection practice can be summarised in Fig. 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.

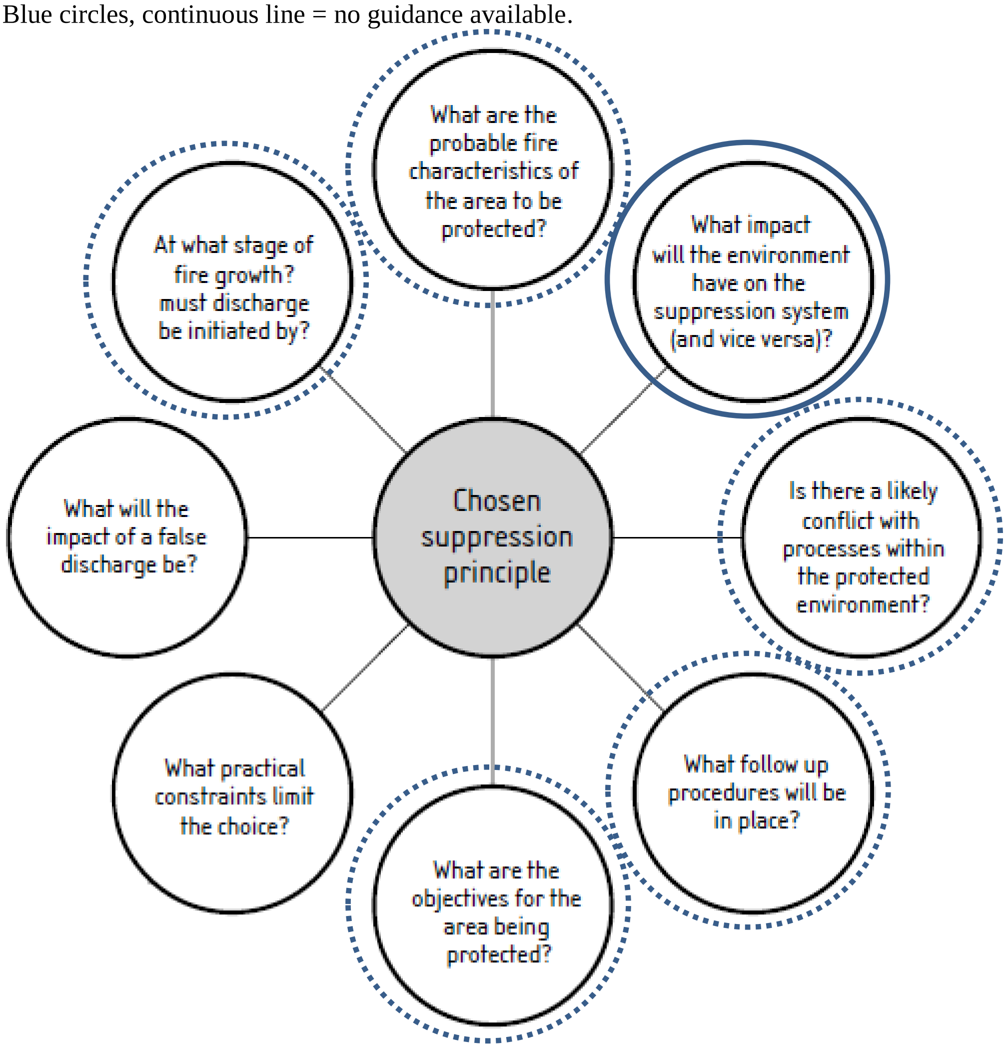

Fig. 2 - A Reproduction and Adaptation of "Fire Suppression System Choice Matrix" (BSI, 2003b, p. 20)

A notable omission from Fig. 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.

3.2. 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). Fig. *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).

