FIRE SERVICE

MANAGEMENT AND COMMAND

OF

MAJOR INCIDENTS

DENNIS TYRONE DAVIS

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Declaration

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Abstract

This study has concentrated upon the decision-making processes used at major incidents by the fire service in the United Kingdom rather than the more routine decisions made on the fireground. This partly because major incidents are safety critical events, involving complex technical or communication issues involving large volumes of information and many agencies, and also because the decisions made and judgements exercised have to demonstrate a robustness in application that will withstand considerable external scrutiny, since often major incidents involve losses that are subject to insurance or legal investigations. The research undertaken indicates that improvements are possible.

The research places the current decision system in context. It does this by considering the cultural traditions of the fire service together with the managerial and organisational arrangements that set the parameters within which judgements and decisions will be made. This approach provides an insight as to how the fire service functions at operations and importantly the relationship between those decisions and time pressured environment in which they are often reached. Practical case studies that were attended

by the author as the senior fire service commander are used to illustrate these features and help provide useful learning outcomes.

This foundation is then used to consider in detail the whole decision support system employed and to offer objective improvements. Explanation of the operational practice employed is assisted by the provision of a number of tables and figures that illustrate the critical parts of the decision system, such as information trees and components and observed inter-agency issues, which are summarised in a systematic decision process.

Having collated and reviewed these findings it is postulated that command competency and situational awareness, the essential pre-requisites, can be improved through use of a new paradigm that emphasises the better use of data derived from a wider range of sources than are currently used. To assist in gaining this improvement greater integration of technology is suggested and options that exploit technology, such as electronic data communications, sensing devices, robotics and visualisation, explored. Additional to the main study a number of allied supportive areas of research have been undertaken. These have included issues like fire service culture, public reaction to a serious fire, emergency action procedures, and toxic plume modelling and fireball impacts together with brief commentaries on September 11th and the future fire service in the United Kingdom.

This research contributes to a relatively new area of study, the fire service decision process used to command and control resources, at major incidents.

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CHAPTER ONE

Introduction

1.1 Overview

Decision-making at critical incidents requires fire service officers to exercise not only judgement, but to analyse a great deal of information in a time-sensitive environment. The decisions made not only have a profound effect upon the safety of the public and firefighters, but provide the basis of review in subsequent post-event examinations. Since the events may be costly in human or economic terms, it is important that decisions reached are the best possible.

The research approach adopted is primarily focused upon observation of fire service decision-making under crisis conditions, rather than the more conventional scientific foundation of experimental work. However, desk research has been incorporated where appropriate to confirm or contest its relevance in practice. Observation studies are, therefore, integral to the development of the hypothesis referred to later in this introduction.

Personal supervision and contribution has been made both in operational command situations and in developing solutions to improve operational fire service decision-making. Again this is referenced throughout the research. The originality of some of this work predates procedures and practices that have now become established standard operating procedures in many UK fire brigades. This contribution is verified by reference to publications delivered as part of the development phase of the research. The process adopted may therefore be described as one of auditing the existing situation and then presenting, within context, outcomes.

1.2 Operating Context

The background for the research undertaken is focused upon command and control of complex incidents. Key case studies are used to identify the practical elements that arise under such circumstances. The focus is upon decision-making in stressful situations, since it is here that the need to source, manage, deliver, interpret and communicate information is of the highest importance.

A systematic approach to enable dynamic delivery is reviewed and improvements are suggested and evaluated for identified weaknesses. It is argued that central to these issues are organisational culture and, in the operational situation, the ability within a dynamic operational scenario to simulate the evolving situation as part of the decision-making process.

The importance of two influences, the managed use of information and cognitive recognition, is that they are given higher priority in this research than is currently accepted within the adopted concepts of fire service decision-making.

The research is introduced from a perspective and background of historical and legislative influences linked to the fire service's own managerial development. This background of historical precedent and legislative influence is briefly compared with other international examples to test the validity of the UK approach. The research then continues to explore decision support systems, together with the availability of decision tools, which might improve those systems. Technology, which may also assist the critical decision-making process, is then discussed in some detail. Confirmation is made using the key case studies to help illustrate where weaknesses occurred and what the possible improvements might be arising from the use of such technology.

Perhaps because it is a uniformed service, the fire service is often perceived erroneously as having a totally hierarchical management and decision-making structure. The reality is a rich mixture of decision-making processes amongst teams of competent and technically aware individuals. Translating this modern management thinking and utilisation of information technology into an aid for operational decision-making is seen as the natural development of the ongoing management changes introduced within the service and applied to daily decision-making[1].

Effectively combining these management techniques and technology systems can ensure that more relevant information, in rapidly useable form, can be presented to emergency workers and the general public at incidents or major emergencies. The safety of both groups is paramount and firefighters, in particular, must be able to exercise best judgement in prediction and mitigation of impacts. Protection of the public, which includes knowing how best to react to any likely off-site environmental and health issues, demands the co-ordination and transfer of accurate information into the public domain. Improvements remain to be made in this activity.

Whilst there are considerable technical complexities effective communication is essential and given the type of information being conveyed, the dynamic nature of major emergencies and the potential fragility of communication systems currently used by the fire service, finding solutions rightly demands priority. Communication interoperability between the emergency services and public agencies offers improvements and risks in that additional barriers, stresses and demands may emerge in parallel with action-prioritised operational activities. The need to know, preferably simultaneously, of any event or action to achieve a co-ordinated response has been the subject of limited research[2] to which this research seeks to add knowledge.

Fire service decision support systems are of paramount importance and the development of a comprehensive hazard management system is integral to protecting the public and the firefighter. Questions concerning cognitive and technical issues also emerged in the research. The experience gained in seeking the solutions emphasises the importance of a robust and effective information highway between an incident site and any fire service control centre to allow interservice co-ordination and the skill of the Incident Commander.

1.3 Research Methodology

A considerable literature search has been undertaken. The volume of information available in this subject area, given its wide remit, is extensive. A focus has had to be made on the decision support system requirements to help ensure the literature pertinent to the research was considered in some detail. Common planning and effectuation phases are used in systematic process models. Qualitative research of what happens in the practical environment is also used. Conventional research methods into public response, involving field evaluation of working practices, procedures and equipment with deduction based upon empirical observation and reflection at personal experience, are also undertaken. The theoretical and conceptual frameworks derived from this research activity have then been modelled where this might be useful in helping explain those frameworks tested in a practical situation.

1.4 Hypothesis

Ultimately a constructed hypothesis has been established, which is that: -

Fire service critical incident decision-making can be improved beyond its current systematic process through the use of decision support systems that incorporate better information management and incident simulation.

1.5 Secondary Research

As mentioned, technologies and tools that help achieve this aim have also been evaluated and, using the case studies, possible improvements identified and in some cases implemented.

The secondary research undertaken is referred to in related areas of cultural change, public response in emergencies, gas dispersion modelling and emergency action procedures. These subjects are annexed to provide further insight into the range of responsibilities and activities allied to the central theme of decision-making. In some cases this subsidiary research required further project definition, sample populations and, in the case of the public response survey, the development of a series of focused questions and data analysis.

1.6 Research Aims

The key premise and central hypothesis documented in this thesis is that operational decision support systems must utilise fully the technology used in the normal business environment for management information and decision-making so as to improve the highly-focused decision-making necessarily required in crisis management.

Therefore within this context, 'information technology' is defined as all those technologies that can be used to gather and support the decision-making process. This includes text and other data management information systems and visual media, such as closed circuit television and robotics, since simulation is emphasised as a key element in determining on-site operational strategies. Interpretation is the task of the fire service Incident Commander and to assist him it is essential that useful information is given when and where it is needed, without overloading or confusing the individual[3].

In seeking to improve operational decision-making consideration is given to integrating a number of matters. These have included: -

(i) legislative concerns, in particular requirements where hazardous materials are involved or for other critical incidents where the demand is for very high quality safety critical data.

(ii) the difficulties and requirements involved in assessing risk and gathering data.

(iii) consideration of any specific needs the decision-making process at incidents highlights.

(iv) practical options available for effective data transfer.

The audit route followed examines the cultural foundations based in history, legislation and managerial development and places them in an operational context with decision management tools and support systems. Examples extending the existing management process are used to illustrate vulnerabilities and opportunities. Operational decision-making, information needs and information transfer are then highlighted as essential activities for investigation. The model shown in Figure 1.1 outlines this overall structure and concepts explored in subsequent chapters.

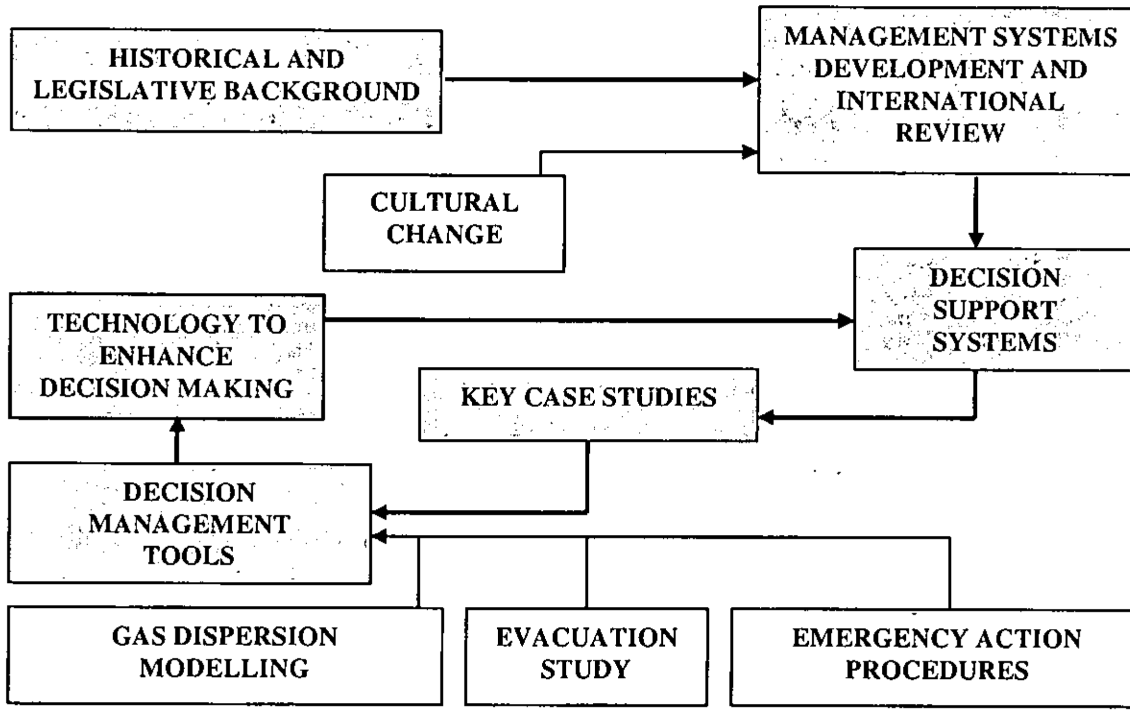

FIGURE 1.1
CONCEPTS OF MANAGEMENT COMMAND AT MAJOR INCIDENTS

1.7 Research Objectives

Gary Klein[4] et al in the USA have developed theories that can be related to urban fireground commanders in complex decision-making environments. These theories underscore the importance of the need for accurate and appropriate information if decision-making is to progress from a model of standard pre-programmed responses, into an objective, dynamic and flexible process, i.e. one that has performance-based outputs. In order to pursue this ideal, of an effective decision support system, an analysis of the information processes used by emergency organisations, combined with an investigation of the integrated information needs and incident operating requirements, is necessary. A number of specific research objectives have therefore been set.

The objectives are:

1. Outline the institutional framework for fire service decision-making from an historical and legislative background.

2. Examine and describe the UK fire service managerial culture that underpins operational decision-making.

3. Compare the identified UK framework and culture with an international sample to identify possible alternative approaches.

4. Illustrate using case studies areas of weakness to enable suggested improvements to be investigated.

5. Define the existing operational decision-making process with its inter-actions so that possible improvements might be improved.

6. Review the existing decision support system to postulate an improved decision support system model.

7. Define new forms of management technological solution tools that assist decision-making in the fire service.

8. Present an improved model decision-making process specifically for fire service operational use.

9. Suggest areas for further research.

CHAPTER 1 REFERENCES.

[1] Murray, B. [1995] *Incident Command Expertise,* International Project Work, Brigade Command Course, Fire Service College, Moreton-in-Marsh.

[2] Auf der Heide, E (ed) [1989], *Disaster Response. Principles of Perceptions and Co-ordination,* C.V. Mosty, St Louise, M.I.

[3] Brunacini, A. [1985], *Fire Command,* National Fire Protection Association, Quincy, M.A.

[4] Klein, G., Orasani, J., Calderwood, R. and Zsambok, C. (eds). [1993], *Decision Making in Action*, New York, Ablex.

CHAPTER TWO

Historical and Legislative Background

2.1 Introduction

This chapter provides insight into the history of the Fire Service and the continuing influence of government legislation. These are important to the decision making process since history has evolved traditions that are prevalent in the United Kingdom fire service of today, and legislation provides part of the overall framework in which decisions are made. Background knowledge of these influences, as drivers within the decision-making process, is essential in order to understand the central tenets of this thesis.

Frequently, in health and safety matters, the demonstration of compliance or reasonable behaviour in the care of employees or the public depends upon effective audit trails that show statutory requirements have been followed. Audit trails require contemporaneous information to be stored and enable the fire service manager, at a later date, to show how those decisions made at that time were determined. The pressure and time frames of operational incidents can make the recording of such information a secondary priority and difficult to achieve[+].

The three cases reviewed indicate that the decision-making process is as a consequence vulnerable to subsequent criticism when, the importance of information that existed and was used during the incident, was not recognised.

[+] Case studies will be used to underscore this critical factor

The clear legislative impetus demands the use of the latest management techniques and information technology to both record and present information to the Incident Commander. A functional area that demonstrates this risk is that of managing hazardous material incidents[1].

2.2 A Brief History

The culture of the modern fire service has been developing since the nineteenth century. Prior to this, no municipal organised fire brigade had existed in Britain since the time of the Romans. The first signs of a municipal UK fire brigade began to emerge in the City of Edinburgh in 1824, where James Braidwood was appointed to organise a fire brigade. In 1832, the Insurance Companies of Alliance, Atlas, Globe, Imperial, London, Protector, Royal Exchange, Union and Westminster all agreed to join with Sun to form a combined fire brigade for the protection of London[+].

This brigade, the London Fire Engine Establishment, also had James Braidwood, as its first leader after he travelled from Edinburgh. In London, he took command of 80 professional wholetime firemen and 19 fire stations and immediately began to create a sense of organisation and efficiency which continued for 38 years until he was killed, when part of a building collapsed during firefighting operations, at a significant fire in Tooley Street, London, on 22 June 1861. Interestingly, Braidwood had identified Tooley Street as presenting one of the worst fire risks in the city.

[+] Again this point is illustrated later when consideration is given to essential first responder information, which shows when the activity of using emergency action codes is scrutinised that even in this well-defined activity weaknesses exist.

Management in the London Fire Engine Establishment was through a superintendent with subordinate officers, foremen, who controlled the firemen. In 1865 the Metropolitan Fire Brigade Act led to the establishment of professional brigades throughout the country. A London Brigade officer called Tozer, who subsequently left London to establish other metropolitan fire brigades, used the London management style and skills, so leading to other brigades embracing those management techniques.

In 1875 the Public Health Act required every urban authority to make provision for the efficient supply of water for firefighting and most municipal authorities then undertook to establish municipal fire brigades. London appointed a Captain Shaw who began to produce routine orders and technical documents designed specifically to structure the good management of what he called "the business"[1]. His influence remains today, since many of his attitudes and opinions have been absorbed within the culture of the fire service.

Shaw[2] summarised his perception of the fireman's roles as: -

> *"A fireman, to be successful, he must enter buildings; must get in below, above, on every side, from opposite houses, over back walls, over side walls, through panels of doors, through windows, through loop-holes, through skylights, through holes cut by himself in the gates, the walls, the roof; he must know how to reach the attic from the basement by ladders placed on half burnt stairs, and the basement from the attic by rope made fast to the chimney. His whole success depends on his getting in and remaining there, and he must always carry his appliances with him, as without them he is of no use.*
>
> *Judged by this standard, the business will be seen to be dependent almost entirely upon the man and not on the gear, and all the best experience has abundantly proved that, however good the machinery and the appliances may be, they cannot work themselves, and without active, energetic, intelligent, and fearless men, are virtually useless".*

Two components of this quotation are of particular importance. Firstly, Shaw referred to firefighting as a business, a matter of continuing interest today, since it was apparent that he intended to operate the brigade in a commercial manner. Even so he was in frequent difficulties over the funding of the fire service. Secondly, Shaw made specific reference to machinery and appliances and he subsequently developed the subject in numerous articles and writings.

The London Fire Engine Establishment had continued to grow and Shaw realised that to manage the organisation he needed to create a sense of unity. In 1876, Shaw[3] stated that:

"In a force situated as ours is, with small bodies scattered over a large area, the difficulties of producing the necessary unity of management and action for instantly dealing with emergencies of every kind, both great and small, are sometimes almost insurmountable, and the strictest discipline is absolutely necessary; but discipline alone is not enough, there must also be that confidence and fellow feeling between all ranks, which makes the failure or success of individuals a source of regret or congratulation to the whole body...".

Shaw thus identified the need to have a vigorous form of management. Equally, he recognised the need for firefighters to have skills and training, which he envisaged being achieved through discipline. In order to accomplish this aim Shaw utilised a building at Southwark, (which Braidwood had built), as the major training establishment of the brigade. In his approach he concluded that:

"real efficiency cannot exist, unless seniors of each rank are competent to perform, not only their own duties, but also the duties of the rank next above them"[4].

This form of approach endured, became traditional within the fire service and some would say still remains.

In 1899, coincident with Shaw's retirement, a Parliamentary Select Committee met to consider how best to regularise local authority fire brigades. Little was done however, until a serious fire occurred at Queen Victoria Street, London, which resulted in the loss of nine lives. This landmark tragedy led to the formation and management of fire brigades as disciplined and organised bodies. Concurrently, by the turn of the century, the various aspirations of firefighters were beginning to emerge with the formation of trade unions and the establishment of their professional body, the Institution of Fire Engineers (in 1918).

During the early part of the twentieth century without central or governmental control or regulation many urban authorities developed their own independent fire service arrangements without regard to their neighbouring authorities. In 1921 a Royal Commission on Fire Brigades and Fire Prevention was instituted to solve the problems that were being caused by such an *ad hoc* approach. The Government did not enact the Commission's report recommendations.

In 1938, the Fire Brigade's Bill received the Royal Assent. This required the establishment of 1,440 separate statutory fire authorities in England and Wales and 228 in Scotland. Its introduction, however, was slowed due to the outbreak of war. On 5 August 1941, the then Home Secretary introduced regulations, which effectively nationalised the fire service forming the National Fire Service (NFS), and took responsibility from local authority brigades on 18 August 1941.

Immediately the 1,668 existing fire brigades in the UK were re-constituted to become 36 fire force areas under 12 regional commanders. The structure and management of the service had dramatically altered overnight. The NFS rapidly needing to secure adequate standards of operation converted an empty hotel at Saltdene, near Brighton, into a large training establishment, effectively the first Fire Service College (FSC).

The primary aim of Saltdene was to produce good officers with ideals and standards that would be appropriate to both leading and developing *esprit de corps* throughout the service. Secondly, the college attempted to raise technical standards within the NFS. The existence of the NFS also enabled the Home Office and Scottish Office to issue advice and orders to the 12 chief regional fire officers, who rapidly translated them into use to speedily improve the efficiency of the service. It was necessary for the NFS to standardise equipment and vehicles, one result for example was the introduction of a standard 400-gallon fire appliance water tank which remains today as a basic design. Nearly 500 NFS orders were issued forming a comprehensive series of instructions, very similar in style to those used by the armed service, and explaining in part the continuing existence of a very strong national service tradition.

The Home Secretary in 1941, Herbert Morrison, made a promise that once the war was concluded fire brigades would return to local authority control stating:

"that they should not be permanently run by the state, but should again become a local authority service"[5].

Importantly, what was not said was how many local authorities it was intended to return control to, and it became apparent that the government was determined that it would not be the original pre-war figure of 1,668.

At the end of the War the Association of Municipal Corporations made vigorous representation to the Home Secretary for the return of fire brigades to local control and new legislation was approved, the Fire Services Act of 1947[6]. The result was that 151 statutory fire authorities came into being; some of them merging with adjacent authorities so that ultimately 147 fire brigades were formed. The Fire Service College also became formally established and a Central Fire Brigades Advisory Council (CFBAC) came into existence. The CFBAC continues to provide guidance and standards, such as risk area categorisation, to fire authorities.

During the intervening period until 1965, because of the perceived threat of the Cold War, these brigades also discharged a civil defence responsibility through the Auxiliary Fire Service (AFS). The AFS retained many of the standards introduced into the NFS. Indeed, whilst the Fire Services Act of 1947 was being established, major flooding occurred in East Anglia, which resulted in AFS deployment of over 2,000 firefighters with 650 pumps, for several weeks, reinforcing the need for common standards. Mutual aid arrangements for civil defence were designed to meet major attack, especially following the closing stages of the war when atomic bombs had been used. In 1965, the AFS was disbanded, in line with the Government's assessment of the improbability of a future war.

In 1974, local government re-organisation produced further change in the structural organisation of the fire service and between 1996 and 1998 further developments led to the introduction of larger and fewer brigades. There are now only 54 fire brigades in the UK. The impetus for change has invariably been political in that fire service change has consistently followed local government reviews. Furthermore, the impact has been to require the adoption of new forms of management and control within the service to manage organisations of greater scale, activity, funding and complexity.

These changes are currently exemplified by the practices now evident in Brigades as they seek to meet financial accountability and performance standards driven by Central Government policies directed to improve public sector performance. Income generation, publicised performance indicators, business planning strategies and collaborative ventures are all part of the current service ethos.

It is evident from this brief review, that the fire service has a very strong traditional base which has been greatly influenced by a centralist style of command management and has equally seen management structure changes as a result of political and service imperatives. The hierarchical style of management, which existed for numerous years, is disappearing, being replaced by business management processes and efficient command and control at operations. These are discussed in the next chapter but it is concluded that these traditions and values of the service remain extremely strong.

2.3 Relevant Legislation

An important element of the information framework available to the fire service must be to help ensure that the service activity satisfies the legislative requirements placed upon it. Significant legislative change has occurred during the last 20 years and will continue with the ongoing influence of the European Union. For example, the legal foundation of the service, principally the Fire Services Act, 1947[7] as amended by the Fire Services Act, 1959[8], has been significantly and substantially modified to take account of workplace directives issued by the European Union, and incorporated into UK legislation[9] under the principle of subsiduarity.

Against this general background, the objective of this section is to assess how the law affects the management and command of fire service attended incidents in order to assess the relevant information requirements, whether through direct fire service arrangements, general legislation affecting employment or European Legislation with its emphasis on workplace and public safety. The Incident Commander is required to operate within the law and the practical consequences of, for example failing to ensure personnel were adequately protected, would not only be hazardous but unlawful. There are also corporate responsibilities that the Incident Commander must discharge, as the servant of the employer, and again these can be onerous, especially if significant economic loss or injury to the public or firefighters were to result from failure to satisfy the legal requirements. It would be impractical to ask the Incident Commander to recall the detail of specific legislation at an incident but this does not remove the implicit need to have a sound working knowledge and for all procedures to help by ensuring the requisite legal provisions have been incorporated in their design.

In the United Kingdom, law operates across the three separate jurisdictions of England and Wales, Scotland and Northern Ireland, each with a distinct focus. UK law also has two different bases. The first is the concept of common law, resting upon interpretations developed from the old common law courts and based on decisions of judges; the second, statute law derived through Parliamentary legislation, initially through principal Acts and their subsequent regulations.

More recently the trend in UK legislation has been towards "enabling and reforming legislation" that avoids having to pass and enact new principal Acts of Parliament, which can be a time consuming and politically fraught process. The new approaches generally enable the responsible Secretary of State (in devolved assemblies and the Scottish Parliament this may be a specific minister or other person) to make regulations, whilst allowing currency to be maintained in the law and for changes to be implemented speedily.

The legislative committee approach is central in the development and scrutiny stages of regulations given ascent by this route as evidenced by the Regulatory Reform Order 2003, which is purposely designed to reduce the extensive extant fire safety legislation and place accountabilities for compliance upon the person responsible. This form of legislative process therefore requires efficient management arrangements for both those who are controlled by, or enforce those regulations. The fire service is part of this process, as regulations, orders and by-laws frequently contain significant details that affect procedures, practices and operations within the service.

2.4 Fire Service Arrangements

The principal establishing legislation for municipal fire services are the Fire Services Act 1947 and the Fire Services Act 1959. The first section of the 1947 Act, entitled Provision of Fire Services, places a series of duties upon every fire authority.* The impact of Section 1.(1)[d] is especially relevant, as it includes the duty to gather, analyse and present data for use on the fireground, something which this research seeks

* Fire authority in the terms of the Act [Section 4] was every County and County Borough Council. This was subsequently amended by local government legislation and may now include Metropolitan areas, Fire and Civil Defence Authorities and within Counties, Combined Fire Authorities or County Councils. Separate arrangements apply in Scotland and Northern Ireland.

to improve. Table 3.1 outlines some of the relevant sections of the Act.

Section l. (1) of the Fire Services Act 1947 states

"It shall be the duty of every fire authority in Great Britain to make provision for firefighting purposes and in particular every fire authority shall secure: -

[a] the services for their area of such a fire brigade and such equipment as may be necessary to meet efficiently all normal requirements;

[b] the efficient training of the members of the fire brigade;

[c] efficient arrangements for dealing with calls for the assistance of the fire brigade in case of fire and for summoning members of the fire brigade;

[d] efficient arrangements for obtaining, by inspection or otherwise, information required for firefighting purposes with respect to the character of the buildings and other property in the area of the fire authority, the available water supplies and means of access thereto, and other material local circumstances;

[e] efficient arrangements for ensuring that reasonable steps are taken to prevent or mitigate damage to property resulting from measures taken in dealing with fires in the area of the fire authority;

[f] efficient arrangements for the giving, when requested, of advice in respect of buildings and other property in the area of the fire authority as to fire prevention, restricting the spread of fires, and means of escape in case of fire."

Through this enabling section, primary legislation requires fire authorities to secure the resources for the range of duties expected by the public. Subsequent sections include supplementary powers and arrangements such as those which allow the fire authorities to recover costs, use others to discharge their functions, gives power to obtain a supply of water for firefighting, as well as arrangements to administer brigades and control staff levels.

As previously mentioned, Section l.(l)[d] of Fire Services Act 1947 is especially relevant to this thesis. It is here that the power and duty are given, which enables the fire service to gather information on buildings and other properties for the purpose of ensuring that brigades can operate efficiently. There are, of course, controls to prevent misuse of information gained by the fire brigades whilst conducting their duties*.

A fire authority may have hundreds of 'risk' premises in its area. It is responsible for the interpretation of thousands of items of information on, for example, hazardous substances. It is required to apply the statutory limitations and controls in force to safeguard its employees and the public and to deliver a fire service that satisfies rapid deployment criteria.

The fire service not only has to gather information, it must deliver it when and where it is most needed (during firefighting and rescue operations) in a manner that conforms to a wide range of requirements, including the legal necessity to increase safety. Failing to manage this information is not considered an option, and examination of the ways and means to meet the information needs of the service in the most testing of circumstances. The Fire Services Act of 1947 amended by the Fire Services Act 1959 remains a comprehensive document, even though it is now some 50 years old. Some of the more important responsibilities under the Fire Services Act, 1947, are shown in Table 2.1.

2.5 Fire Safety Legislation

Fire safety legislation, which is now quite developed, has, to a significant degree, evolved as a reaction to UK tragedies. This history of 'stable door' legislation is illustrated by the examples given in Table 2.2. Developing legislation in this way inevitably creates a series of complicated and interwoven legal requirements. A separate approach exists for the construction control and fire protection of buildings and

* Section 36 (14) (2) (e) of the Fire Services Act, 1947 provides for fines and imprisonment if information is disclosed outside that required by duty.

that is found within the building codes, the primary control for the UK being the Building Regulations[10]. It is worth noting here that Codes do not have the same legal requirement for compliance as Regulations, which are derived from a principal Act. Codes can be supported by Guidance, again voluntary and not enforceable.

The complex nature of UK fire safety legislation resulted in the development of a consolidation initiative during 2000 under the then new approach of regulatory reform.

Section	Arrangements
1	Provision of fire services
2	Arrangements for mutual assistance
5	Voluntary combination schemes
12	Discharge of fire authority duties through other authorities or persons
13	Duty to ensure adequate firefighting water supply
14	Power to ensure water undertakers supply water
18	Appointment and promotion schemes
19	Approval of establishments
21	Requirement to train and equip
23	Establishment of a training centre
24	Inspection of fire brigades
26	Creation of a pension scheme
29	Creation of a Central Fire Brigades Advisory Council
30	Power of entry for firefighting

TABLE 2.1. PRINCIPAL SECTIONS OF THE FIRE SERVICES ACT, 1947

The approach was new in that it enables Ministers to amend primary legislation [Acts] without following the conventional Parliamentary process of placing draft legislation before both Houses of Parliament within the conventional timescale and committee arrangements. That new approach was used for the first time in the UK to bring

The 1959 Act largely gave power to a number of changes relating to administration and regarding conditions of service whilst recognising the use of fire brigade resources at incidents other than fires such as road accidents or dangerous substance releases.

together and amend fire safety law and has now resulted in the publication of the Regulation Reform Order 2003

Fire	Number of Deaths	Consequent Legislation
1956, Eastwood Mill, Keighley	8	The Factories Act 1961
1961, Henderson's Department Store, Liverpool	11	The Offices, Shops and Railways Premises Act 1963
1961, Top Storey Club, Bolton	19	The Licensing Act 1964
1969, Rose & Crown, Saffron Walden	11	The Fire Precautions Act 1971
1985, Bradford City Football Club	56	The Fire Safety and Safety of Places of Sport Act 1987

TABLE 2.2. EXAMPLES OF "STABLE DOOR" LEGISLATION

In 1972, through the European Communities Act[11], the United Kingdom became a member of the European Community and in 1973 became committed, through the Treaty of Rome[12], to all Community Treaties. This requires the UK Government to act, and to be seen to act, through statutory controls in support of the European Parliament's Directives or their interpretation by the executive within the European Commission and European Court.

Consequent upon the introduction of the Health and Safety at Work Act 1974 significant fire service responsibilities fall within the areas of occupational health and safety, which directly relate to working standards. This Act remains the central UK legislation relating to workplace safety. The EC, in 1986, added through special regulations (derived from article 1.1.8a of the Treaty of Rome), controls designed to improve workplace safety. The impact of occupational legislation will continue to expand with increase in European influence, such as the impact of Treaty of the European Union negotiated in 1989 at Mastricht[13] and subsequently adopted.

Both English Statute Law and Common Law use substantial precedents derived from judgements. This is a significantly different approach from the general Napoleonic, European law that has a more prescriptive basis. The Mastricht Treaty established the principle of subsiduarity ensuring Member States could interpret Directives into their own legal framework. This is a somewhat complex arrangement that results in varying interpretations and, in the UK case formal resolution of matters of dispute is through the courts. Guidance, rather than legal requirements, is therefore commonly issued by enforcing bodies, such as Fire Authorities or the Health and Safety Executive, often referred to as the 'Competent Authority'.

The approach is different to UK criminal law. In criminal law, the case must be proved "...beyond reasonable doubt..." whereas in civil cases it need only be "...on the balance of probabilities...". Where an injury does not relate to a standard of behaviour, civil law is applied and negligence and incompetence use the principle of 'res ipsa loquitur apropos negligence' – negligence is assumed (that is a want of care occurred) if an accident happens but if a third party's fault can be demonstrated as being responsible for the accident, the defendant may not be judged to have been negligent; this is an interesting example of being proved guilty until proved innocent. Civil law often relates more to compensation for personal injury, caused by a breach of contract, and therefore tends to be about negligence or incompetence and may include strict or conditional liabilities .

General fire safety enforcement now rests within the Fire Precautions Act 1971[14] with

Negligence, in simple terms, is taken as being that a person knew that there was a better way of doing something and didn't do it – incompetence, on the other hand, is when the person never knew how or what to do. An employer has a duty to assess individuals and avoid employing incompetent persons.

emphasis on adequate means of escape♰ and fire safety protection. Under this principal Act, regulations, through designation orders*, can be made to encompass various premises controlled by a regulation process of certification♣. The Act's features include inspection powers and the need for occupiers to secure adequate safety arrangements. The Act♥ was amended by the Fire Safety and Safety of Places at Sport Act, 1987[15], to offer protection to venues used for sporting occasions following a series of major tragedies.

Originally, Government or Crown premises were exempt from the two principal Acts mentioned. This was seen as a serious anomaly and exemption was subsequently removed by amendments introduced in the National Health Service and Community Care Act of 1990[16] for a series of premises, notably in the National Health Service.

One very positive outcome of the fire safety legislation is that certificated drawings exist for many high-risk premises. The ability to retain, and deliver when required, this information, which includes detailed floor plans, is one simple but important example of the need to have an integrated information system within the fire service.

♰ Means of Escape. This common term is used by the fire service to designate the methods and routes used to escape from a fire. A widely accepted definition is "Physical means by which a person may move to a place of safety by their own unaided efforts"

* Premises designated can include those relating to treatment and care; providing sleeping accommodation; used for entertainment, recreation or instruction and those used for teaching, training or research. Premises to which the public has access or places, in which they are working, can also be designated. In the event, only two designation orders have been made. These are hotels, boarding houses and premises such as factories, offices, shops and railway premises, which had previously been subject to their own legislation.

♣ Fire certificates detail means of escape, methods of fighting fires and giving warning in case of fire together with those means needed to ensure the safe means of escape are secured.

♥ The Secretary of State responsible for fire service matters announced at the Fire '98 Conference held in Glasgow on 9 September 1998 that the Government were supportive of a new Fire Safety Act.

2.6 General Employment Legislation

The Health and Safety at Work Act 1974[17] ensures that everyone involved with work, or who is affected by it, is effectively protected by systematic isolation or mitigation of risk in their general health and safety. The approach is to impose a series of general duties designed to cover all hazards, and a requirement on employers to improve their organisation and systems to ensure safety[18]. It further places a requirement on all employees both to protect themselves[19] and to work constructively with their employers having received information regarding the risks that may be present. Enabling health and safety is an important feature[20] of fire service operations, and includes a process of inspection by an independent inspectorate and a framework for developing and updating detailed safety law. Table 2.3 details the principal provisions.

The Health and Safety Act is used as the foundation Act from which many regulations are derived, often supported by codes of practice or guidance notes, which have significant relevance to the fire service. Table 2.4 illustrates a number of those regulations including those arising from the European Union's Framework Directive[21].

Not only is the fire service not exempt from health and safety regulation, it operates within an environment that is physically demanding[22] and where there could be significant post incident effects[23] such as post-traumatic stress disorder. To meet such operating difficulties[24] a generic risk assessment approach[25] and the concept of 'The Safe Person' has also been developed by, amongst others, the Fire Service Inspectorate[26].

2.7 Major Hazard Premises Legislation

Major industrial hazard controls in Europe exist through a European Council Directive[27,28] issued on 24 June 1982 in response to two major emergencies which occurred at Flixborough 1974 and Seveso 1976. Subsequent emergencies at Chernobyl 1986, Schweizerhalle 1986 and Allied Colloids 1992, resulted in a further Directive. This Directive is known as the Seveso I Directive; a later one, the Seveso II Directive, was issued in 1996.

Two of those incidents were particularly notable. The first occurred in 1974 at Flixborough[29], United Kingdom, and involved a vapour cloud explosion of cyclohexane* used in the manufacture of nylon, causing considerable damage to a chemical plant and the deaths of 28 people. The second occurred in 1976 at Seveso, Italy, which resulted in the release of dioxins and had considerable biological impact on both humans and animals.

Each Member State has established arrangements for regulating major hazards[30]. In the United Kingdom these were the Control of Industrial Major Accident Hazard Regulations [CIMAH] 1984 as amended[31, 32] and now the Control of Major Accident Hazards [COMAH] 1999[33].

A safety case concept[34,35], forming part of the Regulations, is used to direct attention to safety management with requirements based upon notified chemicals and inventories[36]. Reviewed by the competent authority the safety case guides the local authority in the

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* C_6H_{12} A colourless liquid. Flash point - 18°C. Auto ignition temp. 259°C. UN Number 1145. Specific gravity 0.78. Vapour Density 2.9.

Local authorities in the UK context are Municipal, Unitary and County Councils.

preparation of safety plans for both on and off site. Land use controls, which prohibit building in designated areas, minimise the likelihood of the local population being effected by major accidents and ensure notification is given to those local populations that may be affected. This is an annual requirement carried out in addition to alerting communities at the time of an accident.

The process of notification[37] and further requirements under a Seveso II Directive[38] extend the original Seveso Directive through the Control of Major Accident Hazards [COMAH] 1996*.

Local authorities use a range of powers to exercise planning control over major hazard sites, a great deal is derived from war related legislation[39,40,41,42]. Encouraging co-operative planning for major hazards in a similar way to disaster planning has helped ensure the rapid and accurate flow of information so important for effective response at incidents such as the Clapham train crash* in August 1989.

Recently the Health and Safety Executive has unified major hazard law so that COMAH 1999, IRR 1999[43] and the amendments proposed to PIRERR 1992[44] regulations all follow a common format. This is especially relevant in terms of safety case presentation and risk assessment.

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* COMAH requires more explicit safety reports and emergency plans. Land use planning is more firmly established with public information and guidance being more explicit and transparent. COMAH continues to apply a two-tier major hazard approach [adopted in the Seveso I Directive and CIMAH regulations]. This two-tier methodology, using inventory threshold levels, allows those installations having lower risks to apply a simpler set of rules.

* The Clapham rail crash occurred in 1989. The subsequent inquiry [Investigation into the Clapham Junction Railway Accident 1989 (Comd.820) Department of Transport] criticised the lack of integration between services at the scene in that no one had responsibility for knowing how many rescuers were on site at any time.

PART 1 HEALTH, SAFETY AND WELFARE, IN CONNECTION WITH WORK	
Section	**Provision**
1 (a)	Securing the health and safety of persons at work
1 (b)	Protecting other persons from the effects of work
1 (c)	Controlling flammable, explosive or dangerous substances
1 (d)	Controlling noxious emissions
2	Employers to protect employees
3	Protection of persons other than employees
4	Protection of persons who use premises other than employees
5	Control to prevent emissions
6	Requirements on suppliers of articles and substances
7	Employer to be responsible for own and others safety
8	Prohibition on interfering with anything provided for health and safety
9	Prohibition to charge employee for anything done for safety
10 - 14	The Health and Safety Commission and the Health and Safety Executive*
15 - 26	Regulations, codes of practice and inspection
27	Obtaining information
28	Disclosure of information
29 - 32	Provisions relating to agriculture
33	Offences

TABLE 2.3. HEALTH AND SAFETY AT WORK ETC ACT 1974

* The Health and Safety Executive (HSE) acts as the 'Competent' or Statutory Enforcing Authority for a wide range of regulatory issues related to health and safety maintaining inspectors and policy advisors across the spectrum of industries. A National Industry Group (NIG) for the fire and police service exists. HSE have enforced action against fire brigades on a number of occasions including Improvement Notices requiring better risk information systems

EXAMPLE STATUTORY REGULATIONS	
1	The Management of Health and Safety at Work Regulations 1999[45]
2	Provision and Use of Work Equipment Regulations 1998[46].
3	Lifting Operations and Lifting Equipment Regulations 1998[47]
4	Health and Safety [Display Screen Equipment] Regulations 1992[48]
5	Personal Protective Equipment at Work Regulations 1992[49] as amended
6	Control of Lead at Work Regulations 1998[50]
7	Control of Major Accident Hazards Regulations 1999[51]
8	Control of Asbestos at Work Regulations 1987[52] as amended
9	Electricity at Work Regulations 1989[53]
10	Noise at Work Regulations 1989[54]
11	Dangerous Substances [Notification and Marking of Sites Regulations] 1990[55]
12	Notification of New Substances Regulations 1993[56]
13	The Construction (Health, Safety and Welfare) Regulations 1996[57]
14	Control of Substances Hazardous to Health Regulations 1999[58]
15	Chemicals [Hazard Information and Packaging] Regulations1993[59]as amended
16	Health and Safety [Safety Signs and Signals] Regulations 1996[60]
17	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995[61],[62]
18	The Confined Space Regulations 1997[63]
19	The Work in Compressed Air Regulations 1996[64]

TABLE 2.4 HEALTH AND SAFETY AT WORK EXAMPLE STATUTORY REGULATIONS

2.8 Summary

The historical perspective demonstrates that a hierarchical decision process is institutionalised within the fire service. What is also evident is that changes, that have already occurred and will continue, now influence how the fire service manages decisions. Arising from a mixture of historical and legal development this is summarised as having created a service with a traditional public service ethos but operating in a contemporised legislative environment.

The legislative section demonstrates that a comprehensive system of legal controls exists, which demands well-founded and auditable decisions. In critical safety areas these decisions are unlikely to have the benefit of time considered judgements, as the later case studies illustrate, yet do require that all information pertinent to the decision made be recorded. However, whilst this regime does have a legal basis to gather information before the incident occurs it does not contain a method or controls to provide an Incident Commander with readily accessible key details together with all the necessary legal safeguards. Again this deficiency is discussed following review of the case studies later in this thesis.

There is also the practical difficulty for the fire service that existing hazardous material control legislation, so applicable to static sites, is less effective for occurrences off-site although the consequences may be as severe or worse than at a controlled manufacturing or storage facility. This escalation of risk may be a simple derivation of local factors, such as population or environment, present at the accident scene or the inter-action of harmful materials, which at a controlled facility would be segregated if likely to be hazardous.

The basic legal structure remains however of principle legislation placing requirements upon all employers, whether the fire service or any other to protect employees and those at risk, and the growing importance of trans-national, European, direction. Implementing action through any management process, especially in the wider context of society becoming more litigious, places the individual in considerable jeopardy and the organisation at risk of corporate failure if decision-making is not systematic, robust, well informed and capable of showing professional judgement.

The development of the fire service over the past 100 years and the continued increases in legal controls have not always necessarily sat well together due in part to an internalised command system for decision-making that has had an assumed acceptance of being correct rather than being a decision system capable of wide external scrutiny. Whilst it is sensible and appropriate not to subject the judgement of individuals under considerable time and lack of information pressures to the same questioning and tests as those operating under normal constraints of decision-making it is equally unacceptable to deny those same individuals the best access to information that is available. Information access is however only part of the process. Culture and management skills inherent within an organisation greatly affect how well any information will be used to deescalate risk and it is these areas that are explored in Chapter 3.

Finally, very recently in 2003, the UK Government has proposed substantial change for the fire service. A summary of the proposals is detailed in the Appendix 'The Future Fire Service'.

CHAPTER 2 REFERENCES

[1] Eyre, F. [1945], *The Business of a Fireman*, Lomax, Erskine, London.

[2] *As Chapter 2 reference 1, p37.*

[3] *As Chapter 2 reference 1, p14.*

[4] *As Chapter 2 reference 1, p79.*

[5] *As Chapter 2 reference 1, p430.*

[6] *Fire Service Act 1947*, 10 & 11 Geo VI, Ch. 6 TSO, London.

[7] *Fire Service Act 1947*. 10 & 11 Geo.6 Ch41, TSO, London

[8] *Fire Service Act 1959*. 7 & 8 Eliz.2 Ch44, TSO, London.

[9] Kent P. [1996] *Law of the European Union*. Pitman Publishing, London

[10] *Building and Buildings, The Building Regulations, 1991*. [Statutory Instrument No 2768] TSO, London.
Building and Buildings, The Building Regulations [Amendment] Regulations, 1992. [Statutory Instrument No 1180] TSO, London.
Building and Buildings, The Building Regulations [Amendment] Regulations, 1994. [Statutory Instrument No 1850] TSO, London.
Building and Buildings, The Building Regulations [Amendment] Regulations, 1995. [Statutory Instrument No 1356] TSO, London.
Building and Buildings, The Building Regulations [Amendment] Regulations, 1997. [Statutory Instrument No 1904] TSO, London.
Building and Buildings, The Building Regulations [Amendment] Regulations, 1998. [Statutory Instrument No 2561] TSO, London.
Building and Buildings, The Building Regulations [Amendment] Regulations, 1999. [Statutory Instrument No 77] TSO, London.

[11] *European Communities Act*. 1972. *And Treaty of Accession*, Eliz.2.1972.

[12] Kent P. [1996] *Law of the European Union*. Pitman Publishing, London.

[13] *Treaty of the European Union*, signed in Mastricht, 7 February 1992.

[14] *Fire Precautions Act, 1971*. Eliz. 2 Ch27, TSO, London.

[15] *Fire Safety and Safety of Places of Sport Act, 1987*. Eliz. 2 Ch27, TSO, London.

[16] *National Health Service and Community Care Act, 1990*. Eliz. 2, TSO, London.

[17] Kent P. [1996] *Law of the European Union*. Pitman Publishing, London.

[18] Chandler, P. [1997] *An A to Z of Health and Safety Law*, 2nd Edition, Kogan Page, London.

[19] European Union. [1989], *Personal Protective Equipment Directive 89/656/EEC*.

[20] *The Principles of Good management, British Standard 8800: 1996. A Guide to the Integration of Occupational Health and Safety Management Within an Overall Management System*, British Standards Institution, Milton Keynes.

[21] *European Union Framework Directive 1992*. (89/391/EEC).

[22] Crawford, J., Graveling, R.A., Hutchison, P.A., Johnston, J.B.G., Love, R.G., Ritchie, P., Tesh, K.M. and Wetherill, G.Z. [1994]. *Study of the Physiological Effects of Wearing Breathing Apparatus,* Report No TM/9/05, Institute of Occupational Medicine.

[23] McCloy, E. [1992] *Management of Post Incident Trauma - A Fire Service Perspective,* Journal of Occupational Medicine, Oxford, Vol.42, No.3, Pages 163 - 166.

[24] D'Sullivan, K.G. [1992], *An International Analysis of the Effects on Fireground Operations of Increasing Concern for Occupational Safety and Health,* Brigade Command Course Project Report, Fire Service College, Moreton-in-Marsh.

[25] Home Office Fire Service Inspectorate, Publications Section. [1998], *Health and Safety Fire Service Guides, (a) Dynamic Risk at Operational Incidents, (b) Vol.3. A Guide to Operational Risk Assessment.* The Stationery Office, London.

[26] Wells, A. [1997], *The Safe Person Concept,* Dear Chief Officer Letter Number DCOL 1/1997, Fire Service Inspectorate, Home Office.

[27] European Union. *Seveso Directive.* Seveso I adopted in 1982 and Seveso II adopted in 1996. Directive issued by the European Union to control major hazards and improve and use planning and exercising. Name follows Seveso in Northern Italy where an accidental dioxin release in 1976 led to widespread environmental contamination.

[28] Health and Safety Executive. [1977] *Seveso.* The Escape of Toxic Substances at the ICMESA Establishment on 10 July 1976 and the Consequent Predicted Danger to Health and the Environment due to Industrial Activity, English translation is the Health and Safety Executive of the official report of the Parliamentary Commission of Enquiry, by permission of the Parliament of the Republic of Italy, TSO, London.

[29] Department of the Employment. [1974]*The Flixborough Disaster, Report of the Court of Enquiry,* TSO, London.

[30] Health and Safety Executive. [1997], *The Regulation of Major Hazards in Finland, France, Germany and the Netherlands,* TSO, London.

[31] Health and Safety Executive. [1990] *A Guide to the Control of Industrial Major Accident Regulations, HSE(R) 21 (Rev) 1990,* TSO, London.

[32] Health and Safety Executive. [1986] *Guidance Booklet HS [G] 25. The Control of Industrial Major Accident Hazards Regulations 1984 (CIMAH): Further Guidance on emergency plans,* TSO, London.

[33] *The Control of Major Accident Hazards Regulations 1999[Statutory Instrument 1999 No 743] and The Planning (Control of Major-Accident Hazards) Regulations 1999* [Statutory Instrument 1999 No 981] TSO, London.

[34] The Chemical Industries Association. [1976], *Recommended Procedures for Handling Major Emergencies.*

[35] IBC Technical Services Ltd. [1996], *A Risk Based Approach to Assessing Safety and Environmental Hazards,* Conference Documentation.

[36] Health and Safety Executive. [1996], *The Dangerous Substances [Notification and marking of Sites] Regulations, 1990.* Local Authority Circular 27/12, HSE, London.

[37] *The Notification of Industrial Major Hazard Regulations, 1982.*

[38] *Seveso 11 Directive, European Council Directive 96/82/EC of 9 December 1996 on the Control of Major Accident Hazard Involving Dangerous Substances.* TSO, London.

[39] *The Civil Defence [General Local Authority Functions] Regulation, 1993.* [Statutory Instrument No 1634] TSO, London.

[40] *Civil Protection in Peacetime Act,* [1986]. Eliz.2 Ch.22, TSO, London

[41] *The Civil Defence [General Local Authority Functions] Regulations 1993,* [Statutory Instrument No. 1812] TSO, London.

[42] Home Office, [1997], *Dealing with Disasters,* 3rd Edition, Brodie, Liverpool.

[43] *The Ionising Radiation Regulations 1999,* [Statutory Instrument 1999 No. 3232] TSO, London.

[44] *The Public Information for Radiation Emergencies Regulations 1992,*[Statutory Instrument No.2997] TSO, London.

[45] *The Management of Health and Safety At Work Regulations, 1999.* [Statutory Instrument No. 3242] TSO, London.

[46] Provision and Use of Work Equipment Regulations, 1998.[Statutory Instrument No 2306] TSO, London.

[47] *Lifting Operation and Lifting Equipment Regulations, 1998.* [Statutory Instrument No. 2307] TSO, London.

[48] *Health and Safety [Display Screen Equipment] Regulations. 1992,* [Statutory Instrument No 2792].

[49] *Personal Protective Equipment at Work Regulations, 1992,*[Statutory Instrument No 1992/2966], TSO, London.

[50] *Control of Lead at Work Regulations, 1998.* [Statutory Instrument No. 543] TSO, London.

[51] *The Control of Major Accident Hazards Regulations, 1999.* [Statutory Instrument No 743] TSO, London.

[52] *Control of Asbestos at Work Regulations.* 1987. [Statutory Instrument No 2115] TSO, London.

[53] *Electricity at Work Regulations, 1989.* [Statutory Instrument No 635] TSO, London.

[54] *Noise at Work Regulations, 1989.* [Statutory Instrument No. 1790] TSO, London.

[55] *The Dangerous Substances (Notification and Marking of Sites) Regulations, 1990.* [Statutory Instrument No 304] TSO, London.

[56] *The Notification of New Substances Regulations 1993.* [Statutory Instrument No. 3050] TSO, London.

[57] *The Construction (Health, Safety and Welfare) Regulations, 1996.* [Statutory Instrument No. 1592] TSO, London.

[58] *The Control of Substances Hazardous to Health Regulations, 1999* [Statutory Instrument No. 437] TSO, London.

[59] *The Chemicals [Hazard Information and Packaging] Regulations 1993.* [Statutory Instrument No 1746] TSO, London.

[60] *Health and Safety [Safety Signs and Signals] Regulations, 1996.* [Statutory Instrument No 341] TSO, London.

[61] *Reporting of Injuries, Diseases and Dangerous Occurrences Regulations, 1995.* [Statutory Instrument No. 3163] TSO London.

[62] Health and Safety Executive. [1995] Everyone's guide to RIDDOR. Guide to the Regulations, TSO, London.

[63] *The Confined Space Regulations, 1997* [Statutory Instrument No. 1713] TSO, London.

[64] *The Work in Compressed Air Regulations, 1996* [Statutory Instrument No. 1656] TSO, London.

CHAPTER THREE

Management Systems Development and International Review

3.1 Introduction

The historical and legislative background discussed in the earlier chapter provides only part of the cultural and managerial influences, which are so important in creating an organisations' decision-making framework. This chapter briefly reviews the influences exerted by external industrial and commercial environments and, from outside the normal environment of the United Kingdom, compares variations to the UK fire service practice.

In particular it considers the Incident Command System (ICS) of the USA, which was recently tested to extreme levels. It also explains, using a case study of Cheshire Fire Brigade, how these external developments can have a positive impact on the decision-making process.

3.2 Industrial Development

Whilst the early fire service was developing, a more scientific approach to the study of management was also evolving. The concept of management principles, identifying five functions: planning, organising, commanding, co-ordinating and controlling, was established by Fayol[1] (1841-1925), a French industrialist. Fayol added a further 14 principles, one of which was the scalar chain, which he conceived had a direct supervisory link from the highest to the lowest employee. Taylor[2] (1856 - 1915), working in the United States, introduced the concept of job analysis by which productivity could be increased. In so doing he sought to implement a series of production methods. One of his colleagues, Gantt, introduced a process of managing production, which has subsequently survived as the Gantt chart[3].