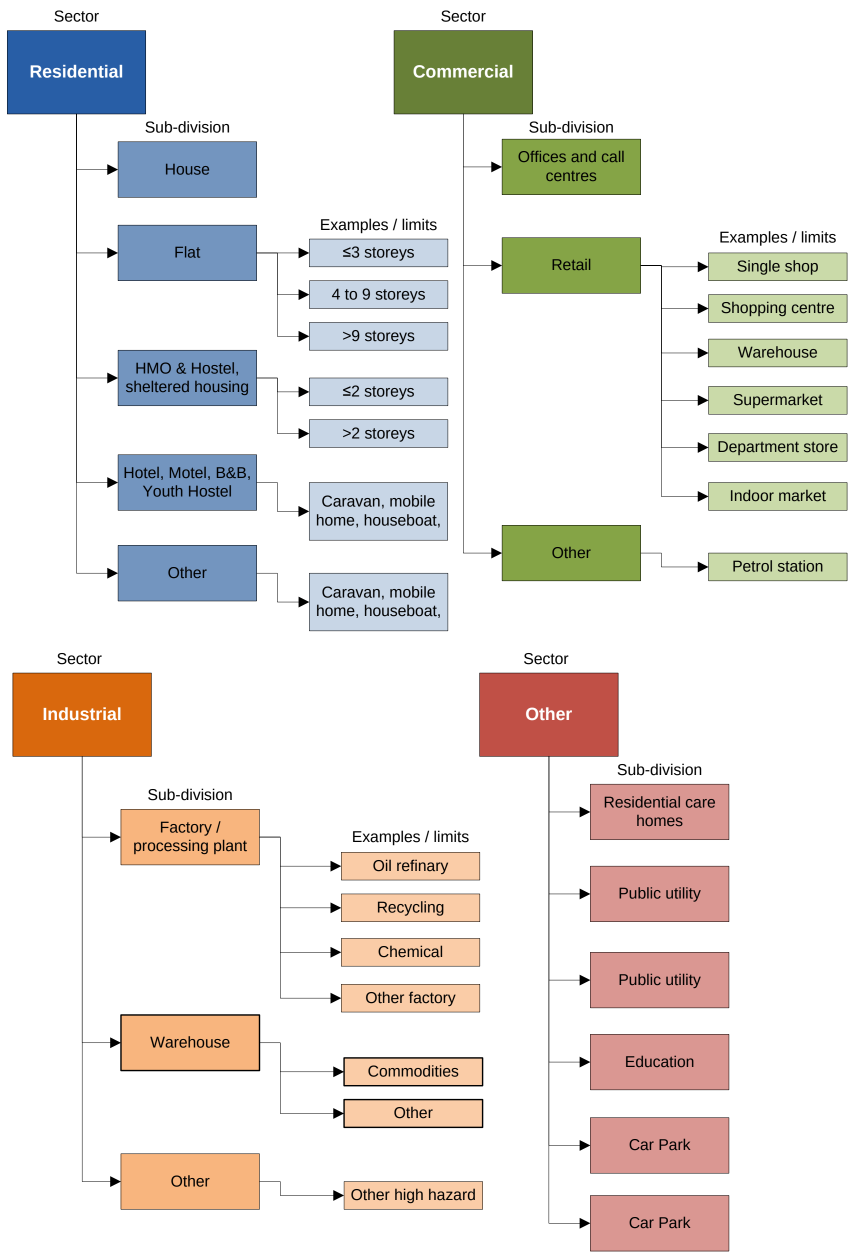

Fig. 3 – Available Building Purpose Groups (adapted from Incident Recording System (Home Office, 1994))

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.

3.3. 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.

3.4. 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 Fig. 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.

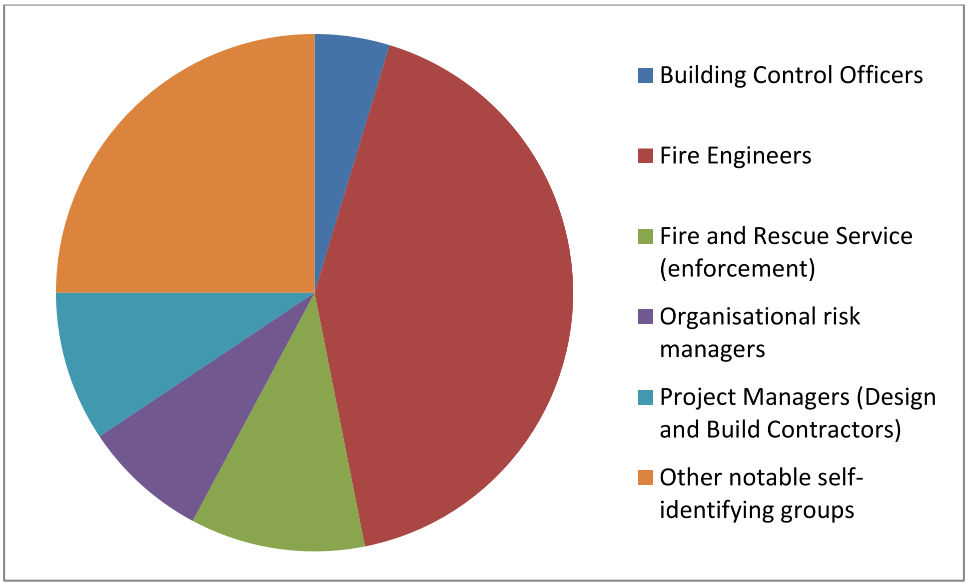

Fig. 4 – Distribution of Respondents' Roles in Specifying Fixed Firefighting Systems

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 Fig. 5 to be created.

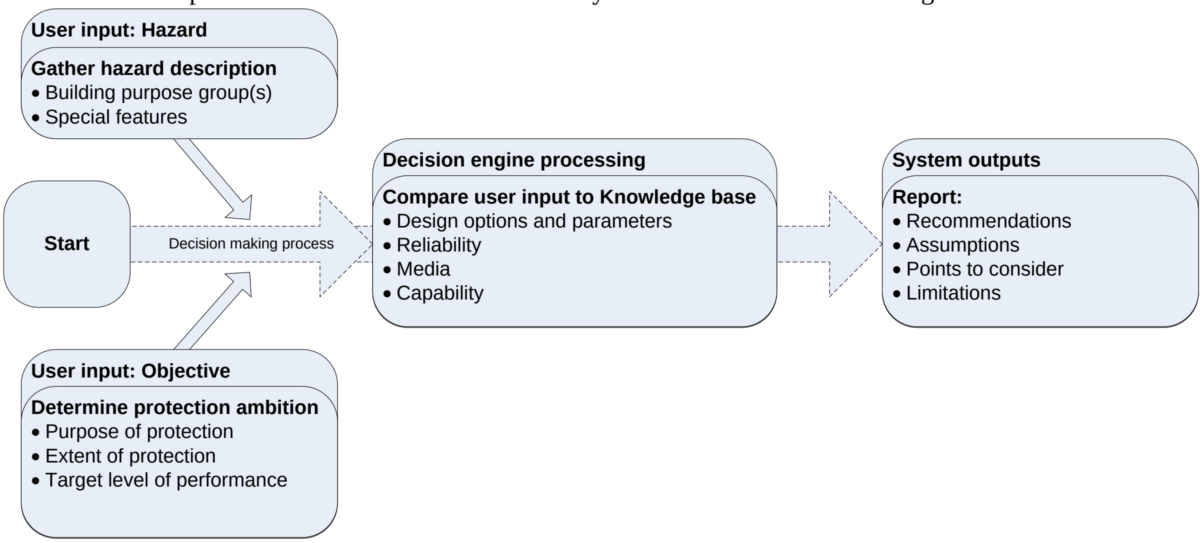

Fig. 5 – Fixed Firefighting System Selection Tool Architecture

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 Fig. *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 Fig. *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. Fig. 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.