It is impossible to know whether the work of these individuals had any influence upon the development of the early fire service. However, personal observations in the later 1960s, suggest that management principles were becoming acknowledged within the fire service, and during the 1970s, management procedures such as those discussed by Adair[4] in his book *Effective Leadership*[5], and by Prior, in his publication *Leadership is not a Bowler Hat*[6], were introduced. Consequently, fire service personnel found themselves becoming acquainted with concepts such as task-based working, leadership, analysis and development. In comparison with previous fire service management, these ideas illustrate that the fire service was observing the external environment, recognising social and cultural changes and responding to the political and economic climate that was manifested in the changing local government scene.

Furthermore, the service was also utilising other industrial ideas such as those related to motivation[7]. Management by Objectives was being adopted and other theories such as those advocated by Drucker in *The Practice of Management*[8] led to the fire service experimenting with task role analysis, job descriptions and the use of learning cultures.

Writers, such as McGregor[9] and Mintzberg[10] who dealt with the systematic process of management[11] had an impact on the service as it moved forward. Strategic planning for the larger brigades that emerged after the changes in 1974 became an integral part of the fire service approach. Organisational principles began to find favour and concepts such as authority and responsibility, particularly in areas of delegation, became subjects of discussion on progression courses for fire service officers at the Fire Service College [FSC].

During the 1980s the author compared and contrasted the management techniques of one multi-national company with that of five fire brigades[12]. The findings of this limited survey indicated that industry was far more likely to incorporate widespread delegation than the fire service. This result, it was decided, arose because the fire service retained a strong hierarchical system and a disciplinary culture derived from the military, suggesting a disparity between the organisational cultures of brigade and industry.

It is postulated that prior to the 1980s, the debates within the fire service tended to ignore the public or organisational relationships. Consequently, highly centralised brigades were operated on an armed service basis. The work of Adair, with group and individual needs, suited the fire service style of team working. There were also signs that managers were seeking to harmonise personal and organisational goals, as opposed to separating them, in tune with McGregor's theory[13]. Managers recognised that individual firefighters were keen to contribute to the organisation for intrinsic rather than materialistic reasons. It was noted that firefighters welcomed this involvement and were motivated towards a broader understanding of what their brigades were trying to accomplish.

At the time, some Chief Fire Officers actively considered moving to the Likert[14] style of management, away from the exploitative authoritative style towards a benevolent authoritative type.

Consultative actions were new in the 1980s and participative group working had not as yet found its way on to the fire service management schedule. Debates amongst senior officers continued, and by the end of the 1980s a definite move from a directive form of management towards that of a staff consultative manager began[15].

The service, however, remained strongly task structured in terms of Fiedler's variables[16]. It would be false to assume that there was a failure to consider the individual. Certainly at this time Maslow's hierarchical identification of needs were well understood[17]. This was witnessed in officer development training undertaken at the FSC.

In the early 1980s further developments in work organisation and democratic arrangements[18] and the cultivation of problem-solving and decision-making strategies were witnessed in discussions at the FSC and its inevitable influence upon fire service officers analysed.

During the 1980s, the importance of technology was again recognised by the fire service. Computers had been introduced towards the end of the 1960s. However, they tended to be used for statistical analysis only and did not have a significant impact in the operation of the majority of fire brigades. Following the reorganisation of the fire service in 1974, communications were perceived as the central key to the new organisations. Consequently, the importance of information systems and information technology was finally recognised. This is especially relevant given the statutory duty placed upon Fire Authorities to gather information for firefighting purposes[19].

Whilst this general management approach was evolving, the fire service observed, particularly in the United States, an introduction of specific fire service management guidance. It has to be remembered that within the US, there are a considerable number of fire brigades, around 32,000. Many of them are small departments and some are quite isolated. The value, therefore, in having a systematic approach to management, which could be published and disseminated, was considered to be of particular importance.

Indeed, in 1969, the first of many books written for the fire service management in the USA was produced by Professor Favreau[20] at the State University of New York in Albany, at the request of *Fire Engineering* magazine and became widely circulated.

Favreau introduced what he termed a scientific approach to management, incorporating specific fire service needs. He defined the management cycle at length and began to study the behavioural sciences in terms of motivation, group behaviour and styles of management. He also argued strongly for executive development coupled with the need for education and research. He failed, however, to provide a methodology other than to argue that the chief executives of fire departments needed to adopt a scientific approach to their management. This work may have prompted other Americans like Brunacini[21] to develop command management and decision systems.

It is suggested that the past 25 years have therefore seen a sea change in the use of management techniques and that fire service managers are far more adapt at using these techniques and skills - a range of working situations.

3.3 Cultural Change

A personal review of cultural change conducted 20 years ago [12] confirmed then that changes in fire service culture would be required if it was to achieve the benefits available to a more flexible organisation. By 1985, changes in fire service management and a wider culture of empowerment* were already beginning to take hold. Moves towards the empowerment of staff tended to recognise that organisations had to constantly improve if they were to be successful. This ability to adapt to new demands required utilising all the abilities of staff and depended upon a relaxation of the hierarchical structure. Important studies by the Audit Commission† reinforced the need for managers to be flexible[22]. The Commission had suggested that whilst the fire service was "notably well managed"; it was also falling well short of reducing the impact of fire by not delivering "prevention rather than cure".

Enthusiasm and motivation, it is suggested, follows empowerment[23] and the more traditional methods of seeking motivation, through rewards, would be achieved at lower cost but in a way that was better suited to a fast moving world[24]. The challenges of continuous improvement also demanded that authority had to be placed where it was most needed and that this, in business terms, tended to be "closer to the customer", a phrase that was much used at the time. The majority of fire service managers recognised that the use of all staff knowledge, as expressed by Drucker[25], was necessary if the organisation was to be pro-active.

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* Empowerment is a general term used to convey the principle of individuals being given the authority and resources to enable them to exercise judgement and action at the lowest possible managerially responsible level.

† The Audit Commission is a statutory independent body responsible in England & Wales (the comparable body in Scotland is the Accounts Commission) for auditing the financial effectiveness of local government.

Linked to these ideas was the emergence in fire service thinking of Total Quality Management [TQM][26] and the introduction of relevant British Standards[27 28] which sought to justify the need for effective audit systems applied to the process and manufacturing industries. These concepts were rapidly adopted generally and produced significant cultural change within organisations. Quality was valued just as much as speed of production and consequently the TQM[29] concepts were used more broadly than originally envisaged.

This, in turn, demanded an understanding and mutual co-operation between teams and groups of people working within organisations[30]. The concepts of devolved authority or empowerment created the idea that individuals should push the organisation as far as possible to achieve its stated aims until they were actually stopped by rules which had been put in place to protect the corporate body[31]. This notion of pushing at the boundaries allowed innovation and response to become pro-active as opposed to reactive. It also demanded that the organisation created a 'first principle' form of approach, often encapsulated in some form of mission statement, although many organisations subsequently went beyond this and began to talk in terms of a 'vision' for their organisation[32]. Empowerment within the fire service demanded lateral cross-functional working and the removal of top-down structures, replacing these with a concept of process[33]. This process of empowerment also created the concept of a "learning organisation", that is one that constantly seeks to improve by internal learning.

The Cheshire case study illustrates an example of cultural change within a brigade highlighting that operational or traditional decision-making can be effectively reformed with positive benefits through the introduction of a modified business management culture.

Progressively these changes have continued, generally because of external influences like the introduction and application on local government and the fire service of regimes designed to achieve better resource utilisation, like 'Compulsory Competitive Tendering'[‡] and 'Best Value'[§]. The inherent management culture retained has however continued with many facets of a traditional and composite highly 'service' based style.

The management evolution of the past 25 years has recently been scrutinised[34] and the review's authors concluded that "we did not realise... just how much potential for reform exists in the current fire service". They argued that the fire service had fallen behind best practice in the private and public sector and were especially critical of what they termed "an old-fashioned, white, male-dominated, manual occupation". Examples cited included unsatisfactory industrial relations, a weak management system and lack of ownership. This latest review is the subject of considerable debate in what is colloquially referred to by fire authorities and government as a 'modernising agenda'. There is therefore clearly in one group of external reviewers' eyes some way further to go in terms of cultural and organisational reform.

3.4 International Comparisons

An international review was conducted to assess if it is the culture of the fire service itself or the defined national context and institutional approach that determines how

[‡] The CCT regime had a legal foundation requiring external tendering for designated services and contract values with the result that some local government services were outsourced.

[§] Best Value has a legal foundation similar in some respects to CCT with the added ability to interpret service contracts in a holistic way to meet local circumstances and within a policy and resource framework.

decisions are made. The established context for major incident response was reviewed since others have previously examined the role adopted and compared the UK with other international arrangements[35] and it is recognised that the US has developed specific responses[36].

To examine the value of these comparison studies the Netherlands and Sweden were chosen for their strategic, high hazard and integrated emergency response features and the US system of incident command reviewed. Other international agencies, such as the United Nations, which of necessity adopt systematic evaluation and management criteria in major disasters, were found to have useful records of accidents involving hazardous materials [See list of selected accidents involving hazardous substances (1970-1998) worldwide, available from the Awareness and Preparedness for Emergencies at Local Level (APELL) program at www.unepie.org/apell/accident.html], but these references did not extend to offering any useful comparative information on the requirements of Incident Commanders.

3.4.1 Netherlands

The Netherlands has similarities to the UK containing a number of major risks located within highly populated urban areas with a well-organised fire service[37]. Serious fires such as the Enschede fireworks factory explosion also illustrate that urbanised risks exist. A seminar visit made in 1996[38], allowed the opportunity to discuss common difficulties with others involved in emergency response from around the world.

The Netherlands legislation* provides public safety protection, which includes a responsibility on municipal authorities to secure a fire service. Each authority also has

* The Minister of Internal Affairs governs with powers from The Fire Services Act of 1985, the Disasters Act of 1985 and the Act on Medical Assistance in Times of Disaster 1991.

the power to employ the organisation that manages the fire service to undertake further disaster management responsibilities, for example, to draw up contingency plans and to provide medical assistance at the time of such disasters. Since some municipalities are too small to maintain their own service or equipment, arrangements exist for mutual aid through Provincial Co-ordination Plans. Final command of disaster management lies with the local Burgomaster. In normal circumstances, it is the local municipal fire service commander who initially takes operational command. The municipal commander also has responsibilities to the regional fire service commander within the limits set by the Burgomaster. Should the event or disaster escalate, the authority of the Queen's Commissioner, who has wider co-ordinating and management powers, may be invoked. The Minister of Internal Affairs can give advice and instruction to the Queen's Commissioners as to how the response to the emergency shall proceed.

Regional alarm centres are established for the command of operational services whilst the Burgomaster establishes a municipal disaster control centre, activating all of the services, and issuing warnings to fellow local Burgomasters and the Royal Commissioner. Once these disaster control organisations are operational, the overall incident management becomes a co-ordinated activity between the two control rooms, one led by the operational services, directly commanded by the Incident Commander, and the other led by the municipal disaster centre staff.

In many ways, accepting the different political control, this is comparable with UK practice, where police, fire service, medical services and health authorities would take action at an executive level to ensure that the necessary responses were properly co-ordinated.

However decision-making in relation to the hazardous incident is a fire service rather than the police function. In order to affect this role, there is a range of locally based response groups, including trained volunteers. In comparison to the UK the brigades involved are often smaller in scale, since in the Netherlands they are based upon individual municipal areas, and this may cause problems of response, capacity and integrated working[39]. The information system requirements recognise this devolved management process using 'teams' to achieve co-ordination. The cultural background of many fire service senior staff is engineering based and the use of multi-disciplinary teams and decision trees are widely accepted. Little conflict appeared to exist in co-ordinating response under these arrangements other than the ability to 'scale up' decisions from a local to regional event.

3.4.2 Sweden

An international event, Exercise Europe '96[40], combined with information gathered at a seminar in Ludwigshaven, Germany[41], earlier that year, enabled a comparative view to be gained on the Swedish approach to major incident management and utilisation of information to be studied as to its effectiveness. The approach is centrally developed and the Swedish Rescue Agency, Raddnings Verket, seeks to train and co-ordinate the activities of all the County Administrative Boards throughout the country. The Agency also trains fire service officers, often with an academic engineering background, to undertake crisis management and decision-making in multi-discipline teams. This centre enables a co-ordinated national response to be made to any major disaster that occurs within Sweden, and it also acts as a co-ordination group to ensure local authorities and emergency services operate in a uniform way. A group discipline is therefore established within the multi-discipline team.

The initial response in Sweden is made through the local fire service and the fire service officer retains command, assisted by the County Administrative Board who are remotely located [sometimes at significant distances given the geography of the country] and whose principal role is to support the local response. The fire service Commander therefore takes responsibility for local decisions relying on information transfer by radio. Part of the County Administrative Board's responsibility is to assess the local situation and to determine whether the municipal rescue services are likely to be overwhelmed. Under such circumstances, the County Administrative Board can take a decision to intervene and assume overall command of the situation. Since remoteness of location is a factor this does not occur for most emergencies, the response remaining local. No advanced technologies to aid information transfer were observed.

A unique part of the Swedish response system is the use of an independent agency, SOS Alarm[42], which provides notification to all the various agencies involved. In practice, municipal fire services may deploy their own resources, after being alerted by SOS Alarm, since they have one of their own staff present in the alarm centre as an advisor, although SOS Alarm routinely make responses. This organisation is well established, but it does create a different situation to that in the UK, since the alarm centre acts as a despatch organisation for many agencies. Importantly this arrangement also allows an early integration of response is undertaken albeit that Police resources, like the fire service, can be deployed independent of the centre with messages and requests from the incident made to local service controls. The Swedish system to operate and function correctly therefore requires a local incident site co-ordination centre.

The Swedish system is therefore centrally co-ordinated at inception through the training, development and support of local Incident commanders yet operates in a localised and sometimes geographically very remote environment in practice. Observation suggests that having the central learning foundation and common support system enables the information and decision process to work effectively. Central despatch and incident co-ordination through joint control rooms reinforces these features helping ensure all the players work to the same script.

The capacity to handle information and make decisions across a broad spectrum of likely incidents again emerges as an issue, in a similar way to the Netherlands. However, the independent despatch organisation is a new phenomenon. Observations did make it apparent that a distinct separation between the control centre organisation and that of incident command existed. During a practical exercise it was also observed that the focus for the incident was firmly in the Incident Commander's mobile headquarters, a vehicle that was equipped with radio and data information sources. The practice suggests that experts attended at the scene rather than attempting to influence outcomes from a remote headquarters.

It was concluded from observation that there were difficulties in conveying information between all the agencies involved. The difficulties were particularly apparent at the de-briefing session following the exercise, where it became obvious that the Central Controller had a differing view of the casualty requirements to the Incident Commander.

Again one common feature in Sweden was that, like the Netherlands, it is the Swedish fire service that assumes responsibility for incident co-ordination within a locally based municipal system, supported by the regional authority. This is the obvious structural difference between these two countries and the UK together with the engineering foundation of many senior staff and frequent multi-disciplinary working. Culture is therefore important, although clarity of command exists through the designate of the fire service as the lead authority.

3.4.3 Incident Command System, United States of America

In the USA following development in California, a system of command, referred to as the Incident Command System [ICS][43], has long been favoured. ICS was introduced particularly for wild land firefighting[44] where large numbers of volunteer fire departments, which are not routinely involved with large incident command, are required to provide mutual aid [There are around 35000 fire departments in the USA and very few are of the UK scale]. Co-ordinated decision-making in such an environment is therefore difficult[45], as the crews are not familiar with each other's operating practices. The primary component of ICS relates to a common terminology where all major functions are pre-designated so enabling all the various organisational elements to be standardised. The following activities are envisaged: -

Function	Description
Modular Organisation	The size and complexity of the incident is allowed to dictate which functions need to be staffed so that the operation can expand or contract as necessary.
Integrated Communications	The plan is to establish various radio networks such as command, tactical and air-to-ground networks with clear text or plain language messages
Unified Command Structure	Since a multi-fire department response is involved, all departments must unify under one Incident Commander[46] so that maximum use can be made of all resources and all tactical operations can be co-ordinated.
Agreed Plan	A consolidated action plan is the objective of the unified command system where all the strategies are inter-linked. Defined spans of control are introduced so that individual responsibilities do not become over extended.
Designated Incident Facilities	The approach required to manage the incident includes the basic activities of establishing a command post and an incident base together with various staging areas or sites where equipment could be stored so that there were facilities to meet the need.
Firefighting Resources	All resources are pulled together either as single items e.g. bulldozer or as task forces and strike teams.
Resource Management	A logistic organisation is created to control the status, i.e. assigned, available or out of use, of all equipment and resources.

TABLE 3.1 FUNCTIONAL TERMS USED IN USA INTEGRATED COMMAND SYSTEM

ICS also determines organisational elements: the command-person, or persons, responsible for information and safety-liaison; commanders in charge of all ground and air resources to identify incident development and resource availability together with technical support and logistics officer[s] who provide for all the services, communications and the general facilities needed. Finally cost administrators, who maintain records of all time allocated by the various fire departments, are engaged to ensure that subsequently the cost of any claims or procurements can be financially resolved. Similar system development has occurred for community response[47].

Elements of ICS could, therefore, be helpful if incorporated into the UK system. The value of a brigade being a "Learning Organisation" would assist incorporation.

ICS is therefore a recognisably systematic approach to incident management, similar to that used by many operational organisations[48]. The management process in the UK, as already described, expresses command and control in three distinct levels of decision-making. The ICS approach could, it is hypothesised, be envisaged in a UK environment as five inter-related tasks: -

1. The operational task being conducted within the area of activity.
2. The co-ordination of resources to support the operational task activities.
3. The functional organisation i.e. the fire brigade responsible, providing the infrastructure and corporate resources.
4. The mechanistic activities of monitoring what are happening, dynamically assessing the risk and potential for change in the operating environment and considering alternative strategies.
5. The review or audit process that ultimately looks at the situation, the effectiveness of the operations conducted and designs practice or procedure modifications that consequentially influence or change fundamental operational policies.

3.3.4 Review of ICS in Practice

Uniquely the ICS decision process was subjected to the events of 11 September 2001. Two fire departments, The City of New York Fire Department [FDNY] in its response to the World Trade Centre, New York City, New York State, and Arlington County Fire Department [ACFD] in the State of Virginia, at the US military facility, The Pentagon, were involved. The nature of these events, with the unprecedented scale of the World Trade Centre structural failure and extensive scope of command interactions, has allowed preliminary evaluation, since far more detail than is publicly accessible would be required, of ICS in practice. Details are described in the Appendix.

Importantly both events have been subjected to external investigations and personal comment has been obtained from the Chiefs of both departments affected to allow evaluation of the effectiveness of the system in action. This is very valuable since both incidents took ICS beyond the more usual mutual aid operations of wild land or structural fires. Since ICS adopts a systematic decision process it offers a foundation for postulating improvement in the UK fire services' operational decision-making. The following comments on both incidents identify weaknesses that need to be addressed in any improved system.

Following the World Trade Centre the McKinsey Report[49] and Chief Cruthers[50] of the NYFD reported that the New York State mandated command system, which has variations to the ICS processes described, did function effectively. ICS strengths were common terminology, manageable spans of control, modulated organisation and integrated communications. Chief Cruthers believed the local variation of having one leader rather than unified command was preferable. Fire Department deployments on site were undertaken using magnetic boards and grease pencils, although the department is now experimenting with a prototype ruggidised computer.

Military assistance in logistics, communications and technology, like robots and geographic information systems, greatly aided operations. Aerial and thermal photography and use of global positioning systems also proved invaluable in the very extended post incident phase when identifying and accurately plotting locations on the extensively damaged and very large site, to support tasks such as recovery of human remains, was required.

ICS was seen to need more institutionalisation within routine operations with better preparedness [training, preplanning, hazard assessments] and improved scalability [matching the dynamics of such large scale events by maintaining critical decision and safety systems]. The ability to conduct risk assessments in real time, matching personnel accountability, information management, incident communications [radio traffic, staff deployments, logistics] and inter-agency functionality [unified command, mutual aid, information sharing and inter communications], were crucial learning outcomes for the decision-making processes.

The McKinsey Report emphasises these communication difficulties concluding that they hindered the fire department's chief officers as they co-ordinated the response. Initially little reliable information was available and some portable radios failed to work within the high rise structures due to repeater malfunctions [repeater systems amplify and rebroadcast the radio signal]. There was a lack of information to the chiefs on what was happening in and to the structures so, for example whilst television was broadcasting extensive coverage, some officers within World Trade Centre 1 were unaware of the incident's progression. Consequently they had little precise background, such as the second aircraft hitting the second tower leading to the fire and ultimate collapse of that tower, with which to manage their assignments. The complexity and quantity of information flows, compounded by the difficulties of inter-agency working [there was spasmodic police and fire communication and a significant uncoordinated response of volunteering mutual aid, for example], resulted in serious resource management problems.

NYFD outcomes recognise that ICS use therefore needs expansion. This will target support for Incident Commanders so that crucial decision functions can be undertaken in a comprehensive, well-defined and flexible way. McKinsey also suggests that highly trained specialised teams may be needed to manage the larger and more complex type incidents with the Department's Operation Centre being extended into a fully functioning emergency operations centre. Planning is also seen as an essential component and so are improvements in communications infrastructure and the deployment of technology.

The After Action Report [AAR][51] prepared on the response by Arlington County to the September11 terrorist attack on the Pentagon, as well as describing the activities of a number of agencies, identifies a number of learning points. Importantly Chief Plaugher of the ACFD reported[52] and the AAR concurs that the ICS and unified command was understood, implemented effectively and operated successfully. This is notable given some participants, for example the military, were unfamiliar with ICS yet were able to work closely with the identified Incident Commander, who was then able to offer explicit information in support of an holistic response.

However difficulties did emerge in communication support operations, central to ICS, in that the ACFD did not have a dedicated mobile command unit and, from initial response to tactical operations, almost all aspects of communications were problematic. Cellular telephones and radio channels became saturated and even handheld portable radios were not interoperable [between fire departments and other emergency responders]. Logistically the scale of the event was overwhelming with short-term shortages occurring in critical high demand items like breathing apparatus. Mutual aid helped overcome these logistic issues as the incident progressed.

Other areas worthy of improvement were found to be better control of those individuals or organisations who responded on their own initiative to the incident, improved physical facilities to harden and better equip control and communication centres to handle emergencies; better interoperability in field communications, stronger and more organised logistics management; and improved co-ordination in managing health related issues, including emergency medical services and receiving hospitals.

It can be postulated that although these incidents, particularly in New York, had unique features there is clear evidence that the well-defined command decision-making process was essential in maintaining action impetus in what could have been chaotic and disestablishing situation for the fire service. What is also evident is the decision system is dependent upon an equally crucial and reliable information communication system.

3.5 Summary

The current overall fire service management approach might be characterised as progressively using modern business management and organisational concepts, including recent developments in information technology, in all operating environments including the fireground.

Although the service remains highly focused and task oriented with a ranking system for managers designed around the hierarchical processes of the fireground and the requirements of command and control, there are clear indications of a culture that uses conventional and appropriate business methods.

External commentators have however indicated that this existing culture is still inhibited in making progress. That change has occurred is also recognised by those same commentators who most recently recorded that 'excellent examples of change and new working practice exist'.

One such example is illustrated by the Cheshire case study shown in the Appendix in which the achievement of the Investors In People and Charter Mark awards demonstrated that cultural change can be accomplished and benefits derived for the management of incidents.

The international comparisons also show that it is practical to have working alternatives to the current decision making processes. One alternative, the USA ICS approach, operates throughout a range of differently scaled fire departments and has been subjected to the most demanding of operational scenarios. These arrangements are now under intensive evaluation following the tragedies of September 11th.

The international review also illustrates that the culture and managerial organisation can be at variance to that existing in the UK and still result in effective incident management. The risk of creating a less effective decision-making system by moving towards a normalised business or commercial operating style is not so great as some traditional fire service managers may caution. This leads to a conclusion that there is no one or perfect way, rather evolution and experimentation with established best practice options from a range of industries and services is practical and may offer a more optimised arrangement than currently exists.

Transferring these conclusions into a UK context allows the examination of options to improve critical decision-making. Three case studies are reviewed in Chapter 4, which reflect the observed weaknesses in the fire service systems used in the UK. Combining the common features found internationally and in the UK is then used to help postulate an improved operational decision-making system.

CHAPTER THREE REFERENCES

1 Fayol, H. [1949], *General and Industrial Management*, Pitman, London.

2 Taylor, F.W. [1911], *The Principles of Scientific Management*, Harper and Row, London

3 Urwick, L. [1958], *The Elements of Administration*, Pitman, London.

4 Adair, J. [1971], Training *for Decisions,* MacDonald, London.

5 Adair, J. [1983], *Effective Leadership*, Pan, London.

6 Prior, P. [1959], *Leadership is not a Bowler Hat*, David Charles, Newton Abbot.

7 Herzberg, F. Mausner, B. And Synderman, B. [1960], *The Motivation to Work,* John Wiley, Chichester.

8 Drucker, P. F. [1968], *The Practice of Management,* Pan, London.

9 McGregor, D. [1960], The *Human Side of Enterprise*, McGraw-Hill, London.

10 Mintzberg, H. [1973], *The Nature of Managerial Work*, Harper and Row, London.

11 Kast, F.E. and Rosezweigh, J.E. [1974], *Organization and Management: A Systems Approach*, McGraw-Hill, London.

12 Davis, D.T. [1980], *The Use of Industrial Decision-Making Methods in the Fire Service,* Cheshire Fire Brigade. Unpublished.

13 McGregor, D. [1960], The *Human Side of Enterprise,* McGraw-Hill, London.

14 Stewart, R. [1970], Managers *and Their Jobs*, Macmillan, London

15 Thompson, J.L. [1994], Strategic *Management Awareness and Change*, Chapman and Hall, London.

16 Fiedler, F.E. [1967], A *Theory of Leadership Effectiveness*, McGraw-Hill, London

17 Maslow, A.H. [1970], Motivation *and Personality*, Harper & Row, London

18 King, B., Strenfert S. and Fielder, F.E. [1978], Managerial *Control and Organisational Democracy*, John Wiley, Chichester.

19 *As Chapter 2 reference 7*

20 Reuben, D.F. and Favreau, H. [1969], *Fire Service Management*, Donnelley Corporation, New York.

21 Brunacini, A. [1985], *Fire Command*, National Fire Protection Association, Quincy MA.

22 Audit Commission, [1995], *In Line of Fire*, TSO, London.

23 Mills, D.Q. and Friesen, B. [1992], *The Learning Organisation,* European Management Journal, Vol.10, No.2, Pages 146.