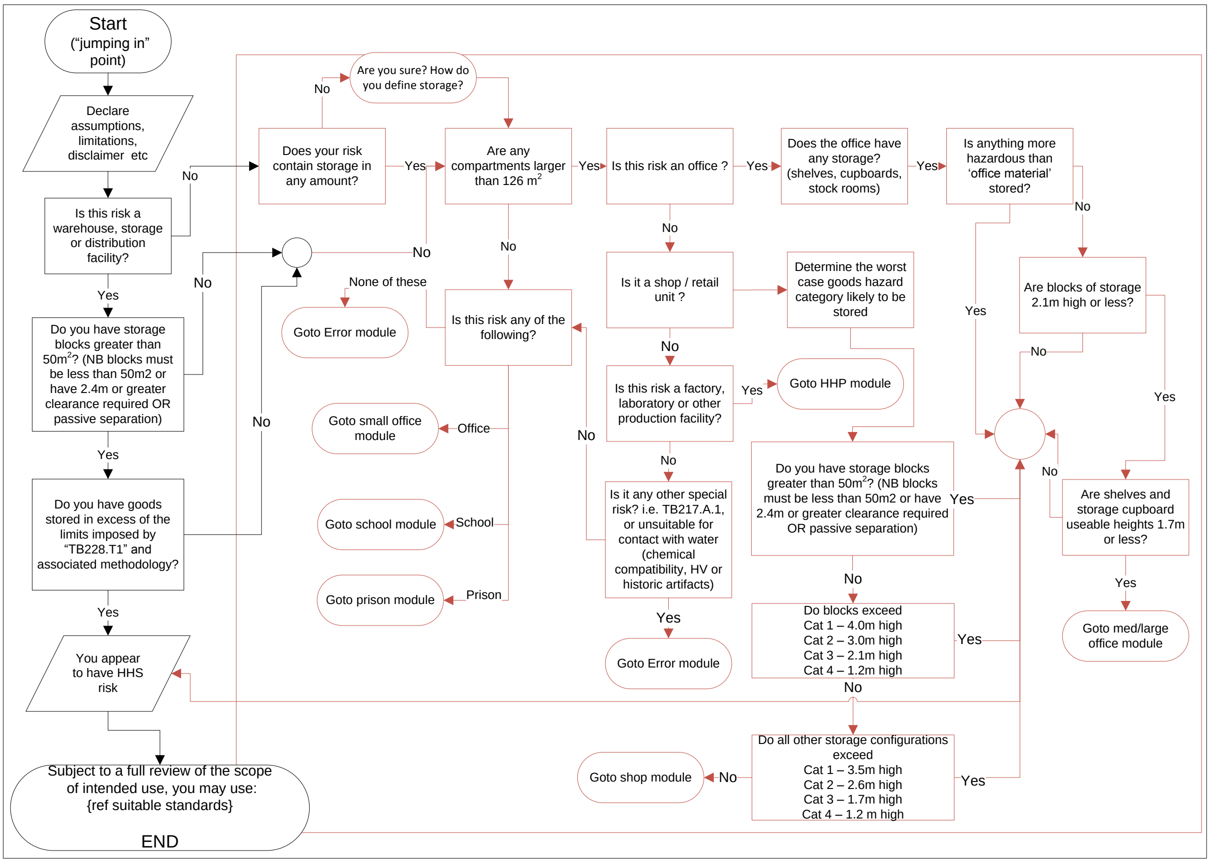

Fig. 6 - Prototype System 'Logic'.

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. Fig. 7 shows a screenshot of 'variables' and a 'logic block' as input in to the development environment. Fig. 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.