24 Lock, D. (Ed.). [1992], *Handbook of Management,* 3rd Ed., Gower Aldershot.

25 Drucker, P. F. [1987], *The Frontiers of Management,* William Heinemann, London.

26 Munro Associates, *Achieving Quality Standards A Step-by Step Approach Guide to BS 5750/ISO 9000,* (London, Pitman, The Institute of Management, 1993) & D. Hutchins, Achieve Total Quality (Hemel Hempstead, Directors Book, Fitzwilliam Publishing Ltd., 1992).

27 British Standards Institution, [1991], *Quality Management and Quality Assurance Standards Parts 2,* BS5750, *Generic Guidelines for Application of ISO 9001, ISO 9002 and ISO 9003,* TSO, London.

28 British Standards Institution, [1991], *Quality Systems Part 8, Guide to Quality Management and Quality System Elements for Services,* BS5750, EN 29004-2: 1993, ISO 9004-2:1991, TSO, London.

29 Southworth, G. [1997], A *Taste of TQM,* Fire Engineers Journal, Vol. 57, No. 191, Pages 23-24, Institution of Fire Engineers, Leicester.

30 Drucker, P.F. [1998], Management: Tasks, Responsibilities, Practices, Heinemann, London.

31 Brehmer, B., Ramussen, J., and Leplat, [1991], *Distributed Decision-Making: Cognitive Models of Co-operative Work,* J Wiley, Chichester.

32 Burgoyne, J., Pedler, M. And Boydell, T. [1994], Towards *the Learning Company Concepts and Practices,* McGraw-Hill, London.

33 Bass, B., and Avolio, B. [1994], *Improving Organizational Effectiveness through Trans-formation Leadership,* Sage, New York.

35 Office of the Deputy Prime Minister. [2002], *The Future of the Fire Service: Reducing risk, saving lives, The Independent Review of the Fire Service*, ODPM, Wetherby, West Yorkshire.

35 Kelly, M.P. [1994], *An International Comparison of the Fire Service's Role in the Management and Control of Major Incident and National Disasters*, Brigade Command Course Project Report, Fire Service College, Moreton-in-Marsh.

36 Kaplan, L.G. [1996], *Emergency and Disaster Planning Manual,* McGrant Hill, New York.

37 Ministry of Home Affairs, [1996], *Crisis Management and Scenarios.*, Crisis Management and Fire Service Directorate, The Haag, Netherlands.

38 *Second International Conference, Local Authorities Confronting Disasters and Emergencies*, (April 22, 23 & 24, 1996 Proceedings, Amsterdam).

39 Davis, D.T. [6 April 1994], *Field Notes Rotterdam Visit,* Cheshire Fire Brigade.

40 Davis, D.T., *Exercise Europe '96,* (Attendance Report, 21-25 September 1996, Cheshire Fire Brigade.)

41 Lambrecht, V., *TUIS, International Chemical Emergencies Conference,* (Ludwigshaven, April 1996).

42 Kulling, P. & Nyman, U., *International Chemical Emergencies Conference*, (Swedish Emergency Response Centre, 18-19 April 1996).

43 International Fire Service Training Association. [1983], *Incident Command System*, Fire Protection Publications, Oklahoma State University.

44 DiNemmo, Drysdale, D. [1995], *Handbook on Fire Protection Engineering*, NFPA, Quincy, Maryland.

45 Walsh, C.V. [1970], *Modern Guidelines for Fire Control, Theo* Gaus' Sons Inc. New York.

46 International Fire Service Training Association [1989], *Fire Department Company Officer*, 2nd. Imp., Fire Protection Publications, Oklahoma State University.

47 Lavah, P.R. and Stoffel, R.S. [1991], *Blueprint for Community Emergency Management*, The Emergency Response Institute, Inc., Olympia, W A.

48 Clark, W.E. [1994], *Fire Fighting/ Principles and Practices;* Dun Donnelley Publishing Corp. New York.

49 McKinsey and Company. [2002], *Studies of New York Police Department's and New York Fire Department's response to the World Trade Center Attack*, City of New York, NY.

50 Chief Cruthers. [2002], *Presentation to CTIF XXIII International Symposium 19 September 2002*, Vienna, Austria.

51 Titan Systems Corporation. [2002], *Arlington County After Action Report on the Response to the Pentagon*, United States Department of Justice, Office of Justice Programs, Office of Domestic Preparedness, Washington, DC.

52 Chief Plaugher. [2002], *Presentation to US/UK Symposium 18 March 2002*, Alexandria, VA.

CHAPTER FOUR

Key Case Studies

4.1 Introduction

Earlier chapters have outlined both from an historical and legislative background the importance of auditable decision-making and how that decision making process might be improved using modern business methods. To illustrate the importance of these factors three case studies are cited to exemplify and demonstrate areas of weakness. The author was present as Incident Commander at each incident. In addition, since all three involved hazardous materials, commonly used emergency action procedures are considered and reported upon separately in the appendix.

In one case, that involving Associated Octel, the incident narrative supplied by the author has, together with five other contributions from experienced police, prison, military and an airline commanders been academically examined as part of a specific study related to the psychology of command as an aid to developing command skills for aspiring commanders[1].

4.2 Shell Stanlow,

Chlorofluoroaniline (CFA) Reactor Explosion

At 03:24 hours on Tuesday 20 March 1990 Cheshire Fire Brigade Control[2] was advised that an explosion had occurred at 03:22 at the Shell Stanlow (CFA) Plant. Standing instructions[3] required a pre-determined attendance of 15 pumping and other special appliances. The fire resulted in a number of injuries and ultimately one death, with considerable damage to the CFA Plant.

The plant control room staff had noted a rapid rise in temperature and pressure in the batch reactor and despite their action in applying additional cooling an explosion occurred causing extensive damage to the plant and injuries to six staff. In particular the control room was extensively damaged and key staff in the room injured and confused. The impact of a control room loss is significant as the inquiry into tragic loss of 167 lives on Piper Alpha in 1988 reported[4].

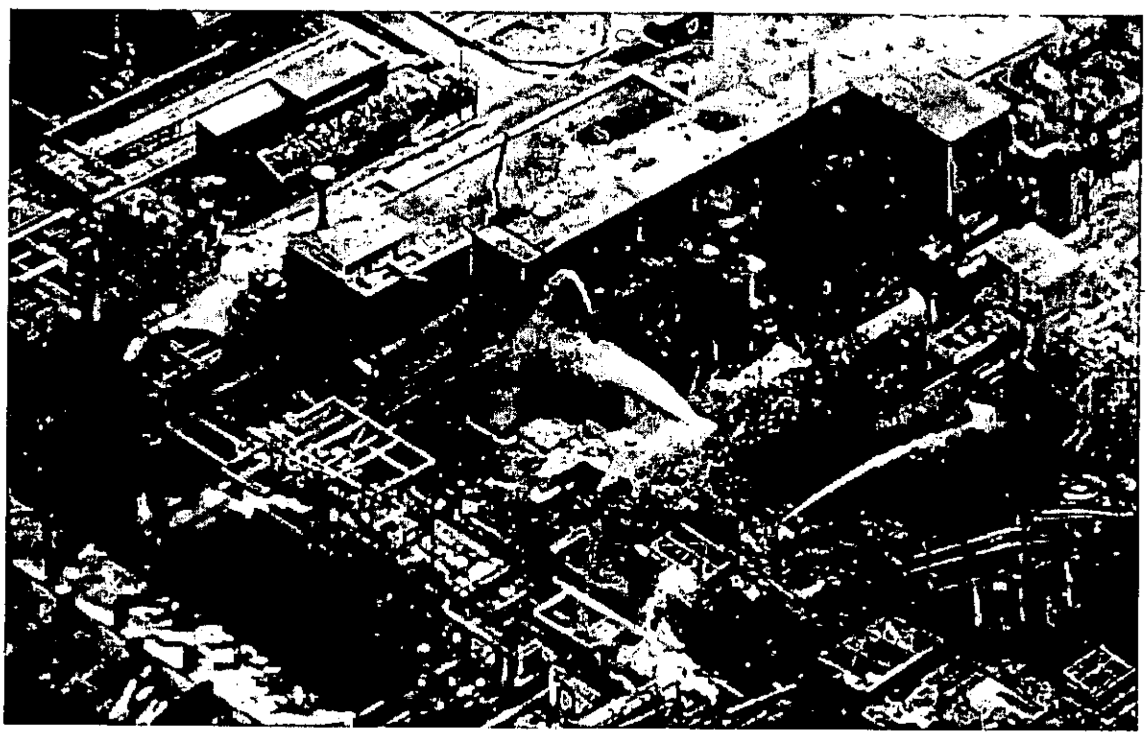

Figure 4.1 Fire at Shell, Stanlow Refinery (Aerial View)
Aerial view showing destruction of reactor area.

The batch reactor was in an open range petrochemical production plant consisting of reactors, process and distillation vessels, with associated pipe work over ground and four upper operating platforms to a height of 30 metres and covering an area of 25 x 35 metres. The plant produced chemical intermediates for use in the pharmaceutical and agricultural industries.

Arriving fire crews found a serious fire already spreading to adjacent plants by radiated heat, running burning liquids and fragments from the explosion. The top of the reactor was found 220 metres away and the barrel of the reactor was completely flattened. A major firefighting attack was mounted using national foam concentrate stocks from a specialist company located some 80 miles away from the site. Environment Agency monitoring of the off-site effects from firefighting water was a further requirement*

The explosion itself had extensively damaged the plant control room. The loss of the control staff, due to injury, left firefighters without essential information because no prior detailed information existed on the number, types and quantities of chemicals involved. This was partially due to the plant involved being used for batch rather than continuous manufacturing and the consequent hazards presented to health both on and off-site could not be obtained. In addition knowledge of the exact stage of chemical reaction could not be defined since instrumentation had been damaged and key staff injured and removed from site. Local information immediately available indicated that firefighting uniform, with gloves, were adequate and that personnel committed into the plant and directly exposed to the chemicals should additionally wear breathing apparatus and a protective chemical suit. There was little detail on the site's general risk information card, partly because of the complex nature of the site.

* Environment Agency - Successors to the National Rivers Authority, Her Majesty's Inspectorate and Pollution and Waste Regulation Authorities - River House, Waterside, Drive Aztec West, Almondsbury, Bristol BS12 4UD

What was quickly established was that large quantities of Xylene* and Toluene* were freely flowing into pipe tracks that run around the site. The fire was ultimately located as having commenced[5] at a reactor, number R7601, which was not involved in a continuous process, but was used for individual batch processing. Some of the chemicals involved in the reaction process were subsequently, after the fire, found to be 6618 kg of liquid dimethyl acetamide, 37.5 kg of solid trimethyl ammonium chloride, 3375 kg of solid potassium fluoride and 4850 kg of liquid dichloronitrobenzene. Thus, unknown to the fire service, a significant carcinogenic hazard had existed. Table 4.1, compiled by the author, illustrates some of the range of washes, solvents, catalysts and products involved and illustrates information that should have been available prior to the incident.

During the firefighting operations a number of personnel were committed close to the plant to apply cooling and foam making jets. Subsequently, all personnel were subjected to medical surveillance, which required them to provide blood and urine samples. In the weeks that followed the incident, a number of personnel indicated they were suffering various symptoms as a result. One month after the incident one firefighter suffering from a chest complaint had an X-ray that showed a shadow on his lungs. Five personnel complained, over a week after the incident, of mouth ulcers. One member of staff subsequently died suffering a heart attack following surgical complications to treat a fractured leg. A study, post-incident, revealed that the cause of

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* Xylene. Mixture of Xylene isomers $C_6H_4(CH_3)_2$ and ethyl benzene $C_6H_5C_2H_5$. Colourless liquid. Flash point 22.8°C. Auto. Ignition Temp. 464°C. UN number 1307 Specific gravity 0.86 to 0.87 Vapour density 3.66

* Toluene. $C_6H_5CH_3$. A colourless, flammable and toxic liquid. Flash Point 5°C Auto. Ignition Temp. 535°C UN number 1294 Specific Gravity 0.87 Vapour density 3.18

the explosion was a previously unknown exothermic reaction and that there was an off-site impact.

CAS No.	SUBSTANCE	B.P.°C	F.P.°C
611-06-3	2.4 DICHLORONITROBENZENE	258	112
127-19-5	DIMETHYL ACETAMIDE	165	70
75-57-0	TETRAMETHYLAMMONIUM CHLORIDE	-	-
7447-40-7	POTASSIUM CHLORIDE	1420	-
108-88-3	TOLUENE	111	4
67-56-1	METHANOL	65	12
367-21-5	3 CHLORO 4. FLUOROANALINE	230	149
25167-93-5	MONOFLUORINATED CHLORONITROBENZENE	-	-

TABLE 4.1 CHLOROFLUROANILINE [CFA] PLANT PRODUCTS

This was an incident where, after the event, a substantial amount of relevant information was uncovered and demonstrates that for petrochemical plants it is extremely important to maintain a robust record of information that will be available for firefighting crews immediately upon arrival even if the central control room is damaged or destroyed.

Lord Cullen who led a formal inquiry into the Piper Alpha disaster noted that on the platform the initial explosion put the main power supplies and control room out of action. The system for control in the event of a major emergency was rendered almost entirely inoperative. He suggested that even though remote but potentially hazardous events had been envisaged there remained a need for a systematic assessment, in the form of a safety case, to help demonstrate potential major hazards risks had been identified and appropriate controls provided. In the Piper Alpha incident control room staff were also injured and confused by the initial explosion. One was knocked unconscious to the floor and the other thrown violently across the room. The control room itself was devastated with debris and damaged equipment. The designated emergency operating system, which included a general alarm to all staff and immediate response by a team of key personnel, was consequently almost entirely inoperative. The loss of the system meant little command or control was exercised over the movement of personnel.

Parallels exist to the Shell Stanlow incident. At that incident again it was the plant staff that had primary knowledge of the current state of the batch process and, more importantly, the hazards from the substances involved. However, since they were injured and were removed from the site the valuable knowledge they had and the safety control system for the plant was rendered inoperative. This demonstrates that not only must all the necessary information be protected and available, it must also be in a user-friendly form for other, expert and non-expert users. Without that information and control and command system decision-making is extremely difficult and safety critical events have a real potential increase in risk.

The provision of information for such plants where unexpected and unusual events may occur is, of course, extremely relevant to brigades. In this case, had a fuller range of product information been available and the hazards likely to be encountered by a significant number of firefighters known, this would have resulted in a significantly different tactical approach. This case study confirms the findings of the HSE report of the fire at Brightside Lane, Sheffield, in 1984, where significant information failures were identified[6] including the difficulty of recording actual decisions made at the incident and demonstrates that, in this respect, little had changed between 1984 and 1990.

At Brightside Lane a very large warehouse and transit shed were destroyed over two days with several hundred firefighters being engaged for over six days. Rapid fire spread, the inability to identify what materials were involved, lack of communications and information about water supplies and health concerns subsequently raised by firefighters all contributed to an operation that was not best controlled. The HSE report, which also looked at off site asbestos risks to the public arising from the smoke plume, identified that owners or occupiers of similar large buildings needed to obtain appropriate information about potentially hazardous materials and make this readily available to the emergency services.

The HSE had noted that the fire service acted with apprehension and uncertainty unaware as to what was exactly involved. Better information would have helped the decision process since in some cases the information held was six years old and did not, for example, reveal the inadequacy of the water supplies. In addition despite exemplary provision of equipment there were identified failures to follow accepted designated fireground tasks and widespread departures from breathing apparatus practice. Command, control and communications appeared to fail and linked to the lack of up-to-date information this created the serious difficulties identified.

The need to enter any 'at risk area' to gain information on hazardous materials or weaknesses that might allow fire development through close visual observation, which are required for decision-making, poses considerable physical risk to the personnel involved. Reducing this risk using other visual reconnaissance methods, which are available, such as consideration of remote and robotic vehicle information gathering is discussed in a later chapter.

4.3 Warrington Gas Works Terrorist Explosion

Shortly before 04:00 hours on Friday 26 February 1993, close to Warrington Fire Station a loud explosion[7] alerted firefighters to a fire that had occurred at the adjacent gas works. Over 709 telephone calls were recorded concerning the incident.

The site was of 7.6 hectares containing on one side three low-pressure gasholders of total capacity of 5,660,000 cubic feet of natural gas, and on the other side in a fenced compound, ten high-pressure [350 psi] natural gas* storage cylinders and distribution valves containing a total of 500,000 cubic feet of natural gas. The premises themselves were listed as a major hazard [CIMAH[8]] site because of the volume of stored gas and remote monitoring facilities installed. Opposite the high-pressure units was a public housing estate, which included the multi-storey homes of elderly residents.

Immediately after the arrival of the firefighters one of the low-pressure gasholders suffered a catastrophic failure of the roof with the gas venting vertically. Whilst

* Natural gas. Methane 88-97%, other hydrocarbons, carbon dioxide and nitrogen 3-12%. Molecular weight mean 17:18g/mole. Lower flammability level 5.0 upper level 15.0. Boiling temp. 109° K. critical temps. 191°K. Heat of combustion 50,010kJ/kg.

substantial, the radiant heat caused no injuries, and only the blistering of the surface of the adjacent and relatively undamaged gasholder that was half full.

All three of the low-pressure gas holders on site were of the common telescopic construction, whereby gas is contained within the holder by means of a water basin housed in a below ground pit. The severely damaged holder subsequently rapidly descended into its pit after the complete evacuation of the gas into an aerial fireball. Investigations revealed that an explosive device had been placed on the upper part of this vessel.

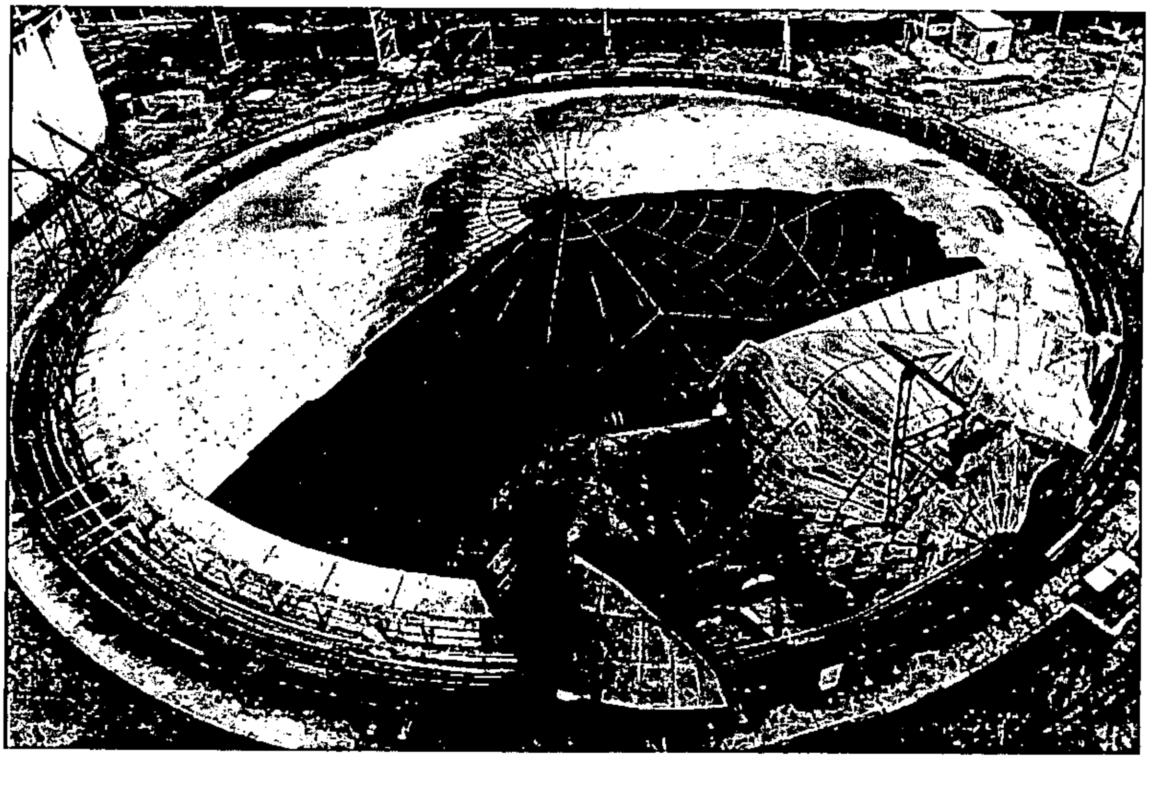

Figure 4.2 Warrington Gas Works (Roof Failure)

A further device had been placed under the high-pressure storage vessels. Damage caused by the explosion of this device resulted in the severe deformation of the high-pressure storage vessel holding cradle but no structural failure occurred.

Advice regarding the determined safe evacuation distances around this particular high hazard site were obtained from the safety plan, developed from an industrial accident scenario not an act of deliberate sabotage, indicated that little hazard was predicted to exist beyond the site boundary. Despite this preplanning assessment the Incident Commander determined that the risk posed from a sudden release of natural gas in a fireball was significant enough to order an evacuation of adjacent properties. During the incident, information was not available of engineering assessments of the level of hazard when malicious explosions were the initiating event. On this occasion the absence of such advice was noted as an information shortfall for future reference.

Subsequently, further research that was undertaken, by both a private consultant[9] and the University of Central Lancashire[10], to identify the appropriate levels of evacuation in the likely worst-case hazard scenarios. Details of this study are contained in the gas dispersion appendix. The first survey indicated that the additional hazard posed was much greater than that advised initially by British Gas to satisfy the then CIMAH regulations and it was clearly possible for a relatively modest breach of containment to create a jet flame capable of causing damage well beyond the site boundary. Table 4.2 indicates the scale of a likely critical breach from either of the two low-pressure gasholders on site. There was also a clear possibility of a fireball of significant energy being formed. A separate and a distinct area of concern to fire brigades are the risk created when flammable gas is released into the atmosphere. Dispersal patterns, under these circumstances, place the gas within its flammable limits.

Gasholder	1	2
Maximum total volume, [m^3]	12,687	16,935
Critical diameter of the breach, [m]	4.7	5.1
Total area of the critical breach, [m^2]	16.3	19.8
Critical volume of the gas, [m^3]	6,090	8,130
Critical mass of fuel, [kg]	2,820	3,765
Total outflow time for critical breach, [s]	15.6	17.1

TABLE 4.2 PARAMETERS OF A CRITICAL BREACH [UCLAN[10]]

The second element of the research project undertaken by the University of Central Lancashire took these conclusions further. This report considered not only a terrorist attack on a natural gas holder but also on a liquefied propane or butane storage vessel. Again, the studies revealed that there could be the development of a considerable fireball and that under such circumstances a risk did exist of deaths occurring some distance away from the storage vessels. This information has been developed and incorporated within a further study relating to fire service plume monitoring. This has added to the available body of information and resulted both in a reconsideration of effective evacuation distances for such storage vessels and the redesign of site operations.

If the vapour cloud is ignited immediately, it may burn as a rising sphere, usually referred to as a "fireball". Rapid combustion of vapour clouds as fireballs has been observed in a number of incidents. The fireball is usually formed if the flammable cloud is fuel-rich, so those non-premixed regions of it burn in a diffusion regime.

The main parameters to be predicted for assessment of hazards from a fireball are:

- Fireball diameter
- Fireball duration
- Thermal flux at the fireball surface
- Heat radiation from fireball at different distances
- Hazardous zones corresponding to various thermal fluxes

Three cases were chosen for further analysis with the gasholder supposed to be filled to its full capacity before the accident, after which it telescopes down until all the gas is released into the atmosphere:

- **Case 1**. Fireball of total fuel mass of **5 tonnes**. This corresponds very approximately to the lower limit of possible flammable fuel quantity after the rapid release.
- **Case 2**. Fireball of total fuel mass of **10 tonnes**. This corresponds to severe damage to either gasholder with all the fuel released into the atmosphere.
- **Case 3**. Fireball of total fuel mass of **20 tonnes**. This is the worst possible case when both gasholders are damaged simultaneously. The separation between the gasholders is small compared to the typical fireball diameter (about 100 m), so it is supposed that fuel clouds escaping from both gasholders form a single fireball.

The characteristics of the fireball are summarised in Table 4.3. It can be seen that in all cases the fireball diameter exceeds 100m and fireball duration is about 10s.

Case	1	2	3
Mass of NG, [kg]	5,000	10,000	20,000
Maximum fireball diameter, [m]	103	129	162
Total fireball duration, [s]	7.5	9.0	11.0
Height of the fireball centre, [m]	77	97	121

TABLE 4.3 PARAMETERS OF THE FIREBALLS IN CASES 1-3 [UCLAN[10]]

Using these results the impact of the fireballs were then calculated and are shown in Table 4.4. Translated into practical fire service personal risk values, the original reason the information was requested at the Warrington incident, the hazard becomes evident.

This data show that the fireball constitutes a very serious hazard because its thermal radiation can be dangerous for people at distances of up to 160 - 350 metres. Radiation-induced ignition of wood can occur at distances of up to 90 - 155 m.

The information available to the fire service at the time of the incident was seriously flawed in estimating the likely worst-case scenario, and the company, at the time of the incident, had difficulty locating an engineer qualified to consider possible catastrophic failure of the storage vessels. Powerful lessons from previous experience underlie these comments. Again Lord Cullen after the Piper Alpha disaster in 1988, when 167 lives were lost following fire and explosion, not only recommended changes to the entire

Zone	Expected effect	Distance from centre of gasholder, [m] (Heat flux, [kW/m^2])		
		Case 1 (5,000 kg)	Case 2 (10,000 kg)	Case 3 (20,000 kg)
1	Wood ignition	91 (26.7)	118 (26.6)	155 (26.4)
2	75% lethality	-	-	35 (69.3)
3	50% lethality	-	31 (65.1)	65 (57.2)
4	25% lethality	23 (63.3)	54 (53.7)	90 (46.5)
5	10% lethality	43 (51.6)	72 (44.6)	109 (39.4)
6	1% lethality	66 (38.0)	99 (33.0)	144 (28.9)
7	First degree burns	126 (16.9)	179 (14.5)	252 (12.4)
8	Pain threshold is reached for unprotected skin by the end of the exposure	165 (10.0)	250 (8.5)	345 (7.0)

TABLE 4.4 HAZARDOUS ZONES SUMMARY FOR NATURAL GAS FIREBALLS [UCLAN[10]]

safety organisation for the offshore industry but also emphasised the critical nature of the safety case and overall control process at major emergencies. The use of predictive information in such a scenario as this is clearly of the utmost importance for public safety. Information on fireballs, which could be directly used in this type of case, is readily available from primary scientific sources. The need for the fire service to have a relevant database that allows it to be involved and contribute meaningfully at the pre-planning stage is also evident from this incident.

4.3 Associated Octel, Ethyl Chloride Reactor Spill and Fire

On the 1 February, 1994 at 20.23 hours, a reactor solution, see Table 4.5, was released from a re-circulating pump at the base of a 25 tonne ethyl chloride reactor vessel at the Associated Octel Company site in Ellesmere Port, Cheshire.

CAS	UN	LIQUOR PRODUCT	EAC	B.Point	F.Point
75-00-3	1037	ETHYL CHLORIDE 90-95%	2WE	12.5	-50
7647-01-0	1050	HYDROGEN CHLORIDE 2%	2RE	-85	-
16603-84-2	1756	ALUMINIUM CHLORIDE 0.1-1.5%	4X	-	-

TABLE 4.5 LIQUOR PRODUCTS AT ASSOCIATED OCTEL [HSE[11]]

A dense white cloud was produced which began to move off-site. The fire brigade attendance was initially directed to provide cooling around the reactor vessel and to project water sprays to help dilute vapour. At 22:08 hours the flammable vapours of the ethyl chloride ignited, causing a major spill fire, which was extremely intense around the base of the reactor. This fire continued to burn for a considerable period of time and was extremely hazardous to all the firefighters involved. Adjacent to the reactor site was a chlorine plant and within the general arrangements on site, were sodium and chlorination plants and a lead alkyl plant manufacturing tetramethyl and tetraethyl lead used with associated compound blending materials to produce anti-knock products for the petrochemical industry. There was a considerable exposure hazard with 17 pressurised vessels containing chlorine, the nearest vessel being approximately 40 metres away from the ethyl chloride reactor.

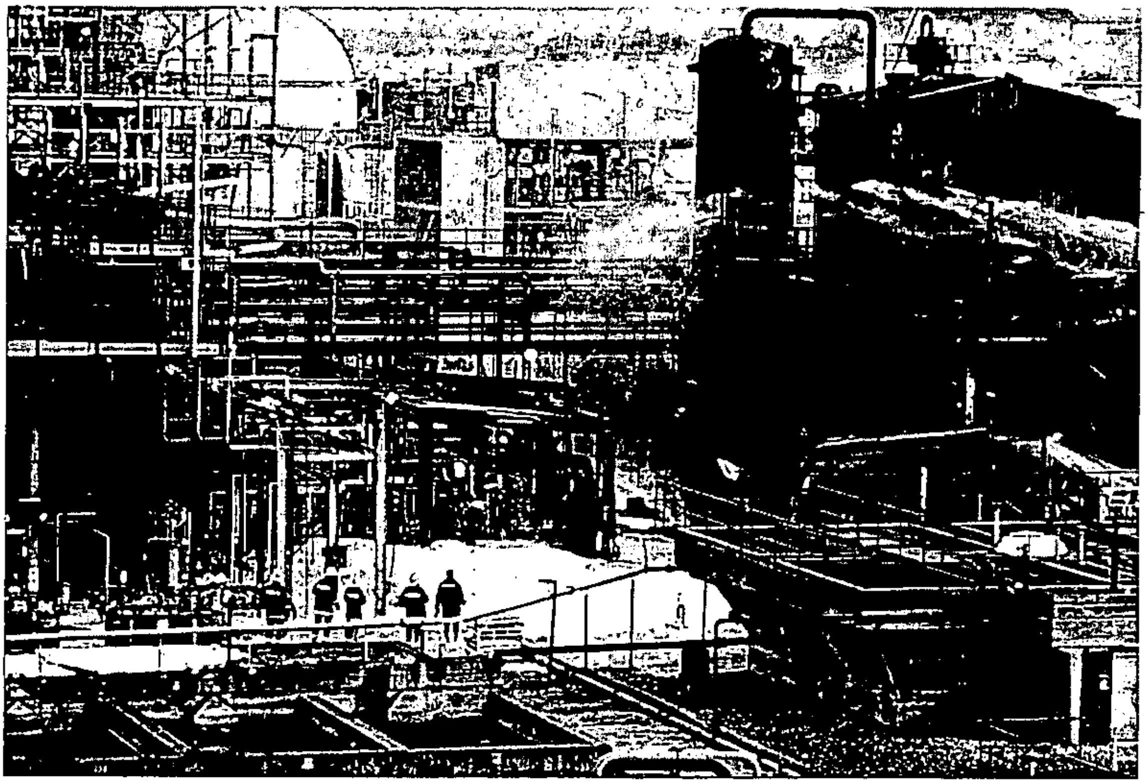

Figure 4.3 Fire at Associated Octel (EC Reactor)

On arrival, firefighters using information from on-site personnel dressed in chemical protection suits and breathing apparatus, entered the cloud and sought to isolate the plant and stop the flow. Subsequently, at 21:10 hours, a manager arriving on-site recommended that foam should be laid to inhibit vapour release. Whilst this process was underway the ethyl chloride ignited and flashed back to the pump area alongside the reactor. This fire burned extremely fiercely with three large vessels containing quantities of reactants remaining within the burning area. One of these vessels had an intumescent cladding designed to withstand fire engulfment for about two hours. At 23:00 hours, as a further precaution, a partial shut down of the entire factory was started and neighbouring factory sites were given advice to start removing personnel from nearby areas.

Off-site a full procedure was already underway to try to alert individuals to the possible risk as the plume continued to grow from the combustion. There were, subsequently, a small number of complaints of ill health and some staff did display symptoms consistent with exposure. Far more importantly there was considerable public alarm, which resulted in the Health and Safety Executive [HSE] conducting a full enquiry into the occurrence. The subsequently published HSE report[11] indicated that the risk assessment process had not considered the particular dynamic elements that had occurred. In addition, undue focus had been given to one major hazard (the risk of an environmental toxic cloud) and this over-concentration had created the situation where other hazards, such as the highly flammable nature of the solvent, were overlooked. In particular, the HSE concluded that there had been improper use of the Hazchem code [2WE] [See Appendix for further explanation] for a storage facility. This code is intended for material being transported and here resulted in the use of water spray on a pool of highly volatile flammable material with a boiling point close to ambient temperature.

4.4 Health and Safety Executive Report into The Chemical Release at the Associated Octel Company Limited - Action by the Cheshire Fire Authority.

One outcome, particularly relevant to the fire service, was that having witnessed and assisted in the investigation on behalf of the Cheshire Fire Authority a series of ten actions to improve operational response to major industrial incidents were proposed. These are contained on page 45 of the official HSE report and reproduced below.

The Cheshire Fire Authority's previous concerns about the handling of industrial major hazard emergencies were reinforced by this incident. These concerns centered on the provision of information, firstly to the public and secondly for those involved in handling the emergency. The Chief Fire Officer has taken the following actions:

(a) lessons learned from the incident have been discussed at a liaison panel providing an opportunity for the Fire Service to discuss initiatives with members of the Cheshire chemical industry and others involved in the planning and provision of the emergency response;

(b) having reviewed the policy of evacuation or shelter for the local population, the Fire Brigade has produced a leaflet and video promoting a shelter policy and explaining the action to be taken in the event of a major accident. The video is for use in schools and the leaflet is being distributed to all residents within North Cheshire and to those near similar major hazards elsewhere in Cheshire;

(c) introduced a new electronic mailing facility which will allow the Fire Brigade to quickly update local TV and radio stations, who have agreed to broadcast the shelter message and other information during an emergency;

(d) secured agreement to use the Cheshire County Council "information point" system,

which is a staffed 24-hour telephone contact point, as an emergency "hotline" which will allow callers to obtain the latest information personally;

(e) following successful trials, there are plans for electronic mailing to link the emergency services, DOSEC and the site operator;

(f) run trials involving a lap-top computer in the cab of the fire fighting vehicles, on methods of storing and quickly retrieving hazard information for fire fighters. More detailed technical information is required for complex major hazard sites and Cheshire Fire Brigade have initiated a research programme into what can be provided. Currently available expert management and hazard information systems have already been reviewed and new systems may be developed;

(g) given consideration to introducing a "tiered" Brigade response to industrial incidents to encourage site operators to call the Fire Brigade more readily. The tiers suggested are:

[i]incidents occurring on-site with no potential to go off-site;

[ii] incidents with the potential to go off-site but without major risk of harm to the public; and

[iii] incidents which are likely to go off-site with potential to harm the public.

There are both advantages and disadvantages, which are to be carefully weighed before implementation;

(h) reviewed the current site warning arrangements and is encouraging the use of sirens throughout Cheshire to a standard specification to avoid confusion by the public

(i) begun to review, with a number of agencies, Cheshire Fire Brigade's overall

response to environmental risk incidents and will shortly enter a joint partnership with the National Rivers Authority for dealing with waterborne pollutants; and

(j) he has commissioned the Defence Research Agency to create an operationally viable robotic vehicle for use in major incidents.

4.5 Evaluation of Case Studies

All three case studies occurred on hazardous sites subjected to legal enforcement and demonstrate a range of difficulties concerning information flow. In each case there was information available but it was not in a suitable form to aid fire service decision-making. Some information accessed was not understandable or did not arrive in time to be acted upon in terms of the development of the fire process. Some information was inaccurate and had a real potential to harm. Most of information available was unsuitable for public and fire service use simply because it was not in a user-friendly format when presented on a fireground. These case studies, derived from personal experience of specific incidents, together with the support for the conclusions offered by externally independent reports, suggest decision-making and data support for the fire service can be improved. This supports the hypothesis that to improve the management of the fireground a staged change and technically improved communication strategy is necessary within the organisational culture. The necessity of a balanced information flow, which does not overload the Incident Commander but ensures that he is in possession of all major relevant facts (here, this could include procedures for providing information to correct the miss-labelling of materials), is developed further within this thesis as part of its findings and recommendations.

In evaluating the case studies a number of key themes emerge. Overall these may be characterised as the missing of safety critical information at times when positive action is essential if risk is to be reduced. The information loss itself may occur either at the pre-planning stage or during the actual incident. Similarly, information loss may arise because of an absence of good analysis, poor presentation of available data or the failure to predict all likely events. These losses may result from weaknesses in understanding the specific circumstances involved and hence the potential hazard or from weaknesses in understanding the products, processes or materials involved. Research and the consequent systematic assessment and identification of risk controls systems are also likely contributors to information loss if they are not effectively conducted.

The complex nature of some hazards does require expert interpretation, using for example chemical or engineering scientific foundations, and there is a requirement for subsequent translation and communication into suitable presentations for non-expert users or alternatively robust provision of that expert advice. The ability of the decision management system to withstand catastrophic events like explosions and acts of terrorism is also exemplified, and this extends the requirement for worst case planning scenarios to go beyond the normally predicted industrial failures.

Many such events are often fast moving and the immediate observed hazards can create false priorities suggesting inappropriate responses with the real risk being far less apparent and the visual signals misleading. There is also the real danger of misinterpretation when events that appear to be similar to previously experienced events have in fact originated from completely different causes and may therefore evolve in a completely different way.

Once engaged in operations, decisions need to be recorded and communicated efficiently so that scenario planning is updated and remains accurate. Maintaining recordable decision sequences for subsequent audits is an important feature given the stated legal responsibilities. These arrangements also assist command and control, as systems are constantly being evaluated and monitored.

The offsite impacts, with the allied public interactions, also need effective evaluation, again based on systematic worst-case scenario planning, so that responses designed to mitigate or prevent harm are efficiently applied. The whole process can be aided by technology subject to it being able to withstand the rigours of operational demands and present information in logical, timely and easily recognised format.

It is suggested from this evaluation that improvement in the operational decision-making process could arise if the following specific summarised activities received greater attention.

- High quality risk analysis
- Methods to effective presentation of all available data
- Accurate event prediction
- Sound understanding of the data and manufacturing processes involved
- Accurate evaluation of actual incident circumstances
- Identification of potential hazards both prior to and during incidents
- Pre-planning with effective data research
- Continuous systematic assessment of risk
- Identification of risk control systems

- Engagement of sector knowledge specialists
- Translation of specialist knowledge for various end users
- Provision of a robust information system
- Matched dynamic response to evolving event situation
- Process based identification of misleading information
- Accurate prioritisation of actions to meet evolving scenarios
- Avoidance of responses based upon superficially similar events
- Recording of command decisions and circumstances
- Continuous monitoring and evaluation of command communication system
- Effective offsite environmental monitoring
- Effective transfer of information to external agencies and the public

Examination of these issues is therefore undertaken in the context first in the decision support systems used in the fire service in Chapter 5 and then with possible decision management tools in Chapter 6 including enhancement of management decision-making using technology in Chapter7.

CHAPTER 4 REFERENCES

1 Flin, R., Arbuthnot, K. [2002], *Incident Command: Tales from the Hot Seat,* Ashgate, Aldershot, UK.

2 Cheshire Fire Brigade, [1990], *Fire at Shell Stanlow Refinery 20th March, 1990,* Unpublished Brigade Report. *

3 Cheshire Fire Brigade, *Operations Group Orders Section 19: Special Procedures, Orders No 19/1, Incidents Involving Large Scale Toxic/Flammable Emissions, Cloudburst/Major Accident Emergency, Includes Appendices 'A' and 'B', September 1995.* Cheshire Fire Brigade.

4 Department of Energy, [1990], *The Public Inquiry into the Piper Alpha Disaster,*Cmd. 1310. TSO, London.

5 Shell UK, [1991], *Fluroaromatices Plant Explosion 20th March 1990,* Investigation Team Report, Unpublished Executive Summary, Shell UK.

6 Health and Safety Executive, [1984], *The Brightside Lane Warehouse Fire, A report of the investigation by the Health and Safety Executive into the effects of the fire at the National Freight Consortium warehouse building, Brightside Lane, Sheffield, on 14 December 1984,* TSO, London.

7 Cheshire Fire Brigade, [1993], *Report and Explosion of Fire, British Gas North Western Warrington, 26th February 1992,* Unpublished Report.*

8 *The Control of Industrial Major Accident Hazard Regulations* [1984], (Statutory Instrument No. 1902), TSO, London.

9 Barnes, W.D., [1993], *An Engineering Review of Gas Storage Vessels of British Gas Longford Works Warrington,* Cheshire Fire Brigade, Unpublished Report.*

10 Makhviladze, G.M., Roberts, J.P., Yakush, S.E., and Evans, D.A. [1994], *An Engineering Survey of Hazards of Gas Storage Vessels,* Cheshire Fire Brigade.

11 Health and Safety Executive, [1996], *The Chemical Release and Fire at the Associated Octel Company Ltd.,* TSO, London.

FOOTNOTE

A significant number of unpublished references are used in this chapter, since the information was gained under the provisions of the Fire Services Act 1947 and cannot be released into the public domain due to commercial or security constraints.

CHAPTER FIVE

Decision Support Systems in the Fire Service

5.1. Introduction

Accurate information is a key requirement for effective decision-making. This Chapter explores decision support systems. Already the legal requirements placed upon fire brigades and Fire Authorities under occupational health legislation[1] and through the extant principal Act[2] have been described. Each requires the securing of information to enable the decision-maker to identify hazards rapidly and formulate possible attack strategies on arrival at the fireground. The provisions of Section 1, Subsection (I), Paragraph (d), of the Act provide direction for, and place a duty on, the gathering of such information. The process, by which specific information on premises is gained under these provisions, is consequently referred to as a 1(i)(d) inspection.

The process of assembling, analysing and presenting risk information to the firefighter is at the heart of the entire operational approach. Guidance on what constitutes good practice is not detailed; rather it remains the responsibility of the individual brigade. This appears unlikely to change. Various practices have consequentially emerged, which reflect, in part, the varying area requirements. Premise information stored and supplied depends upon assessments made by firefighters during 1[i] d inspections, thus the volume and quality of the information stored is largely determined locally.

An Incident Commander at the fireground will also use qualitative risk assessment methods. Qualitative, rather than quantitative analysis, will be used not because of lack of time or facilities to make the necessary calculations but because dynamic risk assessment in fire service practice is used primarily as a basis for decisions.

Quantitative methods are used elsewhere in the fire service to demonstrate, for example, that a particular safety or reliability criterion has been reached in, say, an alarm system. This is a practice that may change as more qualitative data emerges under the process of integrated risk management♦.

Incident Commanders already use some quantitative information regarding, say the amount of toxic vapour escaping into the atmosphere, as and when required. In the fire service risk based assessment has previously been considered in the context of the fireground, as is the setting of priorities for the assignment and the allocation of resources. Determining the appropriate procedures required to reduce and control risk whilst acting dynamically in line with the developing situation generally produces decision-making characterised by naturalistic decision-making strategies. These have been recognised by the Home Office and are now included in the Home Office Fire Service Manual[3].

5.2 Risk Assessment

The identification of hazards and the environment in which the fire service operates provides the basis for risk assessment with the overarching priorities to reduce or control risk and achieve the "as low as reasonably practical" [ALARP] principle adopted in the UK towards risk management.

♦ Integrated Risk Management [IRM] is progressively being introduced during 2003 in the UK. It seeks to move away from prescriptive attendance standards [time bases on area categories with defined numbers of appliances] into assessed intervention or preventative actions designed to reduce fire deaths, losses or property damage. It therefore requires higher data inputs because the emphasis is on human losses, which have qualitative foundations for example in social and economic factors as well as historic previous activity data.

The present approach to risk assumes three broad stages. Firstly area categorisation is used to develop and overall provision throughout a brigade area. This has tended to focus upon the built environment although there are elements of specialised risk analysis for non-fire or large fire situations. Secondly static sites and transient modal movements are assessed and if judged to have potential are subjected to specific risk assessment. Thirdly the dynamic nature of the incident or the precise circumstances actually occurring or likely to occur are continuously assessed in a dynamic way to ensure the decision process reflects actual requirements. Each of these three elements, area, specific or dynamic needs a system of quantified analysis to support decision-making.

Generic guidance is helpful in this regard as it enables the matching of scenarios to safe systems of work, practices or equipment, such as the evaluation of operational tactics with the options of adopting offensive or defensive firefighting for example. However, since operations are often site-specific the requirement is for information within this context. Information overload at complex buildings is a real danger especially in the crucial first moments after arrival. Some premises, notably those involved in the manufacture, storage or handling of harmful materials, may hold significant and essential safety data that requires assimilation within the assessment process by the Incident Commander on arrival at the incident.

Specific risks related to transportation also require consideration. It is also essential to review scenarios relating to acts of terrorism. In the recent past, post September 11th in New York, these risks and the subsequent planning has been referred to in the UK as New Dimension [ND] activity to reflect the new dimension of planning for large scale acts of destruction in which the terrorist is prepared to accept personal suicide. The hazards involved include major structural collapse of building and weapons or improvised devices capable of inflicting harm on large numbers of people from chemical, biological, radiological and nuclear [CBRN] attacks. Confronting likely ND events that present CBRN hazards and the consequent need for mass public decontamination has re-emphasised that fire service decision systems must have intra service and inter emergency service interoperability. These planning issues are further complicated by those dynamic changes, ongoing in any fire or at any incident, such as the release of chemical products or the products of combustion or new substances evolved through chemical reaction or physical decay of structures and materials. Personal and public protection and decontamination of property and structures requires considerable effort in the post attack phase where the engagement of other professions and services can be rapidly expanded. The decision and data support systems are vulnerable at this time unless robustness has been prepared and exercised.

All this activity produces information some of which the Incident Commander needs to assimilate if he is to be able to continuously evolve the operational plan, a plan formulated in the knowledge that the data may contain inaccuracies and/or omissions, and that the set of circumstances faced may be unique. The need is for continuous updating without overload of non-essential material.

The strategy, tactics and operations* adopted on any fireground are therefore usually an extension of existing practices, methods or procedures. Each is designed to counter the

* Strategy is planning and directing the organisation to meet its objectives. Tactics are the deployment of resources to achieve the strategic aim. Operations are the plans, procedures and tasks undertaken to meet the tactical plan.

hazards met in, for example, chemical emergencies by the use of appropriate equipment, such as breathing apparatus[4,5,6].

5.3 Area Risk Assessment

To assess likely operational scenarios, recorded information either on a 'Risk Card' or Vehicle Data Mounted System [VDMS] carried on a first attendance appliance[•] will be reviewed en-route to the incident. The brigade, according to national guidance[7], will have carried out area risk assessment when categorising the initial standard of response. Hitherto UK fire brigades, either in hard copy or electronically, adhered to prescribed national standards, which reflected predominant risk in up to 5 categories of geographic area with an initial response in terms of the pre-determined first attendance defined by the number of appliances, up to 3, and the time in minutes of their arrival at any incident. As already mentioned this whole risk assessment process for fire cover is currently the subject of revision within a process of integrated risk management.

5.4 Pre Response Risk Assessment

Prior information provided to the Incident Commander is critical to the operational decision making process. His assessment and management are key components in avoiding or minimising risk to himself and his crew. Adopting a logical approach to the assembling and testing of acquired planning data is central to this task. Figure 5.1 is a decision tree approach to risk assessment, modified from a system developed by Cambridgeshire Fire and Rescue Service, which aids this process.

[•] Operational judgement is used, in conjunction with national guidance, to identify the number of personnel and type of appliances that should be sent to a premise as the first fire service attendance to any fire. This is referred to as the PDA or pre determined first attendance.

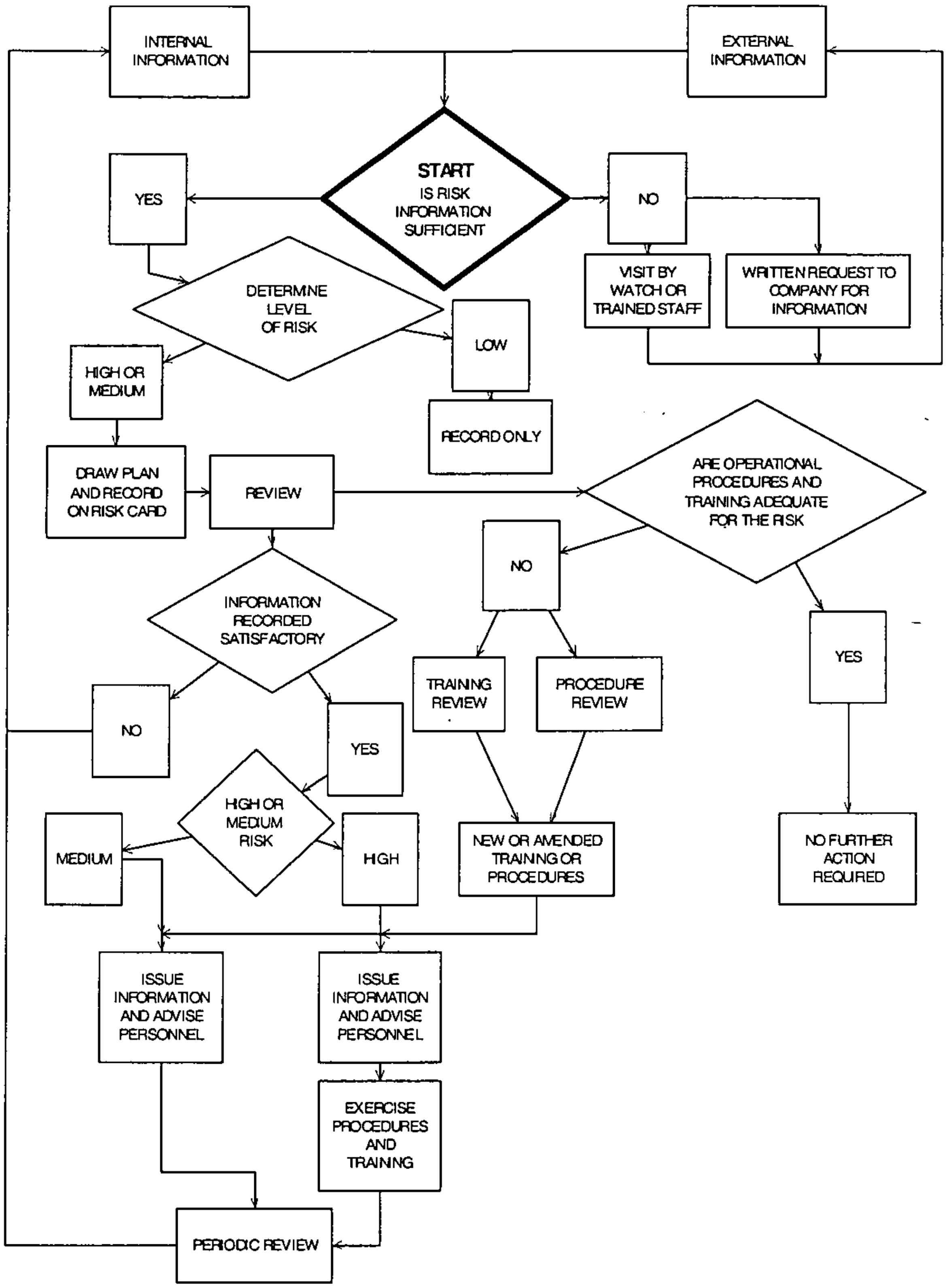

FIGURE 5.1 RISK INFORMATION DECISION TREE

[MODIFIED BY DAVIS FROM AN ORIGINAL BY CAMBRIDGESHIRE FIRE AND RESCUE SERVICE BRIGADE]

The type of decision tree process detailed requires information to be assembled and assessed as likely, or not, to meet immediate needs of the service. Verification visits or further information is requested until a determination can be made, following risk analysis, as to whether the risk presented is low or medium to high. If the risk is judged in either of the higher categories then the details of the hazards are not only recorded but also essential elements, important to crews on arrival, are also transferred to the risk information system on appliances. The information stored can be promulgated to other anticipated users and a practical verification exercise conducted, to confirm planning assumptions. The process also requires evaluation of safe systems of work to meet projected hazards. Any deficiencies found in the evaluation will be addressed either through training, procedures or equipment so providing a designed attack strategy to meet the ALARP principles. This logical and evaluative process offers improvement over the generalised advice nationally available and introduces system reliability and quantification into the overall risk assessment procedure.

This risk assessment process begins when, prior to the inspection, specific information about the premises, available through, for example, fire safety enforcement, is reviewed for relevant hazard data and co-ordination with prescribed operational procedures such as HAZMAT*, is undertaken. Recorded data is also gained from the occupier of the premises or through inspection and is then referenced in a premise specific document generally referred to as a 1[i][d] information*.

* HAZMAT is the term used in the UK and the English-speaking World to manage or refer to incidents involving HAZardous MATerials.

* 1[i][d] is a direct reference to the section within the Fire Services Act (1947) that provides the power to inspect premises for risk information.

Consideration of hazards identified during inspection according to a pre-agreed and determined procedure using the Health and Safety Executive process[8] allows priority criteria to be established for any particular premises and provides a systematic framework for the assessment of risk. This will reduce undesirable decision variations at the time of stress for the incident Commander, i.e. immediate arrival. Firefighters will then be aware of the hazards present during firefighting operations and allow decisions to be prioritised. For example, it is important to consider the likelihood and severity of fire spread. This will require identification and quantification of factors such as the probability of occurrence, the vulnerability of lives at risk, unusual or complex building construction and the storage or manufacturing of materials that are of a hazardous nature or require special procedures and strategies.