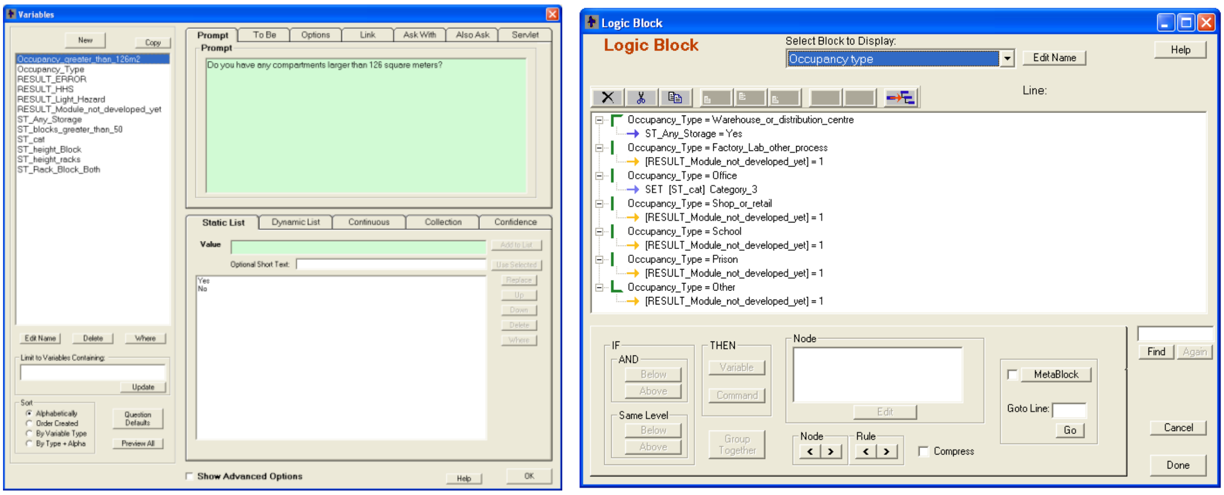

Fig. 7 - Screenshot of 'Variables' and a 'Logic Block'

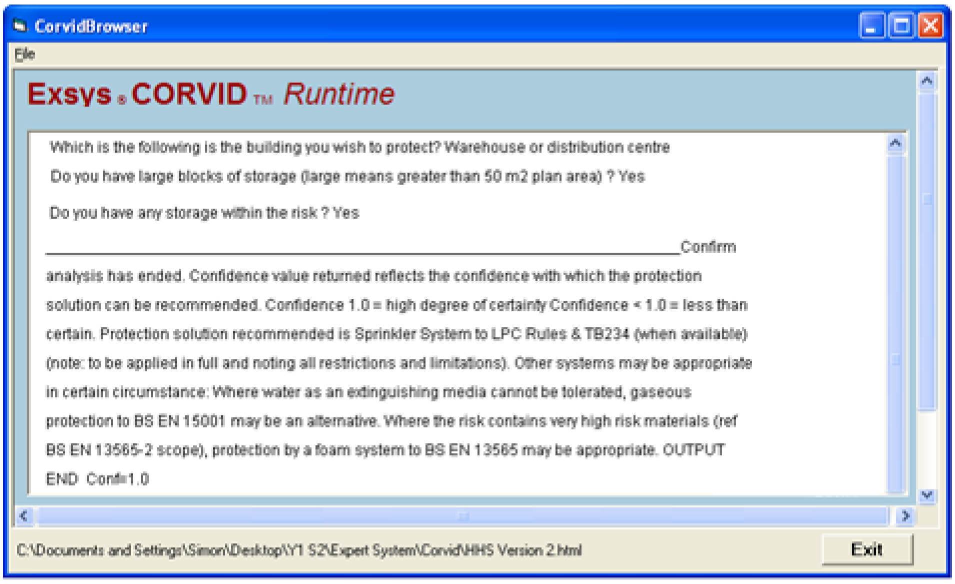

Fig. 8 - Screenshot of Expert System Output

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.

7. REFERENCES

ASSOCIATION OF BRITISH INSURERS, 2009. *TACKLING FIRE: A CALL FOR ACTION,* London, UK, Association of British Insurers.

AVISON, D. E. & FITZGERALD, G. 2003. Where now for Development Methodologies? *Communications of the ACM,* 46**,** 4.

BAFSA, 2012. *Technical Guidance Note - Watermist Systems - Compliance with Current Fire Safety Guidance,* London, UK, Fire Industry Association.

BENDELIUS, A. G. 2008. Road Tunnels and Bridges. *In:* COTE, A. E. (ed.) *Fire Protection Handbook.* Quincy, Massachusetts, US: National Fire Protection Association.

BIRD, S. N., 2012. *Active Fire Suppression System Selection Tool – Components of Active Fire Suppression System Reliability. Unpublished Study.* .

BIRD, S. N., BOUCHLAGHEM, N. M., GLOCKLING, J. & YEOMANS, S. G., 2012. *Decision problem structuring method for the specification and selection of active fire protection systems*. *Innovation in Architecture, Engineering and Construction (AEC).* Sao Paulo, Brazil.

BRE GLOBAL, 2009. *Sprinkler systems explained. A guide to the sprinkler installation standards and rules,* Watford, UK, BRE IHS Press.

BRE GLOBAL, 2012. *LPS 1283 - Requirements And Test Methods For The Approval Of Watermist Systems For Use In Commercial Low Hazard Occupancies*. Watford, UK: BRE Global.