Occupiers and owners also provide essential information in various forms. A good example is the placarding systems referred to in the Emergency Action Code Appendix. The relevance of these systems developed for transportation and trade cannot be over emphasised. They offer in the foundation data considerable advice as to product behaviour and necessary personal protection. In a modified format some brigades, London and Cambridgeshire for example, provide static information for arriving crews in the form of notices on a range of harmful substances from biohazards to radiation.

Information is gathered in the following broad areas:

5.4.1 Buildings and Materials

Fire safety inspection knowledge often includes layout plans and drawings. Many of those drawings may be stored using computer aided drafting (CAD) systems that is especially helpful to responding firefighters who may use them to aid rescue and firefighting operations. The capacity to gain, store and deliver these plans to a laptop computer on site with the capacity to produce hard copy is of great significance in large, complex buildings. Development in this field has been rapid and examples exist, such as Strathclyde Fire Brigade's use of three-dimensional CAD property layouts, using coloured zones, to show hazards or important equipment like sprinkler system controls. Pre-planning centres on the understanding of the performance of building materials and construction and recognising from previous experience how different materials interact[9].

5.4.2. Manufacturing Processes

It has already been stated that the contents within a building or the fire load will have a profound effect on the likely fire intensity and spread. A warehouse fire in Chester[10] demonstrated how a substantial fire loading could give rise to a rapidly developing fire front that produced considerable radiated heat and direct flame impingement at a distance. In this case the fire crossed an 18-metre wide street, ignited buildings on the opposite side of the road and produced thermal heat fluxes in excess of the $20kW/m^2$. Exposure to these radiation levels carried a lethality risk. Firefighters also need to know of the presence of any hazardous material or storage configuration, which may present a risk, for reasons of both personal safety and to allow them to devise an operational strategy. This point is well illustrated by the key case studies.

Recording such information and recognising its value is an extremely important part of protecting both the individual and the wider environment. It is therefore necessary to ensure that, within any information system, the specific details of methods or structures designed to help containment of harmful products such as specially constructed bunded floors or interceptor systems for water spillage are given together with their method of use. This approach affords the Incident Commander the opportunity to consider tactics of which he might otherwise be unaware, and therefore be more effective. The brigade should seek to ensure that full and complete records are kept on all sites and that these are available to the first response appliance on arrival. Sometimes this is practical at a site Security Lodge for access by the fire service on arrival. However at many sites, the Warrington incident is a case in point, this is not a viable or reliable option and access to data using risk cards or VMDS is the only robust option.

5.4.3. Hazardous Substances

Chemical emergencies present firefighters with special and specific health and incident management difficulties as the key case studies illustrate. Most UK and American standard reference documents, which list common chemicals and hazardous materials, are held in control rooms. The Emergency Action Code Appendix covers these issues in some detail. Provision also exists for fire control rooms to access the UK National Chemical Emergency Centre electronic data library held at Harwell. Industrial support through the CHEMDATA[11,12] system also assists.

However, CHEMDATA is neither the only nor, possibly, the best of the chemical databases. Individual brigades, such as Cambridgeshire Fire and Rescue, have decided to develop bespoke databases such as Phoenix. Klein[13] outlines many other valuable sources, including Sax[14], a commonly held publication. In addition there will be available within fire control rooms, access to a wide spectrum of locally-generated information as well as that generally appropriate to incidents involving, perhaps, cryogenic liquids and many other materials stored at low temperature and high pressure. Other UK relevant systems are DOSE (Dictionary of Substances and their effects from the Royal Society of Chemistry) and CHEMBANK, both are Silver Platter information products[15].

The behaviour of some materials may determine how and where they are stored. Some materials clearly must not be stored adjacent to, or within the same enclosure as an incompatible item*. Other materials, for example, agro-chemicals, require segregation and special storage facilities to avoid possible environmental contamination*,[16,17]. There is extensive guidance available from HSE on the storage of incompatible materials[18]. This is essential support material.

A system also exists for handling incidents involving radiation. These provisions, made under the National Arrangements for Incidents Involving Radiation [NAIR][19], are intended to cope with circumstances such as road traffic accidents, or where individual members of the public find a radiation source, where radiation may cause a hazard to the public. The fire service has basic radiation monitoring equipment to deploy at incidents under a RADSAFE* scheme. The present arrangements have worked but there are proposed new arrangements, made under the Radiation Emergencies Preparedness Public Information Regulations (REPPIR), to replace the old PIRER[20] regulations. The integration of these with brigade information systems should be undertaken in a controlled manner to ensure maximum safety of all concerned.

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* Oxidising agents and flammable materials would not be stored together.

* There are specific arrangements in existence, through trade and regularity controls, to bund and register specified stores containing agro-chemicals.

*RADSAFE brings together previous schemes such as the Nuclear and Industry Road Emergency Response Plan [NIREP] and the Irradiated Fuel Transport Flask Emergency Plan [IFTFEP]. The key principles of RADSAFE are early provision of general advice; guaranteed response, support to manage the media and ownership of the clean up actions. Three levels of response exist and the scheme helps in all transport related circumstances.

5.4.4. Chemical Decontamination

Linked to chemical substances is the procedure of decontamination initially undertaken by the fire service. Personal protective equipment (PPE) is categorised for use by its degree of impermeability to chemical penetration. Development of protective clothing is taking place in most developed countries, to provide protection from new materials, to provide better protection from known hazards and to provide greater comfort and ease of use[21].

Within the fire service there is a considerable amount of information available on a wide range of decontamination procedures. For example, the use of breathing apparatus, chemical protective clothing,[22,23,24,25,] decontamination[26,27,28], and the use of foam, as well as many other extinguishing media. This is a complex and continuously developing area and it is important that new developments are incorporated within information systems as routine practice.

5.4.5. Human Behaviour

Human behaviour remains a developing area of understanding. It has obvious relevance to successful operations in, for example, understanding how individuals attempt to take refuge in the event of becoming trapped in buildings[29]. Further research is now apparent in the aviation, retail and nuclear industries although current knowledge and guidance still includes a study that was published in 1946, namely the 1946 Post War Building Studies[30]. New studies have been commenced post September 11th by the Office of the Deputy Prime Minister. Research initiated by the author[31] has also demonstrated the effectiveness in raising safety standards through increasing public awareness and education.

5.4.6. Climate and Geography

In considering the location of any particular risk, it is necessary to evaluate the local microclimate and geography. This is necessary because of the very localised variations that do occur. Premises may be constructed upon a relatively porous material base presenting environmental risk should loss of containment occur for a particular harmful chemical or combustion product. At an elevated site a major spillage will create a risk if, for example, the site is adjacent and above residential accommodation. Understanding the impact of this local geography is extremely important and reference needs to be contained within a risk information profile of the local geography and the way it will impact a hazardous occurrence. The microclimate likewise requires recognition, especially when harmful releases [including smoke] occur[32].

The local microclimate may also differ markedly from the general climate, the most noticeable factor usually being wind direction or temperature[33]. This information may be a major factor in determining whether or not a particular incident is hazardous to a large number of people. Understanding local variations in climate and how that climate will interact with any hazardous material release may be important. By way of example, a marine environment may, with a slightly higher wind and relatively dry aspect, lower the airborne pollution risk. Conversely, if subject to a sea mist and low wind speed the situation may be particularly dangerous, as it allows hazardous gases to concentrate into a dense, slowly moving plume. Systems such as CHEMNET* are able to predict the general effects of meteorological influences, identify local conditions and

* CHEMNET is the free scheme provided by the UK Meteorological Office to the emergency services that will offer immediate and supportive advice on the likely impact of weather conditions upon clouds or plumes of hazardous airborne materials.

inter-relate those local conditions to the circumstances being faced, and as such have distinct operational advantages.

5.4.7. Reconnaissance

An essential element of all dynamic operations is the reconnaissance conducted by the Incident Commander. This activity provides the background data to all assessments relating to operational actions. The reconnaissance is not always conducted personally, both due to scale and other responsibilities, but it is essential.

5.5 Operational Decision Making in Practice

Whilst a hazard may remain constant, and hence may be assessed and documented, it is the circumstance in which that hazard is encountered by the firefighter that ultimately determines the actual level of personal risk. Risk arising from a hazard may change significantly with circumstance and there is now considerable guidance[34,35,36,37] in the UK on risk assessment at the fire ground. To meet changing hazards the fire service introduced a dynamic assessment process for use on the fireground[38] and a summary of this inclusive approach is shown in Figure 5.2.

Probability and prediction remain notoriously difficult to quantify in the fire service-operational environment partly because there is little real documentary evidence or historical fact upon which combinations of hazard and circumstance can be subjected to recorded analysis as exists in other industries. This is demonstrated by the earlier key case studies and it is clear that the risk assessment process requires a hazard information system capable of further expansion, particularly where the same chemicals in different combinations pose very different risks. Klein[39] suggests that it is because of these inherent unknowns that experience and personal protective equipment assume such importance for the fireground.

EVALUATE THE SITUATION, TASK AND PERSONS AT RISK

Consider questions, such as:

- What operational intelligence is available e.g. Risk Cards, 1(1)(d) sheets, fire safety plans; is it current and reliable?
- What tasks need to be carried out?
- What hazards are there in carrying out the tasks in this situation?
- What risks are associated with these hazards to firefighters, other emergency service personnel, the public and the environment?
- What resources are available e.g. experienced personnel, appliances and equipment, specialist advice?

ASSESS THE CHOSEN SYSTEMS OF WORK

Assess the chosen systems of work. Are the risks proportional to the benefits?

- If YES proceed with the tasks after ensuring that:
    - Goals, both individual and team are understood.
    - Responsibilities have been clearly allocated.
    - Safety measures and procedures are understood.
- If NO continue as below

INTRODUCE ADDITIONAL CONTROLS

Eliminate, or reduce, any remaining risks to an acceptable level if possible, by introducing additional control measures, such as:

- Use of PPE e.g. safety glasses, safety harnesses
- Use of BA
- Use of specialist equipment e.g. HP, TL
- Use of Safety Officer(s)

SELECT SYSTEMS OF WORK

- Consider the possible systems of work and choose the most appropriate for the situation.
- The starting point for consideration must be procedures that have been agreed in pre-planning and training.
- Ensure that personnel are competent to carry out the tasks that they have been allocated.

RE-ASSESS SYSTEMS OF WORK AND ADDITIONAL CONTROL MEASURES

If any risks remain, does the benefit gained from carrying out the tasks outweigh the possible consequences if the risks are realised?

- If the benefits outweigh the risks, proceed with the tasks.
- If the risks outweigh the benefit do NOT proceed with the tasks, but consider viable alternatives.

FIGURE 5.2 DYNAMIC RISK ASSESSMENT[38]

Upon arrival at the fireground, and subject to dynamic risk assessment, the Incident Commander formulates a basic operational strategy and determines required resources. This strategy is fundamental to the successful control of the incident. Basic knowledge and guidance is available in the Manuals of Firemanship, supported by local standard operation procedures and enhanced through competency-based training. Safety remains a key component throughout the incident with continuing dynamic risk assessments conducted to take account of the changing working environment.

Activities like finding the most common fire-fighting medium, water, also used for decontamination is an example of where a standard operating procedure is supported by technology. Water supplies are subject to routine hydrant inspection (in which hydrants are examined for ease of access, occasionally flow tested and repaired if damaged, all being recorded). Water and River Authorities routinely use geographic information systems [GIS] extensively for describing layouts of mains and valve positions, such as hydrants, and management of land drainage and as a method of forecasting flooding and avoiding environmental risk. The fire service already finds these GIS systems helpful for routine inspection management. Incorporating GIS registers into operational data systems has clear advantages since these can be further enhanced with other information, such as water pressure, to allow early determination of the number of additional pumps required at larger incidents. This entire aspect of mapping overlays has rapidly developed and many organisations and commercial systems exist, many containing useful fire service data. These systems aid decision making by reducing variables and confirming likely resource requirements. Many other standard operational procedures exist. Some are routine, such as those related to the use of breathing apparatus and well understood others, such as ship firefighting, are used infrequently. Even routine procedures, railway safety and access for example, can become unpractised and require a system of information support. Importantly each supports the decision process by ensuring a well rehearsed and practical series of working evolutions can be undertaken with a realisable and predicted outcome based upon resource inputs that empirically have a demonstrated success.

5.6. Data Support Systems

The identified sources and requirements need to be incorporated into any decision support system. Table 5.1 details a range of information system components already mentioned. For information to be useful, it has to be delivered in an appropriate and timely way. The volume of information involved will vary between areas and from brigade to brigade e.g. the number of premises recorded. However, many common elements exist given the national characteristics of the UK fire service where much of the procedural, tactical, equipment and hazard information systems are developed and promoted nationally. The comprehensive use of information technology, it is hypothesised, represents a practical approach available to the fire service for managing the data bases considered. Significant loopholes, such as data applicability, apply and raising the integrity of data quality is a required step in how these are closed.

The strength of the risk assessment process, which forms an accepted part of fire service procedure is that crews should be familiar with the system they have helped compile and the hazard data is presented in user friendly and relevant way. However there is an observed weakness that despite having data in the cabs of responding fire appliances it does require frequent updating and on occasion is overlooked. This is especially true of hard copy data due to their physical location or the difficulty in reading them en route to an incident. The significant improvement of Vehicle Mounted Data System [VMDS] computers is that the risk information is routinely updated automatically and copied into the brigade control room, so that it can if desired be activated by the turnout instruction and presented in a format that is easily read under various light conditions whilst on route.

Data Component	Available	Remarks
Risk Assessment	Nationally defined system framework capable of strategic and dynamic use.	Systems used on the fireground require an interactive process involving communication between all of those agencies involved.
Hazards	Risks to firefighters, occupiers, the environment and premises identified by inspection and data collation.	The source data is varied between procedures, practices and hard copy recorded data. Some IT links (CAD) exist but not many.
Identification Systems	Statutory marking of hazardous materials and substances both in transport and static models.	Changes occur frequently. Failure to identify correctly may introduce exceptional harm. Many systems are hard copy with limited radio transfer of additional information to the fireground.
Operational Practices	Highly defined and frequently practised operational practices are sometimes complex and infrequently used in real environment.	The recall of essential elements is critical to firefighter safety. Hard copy limits usefulness.
Buildings and of Materials	The built environment with fire safety management services and systems is highly regulated but not transferred to operational pre-planning and therefore not readily available.	Building materials and construction are critical factors in fireground risk assessment.
Manufacturing Processes	Subject to risk inspection process and headline risk information gathered.	Manufacturing processes may fail in abnormal circumstances and require detailed knowledge to ensure safe operational tactics.
Hazardous Substances	Wide range of proprietary and specially designed systems of support.	Effective action phase codes but limited detail for protracted operations.
Fire Science	Well documented but limited practical use to firefighters due to small scale of tests.	Knowledge of combustion products including heat flux and toxicity needed to assess risk to firefighters and general population.
Climate	General synopsis easily available. Plume models IT based.	Local factors may have a profound effect. Models are not routinely translated into local operational environment.
Geography	Improved mapping, GIS and IT systems now available.	Useful for identifying features concerning spread of pollution and media supplies such as water.
Human Behaviour	Not well-documented or available for fireground use.	Practices, educational messages and review essential for public safety.
Reconnaissance	Currently conducted at risk by firefighters with little visual monitoring.	A high priority requirement for successful incident management.

TABLE 5.1 INFORMATION SYSTEM COMPONENTS [DAVIS]

Table 5.1 summarises the main information system components derived from this chapter.

Another advantage offered by VDMS technology is that it requires a centralised compilation process that introduces a structured review of the information gathered with appropriate quality control procedures so adding considerable integrity. For example, with the extensive guidance available on the transportation of hazardous materials[40,41], and the complexity of industrial technologies it is becoming increasingly important to have systems available to the firefighter on the fireground which contains a large amount of fire safety information in a comprehensive and user-friendly form. Hard disc and CD ROM storage formats have proved to be realistic methods of carrying the amount of information required, with ruggidised laptops offering a practical accessing device. In addition because the electronic format is more easily managed, headquarters or control room staff can routinely copy locally produced information for wider distribution thus sharing information and increasing options for emergency service interoperability.

5.7. Command Process

The purpose of command* and control* is to ensure adequate command of operational resources and safe and expeditious control of operations[42] in circumstances that might involve considerable stress[43]. The key person in the entire command and control process is the Incident Commander[44]. This individual may be a part or full time officer since it is the scale of the incident that usually determines the rank of the Incident Commander, although the complexity of the problems faced may require different ranges of skills. Considerable responsibility is placed on the Incident Commander, irrespective of the incident size or the scale of any operational resources, as the fire

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* Command – the authority for an agency to direct the operations of its own resources.

senior fire officer present, must exercise full responsibility for the safe and expeditious management of the incident until he is relieved of that command by a more senior officer.

Integrating the information support system to ensure effective command also requires an efficient communication pathway. It is along this pathway that information essential to tactical decisions or tasks and designed to limit events and lead to a return to safe conditions, will be passed. Effective control, however, requires knowing what resources[□] are available and how they may be assembled quickly to aid the operation. The control process, therefore, requires the gathering of all relevant resource information, including the current status or deployment of any resources. Figure 5.3 shows the more important features of the command process developed in 1996 for use in Cheshire Fire Brigade[45]. This process was successfully introduced and used effectively at a number of major incidents prior to the publication of national guidance.

5.8 Command Organisations

Command is exercised through organisation of personnel on the incident ground[+]. For example the Police secure an outer cordon and the fire service record all individuals in the inner cordon, see Figure 5.4 developed by the author.

[•] Control – the authority to direct strategic or tactical operations in order to complete an assigned function and include the ability to direct the activities of other agencies in the completion of that function.
[□] Resources in this context are not those solely within the control of the fire service i.e. appliances and personnel. They include other physical and human resources available from other services or agencies, e.g. sandbags, specialists or lifting equipment.
[+] Incident ground or fire grounds are common terms to describe the working area in which operations are being conducted. The area is usually physically denoted but not necessarily indicated. It may therefore be a house with the immediate environs of the street outside or an open space like a forest. Identification may be marked using tape or simply be the yard of a factory. It each case entry will, however, be controlled for safety and operational freedom reasons.

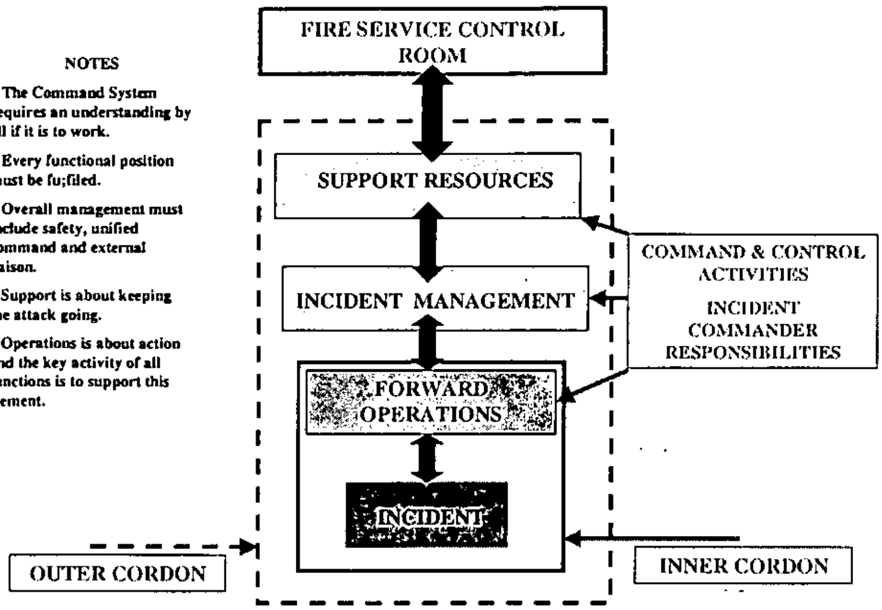

FIGURE 5.3 COMMAND PROCESS [DAVIS]

5.9 Logistics Support

The Incident Commander is assisted by an established organisational support and decision structure through the appointment of designated officers. See Table 5.2 compiled by the author. This indicates that logistics management is a key feature in determining a successful outcome at a major incident. This challenges the assumption observed in the current UK approach of seeking to use only operational i.e. firefighter trained rather than specialist or support staff at incidents. Whilst questions of technical interpretation and extended availability do arise in using non-firefighting staff this sort of human resource related issue is managed in many other organisations operating in a continuous service environment. Integrated communication technology permits the wider use of supportive logistics from remote suppliers and could be further exploited to assist in this activity

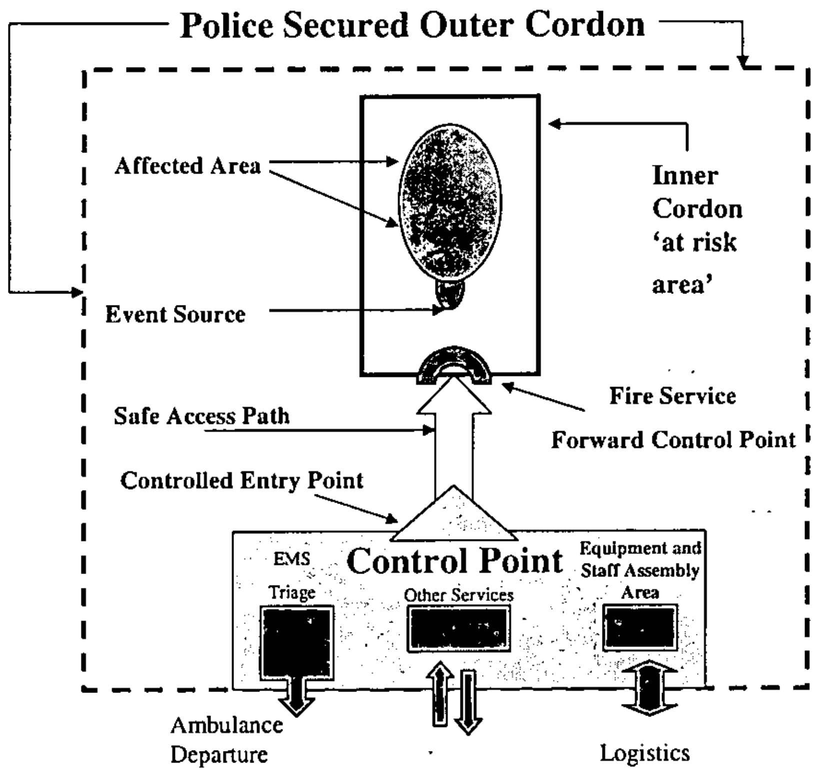

FIGURE 5.4 INNER AND OUTER CORDON [DAVIS]
The control of the inner 'at risk' cordon by the fire service and police supervision of the outer 'secure' cordon helps provide a safe and unrestricted operating environment.

Close liaison is maintained with the other emergency services[♠] and with competent authorities, like the Health and Safety Executive and Environment Agency, since these are the statutory enforcing authorities for individual areas of major incident related legislation.

[♠] The police, for example, who use the designations of gold, silver and bronze to identify their individual responsibilities for strategic, tactical and operational command.

Incident Commander	Responsible overall for Fire Brigade operations at the incident.
Forward Control Officer	Responsible to the Incident Commander for all operations within the Inner Cordon.
Support [Control] Officer	Responsible for co-ordinating all resources including personnel and support tasks.
Sector Officers	Responsible for direct executive command and control over operations and safety procedures for a geographical sector of the incident.
Safety Officer	Responsible for the overall safety of all persons operating within the Inner Cordon.
HAZMAT Officer	Advises the Incident Commander on all matters relating to special procedures, the gathering of information and safety at hazardous materials incidents.
Water Officer	Ascertains water requirements; identifies supplies and initiates action to deliver the required amount.
Foam Officer	Ensures that foam supplies and equipment are readily available in order to commence and sustain a foam attack.
Marshalling Officer	Identifies a suitable rendezvous point at which appliances, equipment and personnel can be assembled prior to being committed to the scene of operation.
Liaison Officer	Establishes contact with other emergency services and outside agencies in order to give advice and guidance on fire brigade operations and to assist a co-ordinated and combined response.
Communications Officer	Establishes and maintains data and voice communication between the Incident Control with Brigade Control and seeks to establish reliable voice communication between the Forward Control, Support Control and Incident Commander and those other fireground officers identified.
BA Officer	All actions concerning breathing apparatus activities.
Fire Investigation Officer	All matters relating to the investigation of a cause of fire, the compilation of reports, and interviewing of witnesses.
Salvage and Damage Control Officer	Organises staffing, equipment and any other measures that are necessary to prevent or mitigate damage to property, materials etc. by carrying out damage control
Press and Media Officer	Advises the Incident Commander and prepares statements for press and media representatives relating to the nature and scope of the incident, progress of operations, and other such approved information.
Ships Stability Officer	Establishes liaison with ship's master and harbour officials and monitors all aspects of ship stability arising from fire fighting operations.
Pollution Control Officer	Initiates action by fire brigade personnel, and secures liaison and assistance with other agencies aimed at preventing pollution of the environment

TABLE 5.2 DUTIES AND RESPONSIBILITIES OF OFFICERS [DAVIS]

At large incidents there is frequently the need to divide the incident ground into sectors[46], for example the rear and front of a building. These divisions introduce further leadership levels, help in managing the Incident Commander's span of control and allow retention of strategic control of operations, leaving individual officers at the actual scene of operations to action any necessary initiatives. To remain efficient any responsibility overlaps created must avoid confusion, duplication of effort and wastage of resources. Sector officers must understand the overall aims within their individual operational sector of responsibility if there is to be a comprehensive and cohesive operational plan. Effective, fast and robust communications help avoid unauthorised or inappropriate action and provide an integrated incident management process.

It is important to highlight that the dynamic nature of incidents requires the same principles of command and control to operate at small and major incidents. Examination by the author of major incidents and the sequential escalation of both the population affected and resource inputs utilised provides the type of continuum illustrated in Figure 5.5.

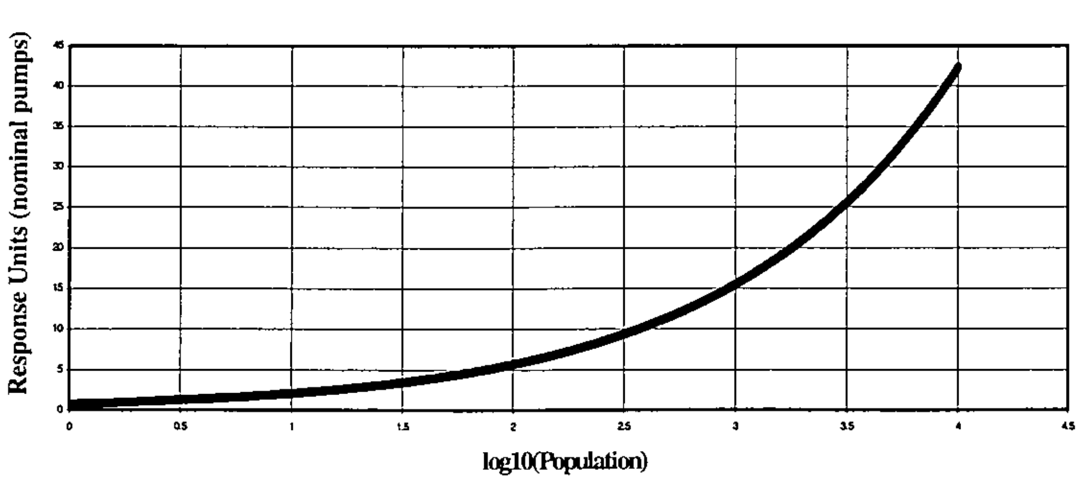

FIGURE 5.5. INCIDENT COMMAND CONTINUUM [DAVIS]

5.10 Working with other Agencies

In the United Kingdom there is no one agency that is charged with total delivery of 'civil protection', although the Home Office leads civil protection planning[47]. This is not the same in all European countries. The consequence is that, when accidents or disasters occur, there has to be co-ordination and, to an extent, interoperability in communication systems whereby all those organisations, which can contribute to the safe resolve of the emergency, can work together effectively

The fire service role predominantly involves the rescue of casualties and the utilisation of special skills to extinguish fires or deal with hazardous or chemical materials. Essentially, its role is to render areas safe and to recover casualties. Military aid may also be available to local authorities under the provisions of Military Aid to the Civil Community.[48] A significant number of other agencies are also involved in various aspects of emergencies such as the Maritime and Coastguard Agency and the Environmental Agency which may be the statutory enforcing authority for a particular area. As described in the previous chapter provision also exists for brigades to access specialist advice and information on hazardous materials. In addition, non-governmental or charitable agencies and volunteer groups, e.g. the Salvation Army and the Red Cross, often give support at major incidents. Industrial support may be available, particularly in cases involving hazardous sites, airports[49] or widespread pollution where, for example, the petrochemical industry may offer assistance.[50, 51]

This multi-disciplinary approach at major incidents can result in complicated patterns of communication of information between all the active agencies[52] and the consequential decision system. For example, in a town centre terrorist attack, all emergency services will be gathering information concerning individuals who may be lost or injured. Creating one access point, the Casualty Bureau, to handle that need and to respond sensitively to public requests demands specific technological and management techniques. The pattern also emerges of dependant decision-making where the actions and decisions of one organisation impacts upon those other agencies involved at the incident. The concept that has evolved and is now incorporated into practice is that of the crisis team 'big table' meeting at which all the senior representatives meet throughout the event to consider action phases and future strategy. In this way the multi-disciplined team is unified in command, contributes or is involved in essential information exchange and participates in decision making.

On the incident ground responding emergency services invariably co-locate mobile incident command units at one incident control point to aid joint working. Control of a major incident is usually retained under police supervision, either in the Force Headquarters or at some pre-agreed location such as local police station. Difficulties can arise if, for example, reliance is placed upon the capacity and capability of the normal communication system to withstand the heavy traffic pressure generated by an incident. Pre-planning tries to compensate by cross messaging between the various services' own information networks. This preparedness for major events, such as Chernobyl[53], has continuously evolved over a period of fifty years into a defined response now referred to as "integrated"[54]- a process in which individual agencies plans fit into a collective area plan using the individual services' day-to-day response as a foundation [This allows the response to be constantly tested, requires limited special resources to implement and can be regarded as robust].

The integrated response is structured to offer a mutually supportive response involving all the emergency services, appropriate departments in Government and local authorities, voluntary agencies[55], commerce and industry. Home Office guidance as detailed in Dealing with Disasters (Dealing with Disasters Together in Scotland) is specifically drafted to aid this planning process, which is co-ordinated under the chairmanship of the Chief Constable for the area concerned. The practice is to establish a Senior Emergency Liaison Committee, which periodically meets and discusses issues of common concern and involves senior officers of the various emergency functions and local authorities. In the UK there is also significant input from Public Health organisations, such as the National Health Service and Hospital and Ambulance Trusts.

The current arrangements have developed from the philosophy that emergency response should be an escalation of day-to-day activities whereby those resources, which are generally available and used routinely may be utilised and expanded rapidly at times of extreme need. Again the outcomes of September 11th has questioned this conventional wisdom and in the USA a separate co-ordinating department, Homeland Security, has been created by the Federal Government to lead overall strategic planning. In the UK the Government has reviewed civil contingency planning at the UK level and is considering new legislation to enhance control and inter agency working. These reviews are vital since experience has now shown that any graduated response assumes continuation of existing systems, like telecommunications that failed in New York. Experience therefore suggests special arrangements are needed to safeguard inter-

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For example extensive planning was undertaken to avoid failure of electronic systems during the millennium date change in 1999/2000.

governmental and emergency service communications, through the ECN* and satellite mobile and terrestrial telephone networks. These emergency arrangements also include access to television and radio broadcasting, providing an information route to the public. If frequently used, all these systems give a higher level of integrity to communication infrastructure. This interagency activity places considerable pressure on any fire service decision system yet is essential. Technology, although itself vulnerable, does however appear to offer the only realistic option.

* Emergency Communications Network. The ECN is a Government terrestrial telephone system that is hardened against significant damage and provides a secure, if basic, communications path between essential government and emergency services.

5.11 Observed Lessons of the Integrated Response

Arising from field observations over many years Table 5.3 summarises factors that have been routinely identified as creating some decision making tensions: -

ACTIVITY	OBSERVATION
Central Co-ordination	Information is needed by a range of users and collected from a range of sources. Regardless of the fire service role, i.e. whether it has primacy of control or not, the Incident Commander is unlikely to be in the same place as all the data. The data available is unlikely to be routed through one point.
Incident Complexity	In complex incidents the time-scales as the incident develops, event parameters and individual service response or needs, are unlikely to coincide in a way that enables a simplified information system to be sustainable. The action phase may be intensive or protracted or both, the available resources and skills may be adequate or overwhelmed, and separation and lack of an effective communications system may confuse the transfer of data between groups even within the same service.
Decision Making	Discretion to determine action may be local and immediate, or require reference to remote commanders. Other users of service resources, e.g. health using fire, police using fire, fire using local municipal authority, etc.,- can give rise to tensions (who has priority), duplication (the resources have other commitments) and responsibility (typically for expenditure, control and legal consequences). Creating framework protocols to enable practice to be effective on the ground requires teamwork, knowledge and experience.
Collective Response	Strategy and co-ordinated tactics and operations require that balanced judgement is exercised by all of the participating players. Declaring implicitly or explicitly which service has ultimate decision primacy is important. The issue that then arises is whether the "controller" has access to all relevant information. If the controller is remote this questions the validity of whether decisions determined in the analytical environment of the remote control centre be implemented and will incident outcomes be accurately relayed back to enable effective strategy evaluation.
Public Evacuation	An important consideration when the public are at risk is whether to evacuate an area. Practical considerations argue for a shelter policy, rather than evacuation since moving people, especially the old and ill, raises considerable collateral risks. It is concluded *generally* that staying in a known location with communications and support unless directly threatened or until planned evacuation arrangements are in place is the better public policy•.

TABLE 5.3 FIELD OBSERVATIONS OF INTERAGENCY ISSUES [DAVIS]

• This was in the early 1990's a novel conclusion requiring a higher degree of public understanding. This was addressed through organised public events[2] and education using purpose-designed material, such as the '*get out, stay out and call us out*' developed by the fire service for fire safety in the home. Validation was required since two messages would be presented to the public by the fire service. The first, for fires in the home, demanded evacuation of the home, the second for a toxic leak required people to stay in their home. The research concluded[2] that receiving two messages, one relating to evacuation and the other to shelter, did not confuse children of primary school age.

5.12 Summary

The fire service decision process described is multi-faceted and engages many agencies. Whilst some decisions may be pre-evaluated, being based upon information researched and pre-recorded with prescribed procedures and practices in place, a great number of decisions can only be made after arrival at the incident. The decision process must therefore have an effective support system.

The information sources required for those decisions may be simple to assemble and assimilate, or conversely dispersed and complicated to understand. The dynamics of the event therefore require flexibility and robustness. Easily accessible and reliable communications are therefore an essential component. To illustrate the decision process a simple flow diagram has been constructed [Figure 5.6]. The information gained will be shared both with other agencies and the public. Firefighters cannot function effectively without this integrated involvement yet they need to avoid overload and have timely based inputs. The data capture process is crucial, as are how the outcomes are presented and the audit trail preserved.

The flow diagram illustrates that the operational decision is dependant upon features like liaison with other agencies; the fire service pre response activity e.g. specific data gained through the described inspection process, and dynamic assessments at the incident; information held by the other agencies both before and during the incident; resource dispositions [currently based upon area based risk cover and now changing to integrated risk assessment]; and the pre-planned responses of the fire service and other agencies integrated through command communications. The need to meet public and media information requirements is also evident.

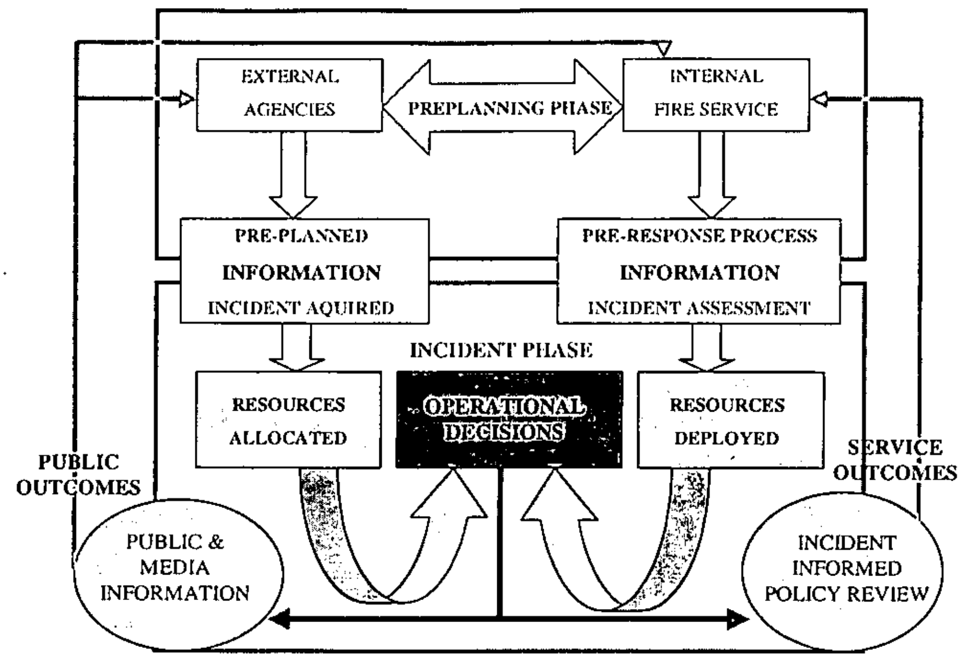

FIGURE 5.6 A SYSTEMATIC APPROACH TO DECISION-MAKING [DAVIS]

Policy review through incident debriefing is also characterised. That policy process itself contributes significantly through standard operating practices and co-operative assignments with other organisations. The policy process also evaluates resource effectiveness as informed by the audit process and will also ensure the integrated personal development training system, designed to improve individual competency, is informed.

Effectively this integrated mechanism confronts the established organisation in a number of ways. Earlier discussions have illustrated the importance of business culture, itself a product of traditional history and legislation. These shifts in management style can be profound introducing at one level new technology or at another devolved decision-making. Each contributes to an expectation of how decisions are to be reached and what form of data analysis or decision system is most appropriate.

This overall expectation and the nature of the established support system is central to how decisions are reached at a time when the individual Incident Commander is at his most vulnerable-when confronting a confused and life threatening situation. Current fire service organisations have evolved, rightly using empirical knowledge, but not necessarily with a critical or analytical objective in focus. That must now change to use technology in a more supportive and interactive way.

Similarly those tensions observed in inter agency working and the need for good central co-ordination, together with recognition of the time and data analysis pressures on decision takers are unlikely to be sustained by simple communication networks. New working protocols and refined decision support systems are required with clearer understandings between all the involved players. As one illustration the decision to alert the public* and advise them what to do in an emergency situation requires interpretation of technical data and a major public information activity by a considerable number of emergency service and other specialists.

The accepted relationship between information management and information technology, now well established in using captured information in relational databases, it is postulated can be extended further with technology providing a support system to assist decision making through simulation and data manipulation, enabling the fire service to manage its intervention in a more proactive, rather than reactive, manner.

* The importance of this task in demanding a first priority decision and therefore dominating action using resources and time must be recognised. The contribution of the policy to 'shelter' rather than evacuate can therefore relive the Incident Commander from significant demands.

CHAPTER 5 REFERENCES

[1] *Health and Safety at Work Etc. Act 1974,* Eliz.2, Ch. 37,TSO, London

[2] *Fire Services Act, 1947,* 10 & 11 Geo.VI, Ch. 6, TSO, London

[3] Scottish Office-Home Office-Department of the Environment [Northern Ireland]. [1998], *Dynamic Management of Risk at Operational Incidents,* TSO, London.

[4] Health and Safety Executive. [1990], Respiratory *Protective Equipment. A Practical Guide for Users,* TSO, London.

[5] *Personal Protective Equipment at Work Regulations,* [1992], [Statutory Instrument Number 1992/3139] *and Amendment Regulation,* [Statutory Instrument Number 1993/3074], [PPE], TSO, London.

[6] Health and Safety Commission. [1992], *Personal Protective Equipment at Work Regulations, Guidance on Regulation 1992,* TSO, London

[7] Central Fire Brigades Advisory Councils. [1985], *Report of the Joint Committee on Standards of Fire Cover,* TSO, London.

[8] Health and Safety Executive. [1987], *Dangerous Maintenance. A Study of Maintenance Accidents in the Chemical Industry and How to Prevent Them.* TSO, London.

[9] *Report of the Summerland Fire Commission 1973,* (Government Office, Isle of Man)

[10] Cheshire Fire Brigade [1996], *Report on the Pickfords Warehouse Fire,* Cheshire Fire Brigade, Unpublished Report.

[11] United Kingdom Atomic Energy Authority [1982], *Chemdata, Chemical Safety Information Software System,* Culham, AEA Technology.

[12] United Kingdom Atomic Energy Authority, [1982], *Chemdata, Rapid Information for Emergency Services.*

[13] Klein, R.A., [1998], *Hazard Analysis Software,* Industrial Fire Journal.

[14] Sax, N.I., Lewis, R.J. [1989], *Dangerous Properties of Industrial Materials,* 7th Edition., Reinhold, New York.

[15] Silver Platter is an information database produced on CD ROM by The Stationery Office.

[16] Cheshire Fire Brigade. [1983], *Report of Fire, Roberts and Hewell.* Unpublished report.

[17] Edwards, T. [1994], *The Prevention of Water Pollution,* Fire Engineers Journal, Vol. 55, No. 176, Pages 13 - 17, Institution of Fire Engineers, Leicester.

[18] Health & Safety Executive,[1998], *Chemical Warehousing –The Storage of Packaged Dangerous Substances',* HSG71, ISBN 0-7176-1484-0, TSO,London.

19 National Radiological Protection Board, [1995], *National Arrangements for Incidents Involving Radioactivity*, NAIR Handbook.

20 *The Public Information for Radiation Emergencies Regulations, 1992.* [Statutory Instrument No. 2997], TSO, London.

21 Blirup, N.O. [1996]. *Protective Clothing - Heavy Shielding,* Fire Engineers Journal, Vol. 56, No. 181, Pages 30-31, Institution of Fire Engineers, Leicester.

22 Bosley, K. [1996], *Degradation of Chemical Protective Clothing,* Fire Research and Development Group, Research Report Number 69, CFBAC Joint Committee on Fire Research, Home Office.

23 Health and Safety Executive. [1990], *Respiratory Protective Equipment. A Practical Guide for Users,* TSO, London.

24 Home Office, (Fire Department). [1974], *Breathing Apparatus and Resuscitation,* Book 6, 1st Imp., TSO, London.

25 Joint Committee on Appliances, Equipment and Uniform Sub Group. [1996], *Guidance on Selection and Use of Chemical Protective Clothing,* Dear Chief Officer Letter Number DCOL 2/1996, Fire Service Inspectorate.

26 Rimen J.G. [1994]. *An Assessment of Fire Services Methods for Chemical Decontamination, Publication* 9/94, Fire Research and Development Group, Home Office.

27 Rimen, J.G. [1995], *Methods of Decontamination after Chemical Incidents Summary Report,* Fire Research and Development Group, Research Report Number 63, CFBAC Joint Committee on Fire Research, Home Office.

28 Fire Research and Development Group, [1995], *Trials of a Prototype Chemical decontamination System for Possible Fire Service Use.* Report 2/95, Home Office.

29 Comeau, E.R. [1997], *Residential High Rise, North York, Ontario, 6 January 1995, Fire Investigation Summary*, National Fire Protection Association, Quincy, Mass.

30 *Post-War Building Studies, Fire Grading of Buildings,* [1946], Joint Committee of the Building Research Board of the Department of Scientific and Industrial Research, London, TSO.

31 Davis, D.T., [1998], *Study into Evacuation of Residents Following a Serious Fire, Lightfoot Street, Chester, Cheshire, 25 October, 1996,* Poster Presentation, University of Ulster Conference on Human Behaviour.

32 Pugh, R.W. and Johnson, R.W. [1988], *Guidance on Vapour Releases Mitigation,* Centre for Chemical Process Safety, American Institute of Chemical Engineers, New York.

33 Holford, I. [1994], *Looking at Weather,* Weather Publications, Brockenhurst.

34 Home Office. [1998], *Fire Service Guide to Risk Assessment for Health and Safety,* TSO, London.

35 Health and Safety Executive. [1997], Guidance Booklet HS [G] 65, Successful Health and Safety Management, TSO, Norwich.

36 Health and Safety Executive. [1992], *Management of Health and Safety at Work Regulations, 1982,* Approved Code of Practice Number LZ1, TSO, London.

37 Health and Safety Executive. [1992], *Management of Health and Safety at Work Regulations, 1982,* Approved Code of Practice Number LZ1, TSO, London.

38 HM Fire Service Inspectorate, Publications Section. [1998] *Health and Safety Fire Service Guides, (a) Dynamic Risk at Operational Incidents.* TSO, London

39 Klein, R.A. [1998], *Strategic Planning for Major Incidents*, Fire Engineers Journal, Vol. 60, No 206 pp36 – 44

40 Health and Safety Commission. Approved Documents. [1996], Approved Requirements and Test Methods for the Classification, Packaging and Labelling of Dangerous Substances for Carriage 1996 [L88] with Supplement 1999; Approved Carriage Lists 1996 and 3rd Edition [L90-ISBN 07176 1223 6 and L90 ISBN 0 7176 1681 9]; and Approved Requirements for the Packaging, Labelling and Carriage of Radioactive Material by Rail [L94] with Supplement 1999, TSO, London.

41 The Carriage of Dangerous Goods by Rail Regulations, 1996. [Statutory Instrument Number 2089], TSO, London.

42 HM Fire Service Inspectorate, Publications Section, [1999], *Fire Service Manual, Volume 2 Fire Service Operations Incident Command,* TSO, London.

43 Central Fire Brigades Advisory Council. [1997], *Fire Brigades Operational and Training Activities: Management of Physiological Stress,* Dear Chief Officer Letter Number DCOL 8/1997, Fire Service Inspectorate, Home Office.

44 Sherrington, J. [1996], *Incident Command for the Future,* Fire Engineers Journal, Vol. 55, No. 179, Pages 36-39, Institution of Fire Engineers, Leicester.

45 Davis, D.T., [1996], *Cheshire Fire Brigade Operational Orders*, Unpublished.

46 West Yorkshire Fire Service. [1997], *Incident Command System Seminar Document.* Siemens Plessey Systems, Christchurch, Dorset.

47 Home Office, *Change to the Lead Government Department Arrangement and Guidance to Emergency Services Etc,* (Home Office Circular no 23, 1995)

48 Ministry of Defence. [1989], *Military Aid to the Civil Community* [pamphlet]

49 HM Chief Inspector of Fire Services. [1993], *Management of Emergencies at Civil Airports and Aerodromes,* Dear Chief Officer Letter Number DCOL 7/1993. Fire Service Inspectorate, Home Office.

50 CHEMSAFE Chemical Industries Association. [1976], *Recommended Procedures for Handling Major Emergencies*

51 Robinson, A. [1997], *Chemical Incident Support - The Chemsafe Scheme,* Fire Prevention, Issue 305, Pages 26-28, Fire Protection Association, London.

52 Hodkinson, P.E. and Stewart, M. [1991], *Coping with Catastrophe,* Routledge, London.

53 Joint Working Group on Chernobyl. [1993], *The Role of the Fire Service at Incidents Involving Radioactivity,* Technical Bulletin 2/1993, CFBAC Joint Committee on Fire Brigade Operations, Home Office.

54 Home Office, [1997], *Dealing With Disasters Together in Scotland,* 3rd Edition, (Brodie, Liverpool)

55 Home Office, *Disaster Planning for a Caring Response*, (London, TSO, 1991)

CHAPTER SIX

A New Decision Management Tool for the Fire Service

6.1 Introduction

Central to this study is the concept that operational decision-making can be improved. Understanding how command decisions are reached is therefore a pre-requisite to enabling that improvement both through command competences and to understanding situational awareness. Presenting data so that the Incident Commander and his team might use it effectively depends on recognition of the relevant information and its presentation in a useable form and volume.

Knowing how the data is used in dynamic decision-making is important and there are interesting parallels in military systems, as US research demonstrates[1], where integrating information technology systems into command and decision-making processes aided the process thus confirming earlier observations regarding the importance of organisational culture, i.e. the continuous learning concept.

6.2 Data Overload and Relevance

Information overload is always a possibility for the Incident Commander who is faced with gathering data and planning operational strategies. Time pressured decision-making heightens stress, which can degrade analytical skills and hence decision quality. Ehrhart describes the importance of the modern military command centre in supporting force level data fusion so that it can meet contingency operations and also indicates that it is extremely important for any command centre to pursue a layered approach of information presentation, so that the essential information regarding the battle in progress, in the case of the armed services, is given with the minimum amount of necessary detail. This can be tailored to match the decision requirements of any individual preference.

Ehrhart's work and that previously done by the US Airforce[2] contends that it is important to ensure that senior decision-makers working in a time sensitive information environment only consult detailed information when it is required for a concurrent decision. He also notes that in certain areas, technologies are under-exploited since system designers are unaware of the potential to assist command.

Andride[3] in "Handbook for Decision Support Systems" emphasises the need for any decision support system to have its defining requirements specified in terms of the users, their tasks and the organisational context in which the decisions are to be made. Research by Lt. General Nelson of US Airforce[4] confirms the requirement to avoid overload, stating the importance of avoiding what he refers to as a "blizzard of options with complex selection trees" and focus instead on the simplicity required at the point where the information is to be used.

This US research also relates to the interaction referred to in earlier chapters concerning both the cultural foundation and practical application options, usually found in established standard operating procedures or practices, available to an Incident Commander. The user profile, therefore, is quite critical to ensuring the right support is offered to the decision making process. This again confirms the importance of moving towards being an organisation that recognises the interactive relationship between Incident Commander and his command team. Further reinforcement of this essential point comes from the knowledge that the cognitive task requirement used, in battlefield/incident management, will involve a number of commanders, some of whom do not interact extensively with the command system although they are working within the operational activity area.

It is contended that in the decision-making context of the fireground the Incident Commander's position is essentially similar. In many countries of the world the fire service is formally part of the military (e.g. China, Russia). This is a different argument to that of Neal[5] who states that many emergency planners have an almost para-military approach to disaster management since they were appointed in the cold war era and have continued that style of command management.

Ehrhart[6] again makes the point that the task profile is itself a key part of the decision making process which will hinge on the commander's awareness of the situation and assessment of the options generated. In this context it is essential that in the planning process there is a shared agreement, a key outcome for the organisation of what all the commanders see as the evolving battle plan and the components of information they all need to make the plan work. This is a process of empowerment that enables decisions, based upon established guidelines or frameworks, to be deviated if this is desirable following a communication system failure that requires the local commander to act independently.

Translated into fire service operations and the various officers deployed, including the Incident Commander, the information requirements are shown to be significant. The command team functions have already been detailed and show a range of support activities, each having specific data needs. The Incident Commander and those involved in the strategic, tactical and operational decisions have further requirements, especially relating to the dynamic environment of the incident's progress. Those active at operations, the firefighters, have an important role in these requirements for both supplying data [e.g. what is happening inside the risk area which can only be entered with personal protection] and using the data [e.g. identifying a risk room or an item of risk equipment]. Tacit and explicit data therefore has value.

In developing models for decision-making, Perry and Moffat[7] argue that there is a taxonomy of decision-making analysis, which has at least two attributes. The first is an attempt to measure understanding of how the decision-making mental processes are used and this effectively follows Klein's[8] model of primed decision-making. The second attribute includes consideration of the extent to which the decision-maker operates within a context similar to that in which he normally makes real life decisions, that is, does the decision-making process correspond to everyday activity?

Perry and Moffat constructed a model of decision-making through a study of naval commanders taking combat decisions. They attempted to identify what information had value and whether different commanders who were all senior, experienced naval commanders would take the same decision when confronted with the same information. They found that the commanders would make significantly different decisions at critical points even when presented with the same information in the same operational context. Their studies revealed that it was the form of presentation of the information that most influenced the decisions taken, and that proper presentation enabled a balanced view to be taken by the commanders. Table 5.1 identified the key components of information that would be used by the Incident Commander under such circumstances.

They also noted that in combat, decisions had to be taken in the absence of full information, which is analogous to the situation as experienced on the fireground. They concluded that when information was available it was relied upon and was considered valuable to the decision making process. This, to them, confirmed the fact that just because the information was not available it did not detract from the fact that the information had value. The distinction being drawn was between essential and valuable information. Situational awareness in this situation is primarily a local stimulation and may be satisfied by heuristics and recognition primed decisions based on previous experience.

This distinction is important. The Incident Commander will need the essential information and it must be supplied. Useful information is supportive but not essential to bringing the incident to a satisfactory conclusion. In any fire service information system the difference between the two must be apparent, so ensuring a data hierarchy and reliability for use in operational decision-making.