BSI, 1986. *BS 5306-0 Fire extinguishing installations and equipment on premises. Guide for the selection of installed systems and other fire equipment,* London, UK, British Standards Institute.

BSI, 1991. *Quality vocabulary*. *Part 3: Availability, reliability and maintainability terms - Section 3.1 Guide to concepts and related definitions.* London, UK: BSI.

BSI, 1999. *BS EN 12259-1 Fixed firefighting systems. Components for sprinkler and water spray systems. Sprinklers,* London, UK, British Standards Institution.

BSI, 2001. *BS 7974: Application of fire safety engineering principles to the design of buildings — Code of practice*. London, UK: BSI.

BSI, 2003a. *Application of fire safety engineering principles to the design of buildings*. *Part 1: Initiation and development of fire within the enclosure of origin (Sub-system 1).* London, UK: BSI.

BSI, 2003b. *Application of fire safety engineering principles to the design of buildings. Part 4: Detection of fire and activation of fire protection systems (Sub-system 4).* London, UK: BSI.

BSI, 2003c. *BS EN 12094 - Fixed firefighting systems - Components for gas extinguishing systems (multiple parts),* London, UK, British Standards Institute.

BSI, 2005. *BS 9251 Sprinkler systems for residential and domestic occupancies. Code of practice,* London, UK, British Standards Institution.

BSI, 2008a. *BS 9999 Code of practice for fire safety in the design, management and use of buildings,* London, UK, BSI Group.

BSI, 2008b. *BS EN 15004-1 Fixed firefighting systems. Gas extinguishing systems. Design, installation and maintenance,* London, UK, British Standards Institute.

BSI, 2009a. *BS EN 12845 Fixed firefighting systems — Automatic sprinkler systems — Design, installation and maintenance,* London, UK, BSI Group.

BSI, 2009b. *BS EN 13565-2 Fixed Firefighting Systems. Foam systems. Design, Construction And Maintenance,* London, UK, BSI.

BSI, 2009c. *PD CEN/TR 15276-2 Fixed firefighting systems — Condensed aerosol extinguishing systems Part 2: Design, installation and maintenance,* London, UK, BSI.

BSI, 2009d. *Risk management. Principles and guidelines.* London, UK: BSI.

BSI, 2010. *DD 8458-1 Fixed fire protection systems. Residential and domestic watermist systems. Code of practice for design and installation,* London, UK, British Standards Institution.

BSI, 2011a. *BS 5306-0 Fire extinguishing installations and equipment on premises. Guide for the selection of installed systems and other fire equipment,* London, UK, BSI.

BSI, 2011b. *BS 5306-4 Fire extinguishing installations and equipment on premises. Specification for carbon dioxide systems,* London, UK, British Standards Institute.

BSI, 2011c. *BS 6266 Fire protection for electronic equipment installations - Code of practice,* London, UK, British Standards Institute.

BSI, 2011d. *DD 8489-1 Fixed fire protection systems – Industrial and commercial watermist systems – Part 1: Code of practice for design and installation,* London, UK, British Standards Institution.

BSI, 2011e. *PAS 95 Hypoxic air fire prevention systems – Specification,* London, UK.

CALADO, R., FELLOWS, R. F. & LIU, A. M. M., 2009. *Research Methods for Construction,* John Wiley & Sons.

COLLINS, 1994. *English Dictionary,* Aylesbury, UK, HarperCollins.

DCLG, 2012. *Fifth statement of new regulation - Measures coming into force between 1 January and 30 June 2013*. London, UK.

DENZIN, N. K. & LINCOLN, Y. S. (eds.) 2003. *Stratergies of qualitative inquiry,* California, USA: Sage Publications Ltd.

DEPARTMENT FOR COMMUNITIES AND LOCAL GOVERNMENT, 2010. *The building regulations 2010 fire safety approved document B,* London, UK, NBS for the Department of Communities and Local Government.

DOD, 2005. *DoD Guide for Achieving Reliability, Availability, and Maintainability*, Washington, USA, Department of Defence.

EASTERBY-SMITH, M., THORPE, R. & LOWE, A., 2002. *Management research: An introduction*, London, UK, Sage Publications.

FPA, 2010. *LPC Rules for Automatic Sprinkler Installations 2009 Incorporating BS EN 12845*, Moreton-in-Marsh, UK, Fire Protection Association.

FPA, 2011. *LPC Rules for Automatic Sprinkler Installations 2009 Incorporating BS EN 12845*, Moreton-in-Marsh, UK, Fire Protection Association.

GLOCKLING, J., 2012. *Analysis of Warehouse data: Insurance costs vs. area of damage. Unpublished correspondence between Fire Protection Associai and Business Sprinkler Alliance.* Moreton-in-Marsh, UK: FPA.

HALL, J. R., 2010. *U.S. Experience with sprinklers and other extinguishing equipment*. Quincy, MA.: NFPA.

HALL, J. R. & WATTS, J. M. 2008. Fire Risk Analysis. *In:* COTE, A. E. (ed.) *Fire Protection Handbook.* Quincy, Massachusetts, USA: NFPA.

HMSO, 1971. *Fire Precautions Act*. London, UK: HMSO.

HMSO, 2005. *The Regulatory Reform (Fire Safety) Order*. London: England and Wales.

HMSO, 2010. *The Building Regulations No. 2214*. London: England and Wales.

HOME OFFICE, 1994. *Incident Recording System*. London, UK.

INSTITUTION OF FIRE ENGINEERS. 2011. What is Fire Engineering? *What is Fire Engineering?* [Online]. Moreton-in-Marsh: Institution of Fire Engineers. Available: http://www.ife.org.uk/about/about/fireengineering [Accessed Web Page 2011].

LPCB, 2005. *LPS 1230 - Requirements for Fire Testing of Fixed Gaseous Fire Extinguishing systems*, Watford, UK, BRE Certification.

MEDSKER, L. & LIEBOWITZ, J., 1993. *Design and Development of Expert Systems and Neural Networks*, New York, USA, Macmillan College Publishing Company.

OFFICE OF THE DEPUTY PRIME MINISTER, 2006. *The Economic Cost of Fire: Estimates for 2004*, London, UK, Office of the Deputy Prime Minister.

OFFICE OF THE DEPUTY PRIME MINISTER, 2011a. *The Economic Cost of Fire: Estimates for 2006*, London, UK, Office of the Deputy Prime Minister.

OFFICE OF THE DEPUTY PRIME MINISTER, 2011b. *The Economic Cost of Fire: Estimates for 2008*, London, UK, Office of the Deputy Prime Minister.

ROY, D., 1997. *The cost of fires - A review of the information available*. London, UK: Home Office.

STRINGER, E. T., 2007. *Action Research*, California, USA, Sage Publishing Ltd.

SUGDEN, D. 1998. Fire safety Engineering - Are we really in control? *Fire safety engineering*, 5.

THE FIRE PROTECTION ASSOCIATION, 1999. *LPC Design Guide for the Fire Protection of Buildings*, Moreton-in-Marsh, UK, The Fire Protection Association & ABI,.

THE GENEVA ASSOCIATION. 2011. About Us. *About Us* [Online]. Geneva: The Geneva Association. Available: http://www.genevaassociation.org/About_Us/Introduction.aspx [Accessed 22/12/2011 2011].

THE HONOURABLE MR. JUSTICE COULSON IN *CADBURY V ADT* EWHC 1936, 2011. *Trebor Bassett holdings limited and The Cadbury UK Partnership (formerly known as The Cadbury Trebor Bassett partnership t/a Monkhill confectionary) v. ADT Fire and Security PLC*. High Court (Queen's Bench Division).

WATTS, J. M. 2008. Systems Approach to Fire-Safe Building Design. *In:* COTE, A. E. (ed.) *Fire Protection Handbook.* Quincy, Massachusetts, USA: NFPA.

WILKINSON, P., GLOCKLING, J., BOUCHLAGHEM, D. & RUIKAR, K. 2012. A Historic Perspective of Fire Engineering in the UK. *Journal of Applied Fire Science* 21**,** 37-51.

WILLIAMS, C., 2009. *Automatic fire sprinkler systems A good practice guide,* Watford, UK, IHS BRE Press.