Perry and Moffat[9] also attempted to explain that the variance in decision outcomes related to the variation between the decision-makers rather than in the information provided. Key components here, appear to be both an understanding of how the individual would operate, recognising which external decisions were important and then placing the whole process within a realistic scenario.

Neal's[10] research identifies that systematic research for over four decades has indicated that rigid bureaucratic command and control approaches to emergency management generally lead to ineffective emergency response, control being procedural and relatively inflexible perhaps. He suggests that flexible organisational configurations are likely to give a more effective disaster response, so supporting the goals of a learning organisation. This is based upon his observations that poor disaster response is not a necessary consequence of departure from standard procedures that have been laid down to manage the disaster, but is more likely to occur because of the rigidity of the response process itself. His argument is that while bureaucratic approaches to command and control have led to a massive amount of literature on disaster behaviour, this is ignored or misinterpreted. Similar arguments might be presented to demonstrate why Incident Commanders frequently do not use available operational or technical brigade orders.

Neal argues that a plethora of disaster studies debunk traditional misconceptions about how responses occur, and yet command and control systems continue to subscribe to disaster myths regardless. The assertion is that this tight command and control approach relies on a small number of cases, which are often anecdotally based. His preference therefore is for a human resource model, such as that presented by the Disaster Research Centre of the University of Delaware[11]. These findings confirm the necessity, outlined earlier, for ensuring that fire personnel are trained in accessing information and have access to suitable information systems.

Perloff [12] considers video conferencing for command and control, arguing that complex communication tasks are made easier if the commanders use interactive graphics and share documentation. He particularly argues that new compression technologies for information transmission could make video conferencing for military command and control possible under battlefield conditions. Given the dynamic nature of fireground operations such an arrangement could improve co-ordination and performance particularly where resources are dispersed with delegated control. Increased integrated imagery and document transmission facilities would similarly allow intelligence images and interpretations to be widely circulated so drawing forward a stronger interactive response, especially from remote commanders, who could confer quickly and answer questions about particular assignments.

These broad conclusions do not reflect the more recent introduction of computerised reasoning systems that seek to offer best practice derived from analysis of case studies. Learning systems of this kind appear to be in their infancy in the fire service, only one European pilot was found to exist, but they do appear to offer real potential. Linked to competency based training simulators safety critical decision making could be improved. In the interim evaluation of effective and predictable logic trees that trace known practice suggests the construction of new paradigms may provide a foundation to improved decision making.

6.3 Decision-Making Models

Klein et al [13] considered complex naval command and control environments. He identified the use of recognition prime decision (RPD) models, which enable commanders to determine achievable goals using relevant clues with actions that typically work. RPD[14] is categorised as allowing the commander to:

1. Focus on his assessment.
2. Aim to meet the situation satisfactorily, not necessarily perfectly.
3. Usually act on his first option only.
4. Develop a series of action plans.
5. Be able to check his plan using mental simulation.
6. Be able to elaborate and improve the plan as the process moved forward.
7. Recognise that action is the primary activity of the decision-maker.

Using a RPD approach the Incident Commander implements a viable series of actions without lengthy deliberation. The process involves "situation awareness", a state of knowledge where there is a perception and comprehension of elements within the operational environment and anticipation of their future status. It was found that 87% of decisions were developed through a feature matching processes; feature matching is a process where the situation is within the experience of the Incident Commander on the basis of the observed set of clues.

Developing situation awareness is a RPD priority since it leads to identification of actions. This is an important point, particularly when applying RPD systems to firefighting[15] as operations in a time-constrained domain, when the firefighter may be forced to concentrate on action rather than situation assessment.

The fire service decision-making process could also be considered with approaches that are categorised as naturalistic. Research in the US[16] has led to the development of the concept of Naturalist Decision-Making [NDM] and the conclusion that NDM is more suited to the complex nature of operational activities. NDM has now become accepted in the UK by commentators such as Flin, who view it as helpful to understanding operational decision-making[17] where time constraints, lack of information and other pressures can create a highly stressful environment for the Incident Commander.

Ten factors that are judged to characterise NDM:

1. Lack of definition in the roles of the participants
2. Uncertainty and loss of data
3. A rapidly changing situation
4. Shifting and competing goals
5. Action orientated responses
6. Stress
7. High loss stakes
8. Multiple teams
9. Challenging organisational forms
10. Experienced decision-makers

The NDM concept suggests that mapping a present incident onto an Incident Commander's previous experience enables him to fill any gaps through a process of comparison. Fireground commanders interviewed frequently stressed that they were not making decisions or choices, but were solely reacting on the basis of their experience, moving their plan to meet the needs of the situation[18]. The commanders frequently found that it was not necessary to exercise options or to make choices in an optimal sense. Some argued that taking the time to consider issues was in itself an unnecessary stress.

Reviewing NDM has led to the conclusion that it has value for fireground command. This is borne out by a study undertaken by Burke and Hendry in the London Fire Brigade in which simulation based assessments were broadened to attempt to identify, in a group of experienced commanders, the process by which they reached their decisions. The work was part of a study seeking to improve the selection of, and future for, fire commanders[19].

The London study also confirmed the work of Klein in that 81% of fireground commanders perceived that they exercised little choice, worked on a response that was primed by prior knowledge and, like their American counterparts, did not consider alternatives when reaching their decision. They noted that the majority of commanders appeared to reach the decision point intuitively. Thus simulation clearly has merit in training when linked to RPD[20] and NDM.

This study also recognised that to the fireground commander visualisation played a key part in determining his final action plan. This is referred to later when considering the use of technology on the fireground.

Exploring these concepts is further aided by work by Crichton[21], who summarises command skills from other authors [Flin et al] as:

- Decision-Making
- Situation Awareness
- Leadership
- Planning
- Communicating
- Monitoring
- Delegating
- Prioritising
- Team Co-ordination
- Stress Management

Crichton further describes the relationship between situation awareness and decision making as a continuum in which decision making strategy options move from recognition primed to creative outcomes through stages that included rule based and analytical cognitive thinking. The continuum is inclusive of the impact of time and risk pressures adding stress to the overall process.

Crichton also concludes that effective command requires:

- Competent, skilled, adaptive, flexible and versatile Incident Commanders and Command Teams
- Command strategies that move through the continuum mentioned from recognition primed to creative
- Situation awareness that is time and risk sensitive
- Simple and robust decision frameworks that are practised and reviewed.
- Opportunities to test and train these arrangements in simulated environments.

This contribution by Crichton is both recognised and supported. It draws on the examination of skills conducted by Flin and Arbuthnot and extensively reported in their jointly edited publication. That study identified the gap in understanding between academia and those that have observed and analysed the performance of Incident Commanders as practitioners. In the joint publication the functional exercise of command is set in context using six case studies, one contributed by the author. That is the incident related to the Associated Octel fire and explosion referred to in the Key Case Studies chapter. The use of case studies in this way is fundamental in aiding the understanding of why decision-making can appear at incidents to be intuitive. The main lessons being:

- Remaining focused on the desired outcome [often maximum safety or minimum cost]
- Dynamic situational awareness [managing risk against success]
- Effective communication and data analysis [control systems and information presentation]
- Skilled interpretation and fluidity in the use of options [command team skills and confidence even to use novel decisions]

The outcome therefore is far more likely to result from a sophisticated background of cultural, historical, managerial and operational understandings aquired personally, although not necessarily recognised by the individual, which are applied in the operational circumstances. Practising that application in the most routine of situations alongside a readily understood command and control framework is seen as most advantageous as it assists in reinforcing good practice without the stress of time pressured and complex situations.

6.4 New Paradigm for Fire Service Decision-Making

Essentially it is considered that NDM has considerable value as a practical approach. Burke identified, the decisions made by many fire commanders appear to demonstrate a perception of very limited choice so far as the individual is concerned. Flin, Arbuthnot and Crichton all indicate how decision-making processes can vary between situations using more or less cognitive skills.

Observing what happens on the fireground it has been noted that visualisation is a key contributor to situational awareness and fireground decision-making. Equally command performance is improved if there is an organisational cultural background based on a learning organisation, which provides enhancement to the NDM approach.

In the fire service the entire learning and training approach emphasises the need for all personnel to fully understand equipment and procedures, the rationale being that the operational scenario cannot be predicted. It assumes equipment deployments, tactics and procedures are utilised within a universally understood framework. Thus the multi-skilled firefighter is expected to be capable of recognising omissions through situation signals or 'clues', whilst at the same time comprehending the inherent strengths of the equipment and essential safety procedures. This provides an extremely flexible yet robust system for operational response, which can be activated under very stressful and time-constrained conditions where noise[22], heat and/or humidity interferes with the mental reasoning or physical strength of the individual.

This is essentially a form of two-phase working, using both analytical and RPD skills and which also places high importance on the communication requirement and primacy of the Incident Commander[23]. Central to situation awareness are the clues gained by observation. The sensory signals of sounds and smells, which the individual experiences greatly influences the responses he will make[24]. Visualisation in this sense is critical, and how it might be aided is described later. However, at many incidents the weakness and stresses in the decision-making by the Incident Commander[25] appear to be generated by the desired speed of response and lack of information available.

Encapsulating both defensive and responsive actions, the Incident Commander may integrate elements of response in a modular way. The whole process appears to try and act in equilibrium having prescriptive responses and flexibility whilst also avoiding being a simple repetition and imitation system, given that it may be confronted by complex changing situations that will create additional tensions and demands. The fire service officer will be operating using both a stability paradigm and one that sits outside the arrangement and is therefore conversely extremely unstable [26].

Simulation and visualisation are also used extensively in considering the best tactic to deploy. The cognitive ability to visualise the incident is a key component of operational command and, in some cases, the commander's own personal experience and skills may unduly influence the decision reached by for example short circuiting what should be an analytical process. Under these circumstances the balancing influence of the command team and the control system assumes a crucial role.

Improving those skills is an outcome of learning and in this context the concept of a learning organisation, an organisation achieving continuous improvement in a climate free of blame and attuned towards positive progress, is relevant[27]. Audit processes, such as the incident debriefings that follow major incidents, reinforce this particular developmental process[28]. A participative culture is another part of the strategy that seeks to use positive criticism as a route to improved performance[29].

Operating in this way the Incident Commander derives benefits:

- The IC will be better educated, more flexible and thus better able to accept and interpret information from a wide range of sources and interpret it more effectively
- The organisation will be in a position to produce and provide more relevant information without the risk of information overload by assessing its value and priority

at a given incident.

- The IC will operate in a culture that values all contributions and consequently be more inclined and confident in accepting and giving advice and instructions. The culture should also speed up the communication of information on the fireground.

It is suggested; therefore, that decision-making in the fire service should be interpreted as operating at two distinct levels, one action-centred and the other open to the wider environment. It is postulated that in the overwhelming majority of fireground operations the fire service involvement is a short-term highly action-orientated activity rather than a longer-term strategic management system. Exploration of the NDM approach is seen to have value, although it appears to emphasise only one aspect of operations on the fireground and does not fully recognise how the fire service manages.

A provisional incident command and control system was developed within Cheshire Fire Brigade to encapsulate these ideas. This resulted in a new paradigm, Figure 6.1 that was formulated to incorporate advisory documents, such as Dealing with Disasters[30] and the Fire Service Operating Procedure for Major Incidents[31] and the issues of simulation [situational awareness and anticipation] and repertoire [standard operating procedures]. It was after the Home Office published further guidance[32] slightly modified. The paradigm after implementation and review following operational use at many operations, including major incidents such as the Chester warehouse fire in 1996[33], has demonstrated adaptability in use at a variety incidents and ease of understanding by personnel at all operational command levels. The model illustrates how the essential elements of information, resource commitment and an established repertoire of actions are employed in incident management. Remote observation to allow visual appraisal of the fireground whilst not generally available at the time of development is suggested as an improvement and future key determinant leading to improvement in fire service decisions.

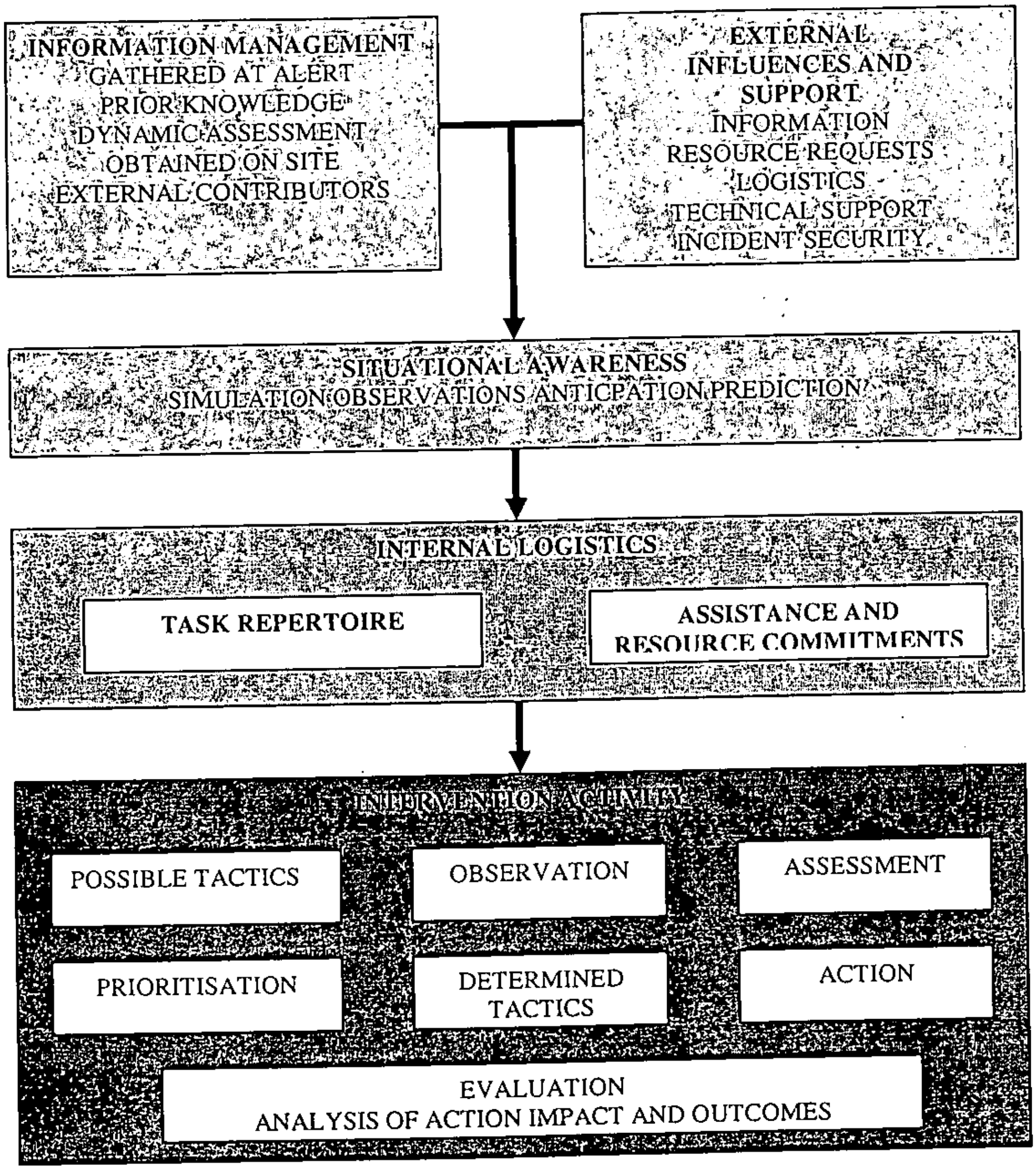

FIGURE 6.1 PROPOSED DECISION PARADIGM FOR FIRE SERVICE COMMAND AT MAJOR INCIDENTS [DAVIS]

Thus the approach portrayed utilises the known and observed practices previously discussed. Fundamentally the number of practical options is dictated by the repertoire of skills and equipment configurations available. Whilst the fire service role continues to expand this repertoire remains a definable input and hence predictable. What cannot be defined or fully predicted is the actual operational environment in physical or emotional terms. Thus the environment may be mapped to a previous experience and recognisable or it may be novel. Likewise since prior or assumed knowledge may assist or mislead the importance of dynamic assessment is confirmed.

Consequently there remains a constant and vital role for cognitive assessment to simulate and anticipate the impact and outcome of decision options. This simulation may be enhanced by actual observation and the ability to achieve observations is therefore highly relevant. Although technology can assist in this area current practice suggests little importance is placed upon this factor in decision making. Rather practice appears to invest in personal protective tools that continue the historical approach of placing firefighters into hazardous situations.

It is postulated that more likely improvement in decision making to reduce personal risk will occur from investment in assembly and analysis of data from various sources and the synthesis and simulation of that information into operational options. Technology can provide that platform, a platform that can then be extended through the use of artificial intelligence and computerised simulation to provide interactive learning for potential commanders thus reducing their personal vulnerability to poor decisions and improving overall public safety.

This initial paradigm is then refined still further producing the version outlined in Figure 6.2

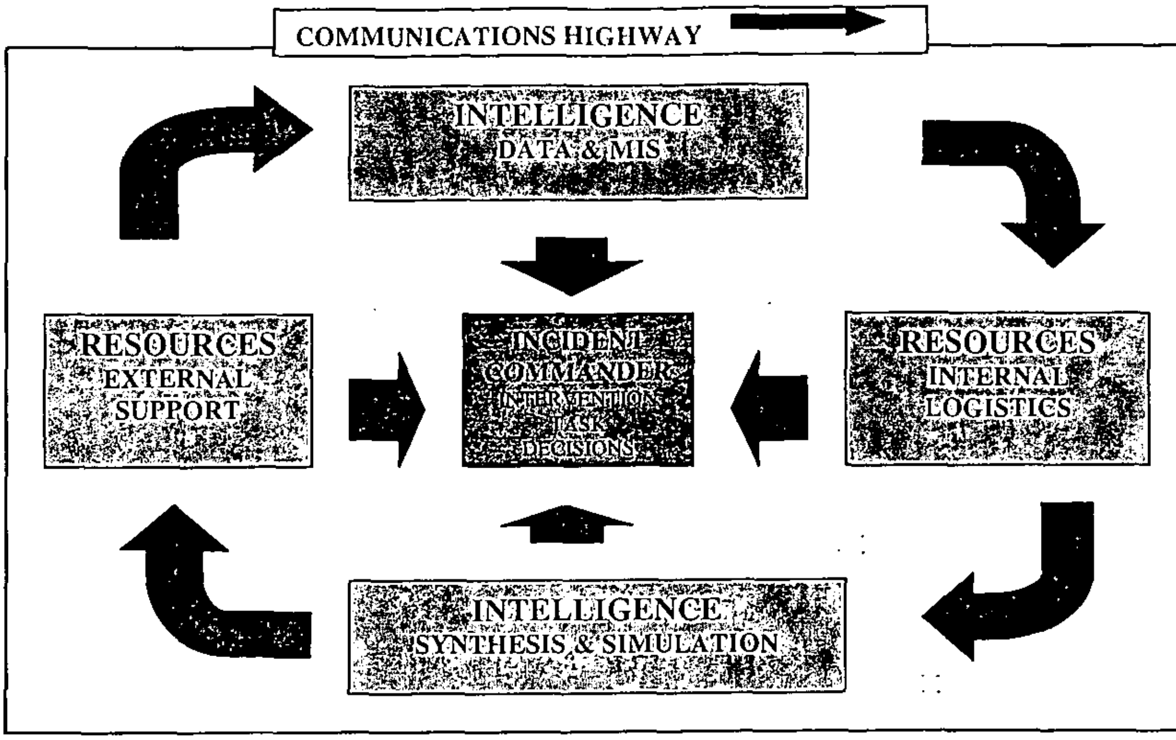

FIGURE 6.2 CRISIS DECISION-MAKING PARADIGM [DAVIS]

This paradigm accepts the central concepts behind the existing NDM models, particularly that the commander maps the present incident onto his previous experience and takes action deemed appropriate based on that experience, whilst also focuses upon two other important influences. The first relates to the cultural way an organisation uses information; the second raises the importance of enhancement of situational awareness through better visualisation using technology.

Consequently this new paradigm envisages a wider integrated relationship than that currently accepted. The links between the command and control process; the use of a repertoire of practical task orientated responses; the availability of assets and logistical support; and the operational analysis and evaluation process, all remain. However greater emphasis is placed on having higher-level management for information and a new component that of dynamic simulation is introduced.

Consequentially anticipation of the developing situation combined with actual observation become integral in the decision-making process. This new paradigm therefore helps illustrate how excess poorly presented information [overload] and the inappropriate behaviour by senior remote commanders [decisions based by proxy on ground commanders using relayed images] could distort the decision process and represent a danger to achieving a successful operational outcome.

Fire service culture, in changing to more participative organisation styles, allows better cross-functional working and the creation and introduction of more open decision approaches. The author identified these initially as 'participative' although they are now more widely described in management terms like 'continuous learning organisation'. They can be tailored to enhance fire service operational requirements and this process is described in the Cheshire Case Study Appendix.

This organisational approach also challenges the previously held view that two distinct management decision styles, i.e. one on the fireground and one in the station, need to co-exist within the fire service and suggests that one encompassing decision culture is appropriate. Thus as the fire service moves towards greater empowerment of staff, it essentially establishes a more flexible organisation willing to seek out opportunities to use a wider range of management tools to analyse and assess available information.

It is this conclusion that emphasises simulation and suggests extension to incorporate and enhance the importance of visualisation, which in turn requires improved technical and technological assistance.

This paradigm, which has been tested under operational conditions, recognises that equilibrium exists between intelligence and physical resources within an integrated communication network. It therefore suggests that the best use of resources will occur from greater use of information and predictive analysis. Practically the paradigm requires further incorporation of technology to help capture and use data in real time. Once captured this data could through case study analysis provide expert logic tree based computerised decision support systems, so helping reduce errors and improve decisions. Extending this process through computer assisted simulation could produce a safe learning environment for potential command officers.

6.5 Transferring into Operational Practice

However applying such novel concepts in practice demands significant communication. Incident Commanders, for example, may accept that a flexible approach will support their actions and provide good results, but it may also leave them vulnerable if they act outside accepted practices and the advice given within instruction manuals or nationally recommended procedures. Indeed, failure to follow this guidance would, should an accident involving personal injury or loss occur, leave the individual Incident Commander vulnerable to a legal challenge that may include corporate responsibilities. That said firefighters and their commanders frequently take unorthodox approaches to achieve successful outcomes.

Fire service response is inevitably equipment and procedure-based[34] and in a conventional UK fire brigade this will centre on the arrival of the first appliance with a crew of up to five firefighters. There may be up to thirty actions that could be followed by the arriving crews, each of them concentrated on a particular procedure or piece of apparatus or equipment. The on-scene 'clues' will suggest which of the possible actions might be appropriate, dictating the actions to be taken by the Incident Commander. Visualisation of the situation occurs en-route, discussing tactics prior to arrival amongst crewmembers. The en-route analysis includes consideration of available risk information and how this information is presented affects its value.

On arrival, the on-scene clues (noise, smells, and the actual scene unfolding in front of the arriving crew) will all suggest certain actions and options. If a crowd has formed it can influence priorities of action since rational, normal human behaviour when applied in abnormal circumstances and at the wrong time can be confusing and inappropriate[35], so posing a threat to efficient management of the incident.

Information overload is also a risk during this critical phase so it is essential that data given to the Incident Commander needs to be precise, recognisable and appropriate allowing calm analysis. Unwitting supply or mis-information will create new, false priorities. For example, a common occurrence is for individuals to say that someone is trapped within a building when in fact everyone is safe, thus committing the responders to an unnecessary search and rescue task.

In the action-orientated phase the Incident Commander is confronted by, perhaps, a confusing scene and yet is required to identify key factors and select options from the accepted repertoire of firefighting and rescue activities to meet that scenario.

The description of events above reinforces the RPD approach and confirms the work of Burke and Hendry[36]. There is a clear recognition in those studies that the responses made by Incident Commanders are generally those which are so entrenched through training or through procedural knowledge that they are used automatically and without a great deal of analysis. However, some incidents, such as those outlined in the Key Case Studies, are particularly challenging and present Incident Commanders with very difficult scenarios. These incidents may require the fire service to work with paramedics or trauma teams, whilst simultaneously conducting a rescue operation. Work of this nature can require a different form of approach. Although the operational skills and equipment may be well understood, the particular circumstances may be quite unique. It may require extensive periods of analysis before the rescue is actually conducted.

In addition there are other incidents, typically rescues, where individuals are in such a position that they require the fire service equipment to be deployed in a completely novel way. There will also be situations where the personal injury risk to the firefighter is judged to be a significant factor, for example, silo or deep underground working. Such non-typical rescues are occurring on a more frequent basis, partly as technology in the manufacturing areas increases and partly as a direct result of human mobility and the increasing use of transport systems. The system of command and control used in the fire service has to recognise this operational environment.

6.6 Summary

The process of decision making on the fireground has been analysed, primarily outside the fire service and in the USA with complementary and overlapping models of RPD and NDM. Both emphasise the importance of mapping the information obtained at the fireground onto the Incident Commander's previous experience, in order to pursue a plan of action. Even before these theoretical developments became more widely known UK brigades had empirically recognised that training and simulation were essential for effective activity by firefighters on the fireground.

The summary drawn is that the observed process may be improved still further using technological support, a point raised in Chapter 7. Enhancement may also occur through cultural change, which promotes the notion of modest risk taking, team based working and more interactive decision-making.

The concepts and approach of being a learning organisation help overcome those limitations that do arise when new methods of reaching better decisions are introduced. This is because an open culture of learning opens up the whole process of receiving, analysing and communicating information, so aiding clearer understanding in multi-disciplined team working. The experience of introducing this type of change in the Cheshire Fire Brigade over a three-year period confirmed this approach did secure an enhancement and improvement of decision making and hence performance at operational incidents.

Furthermore these cultural changes stimulate awareness of the wider contribution, offered by other agencies and technology, so encouraging an attitude of constructive challenge and broader participation by other contributors. The move from a more restrained traditional culture seeks to reinforce past practice with the added strength of the simple 'could this be done better' question so promoting continuous improvement in overall performance by better understanding learning outcomes from case studies.

In the quoted examples used in this research it is apparent a higher level of safety could have ensued had the elements of greater situational awareness and access to sound data been in place. None of the three case study events should however be regarded as a failure in terms of fire service intervention. What in fact occurred was that hazards capable of identification continued to threaten yet they could have been mitigated and in some instances even removed. Refining the decision making process along the lines outlined in the new decision paradigm can help achieve this worthwhile aim.

CHAPTER 6 REFERENCES

1 Ehrhart, L.E. [1997], *Integrating Multimedia Information for Joint Theater Command and Control,* IEEE, 724-731.

2 United States Airforce Air Combat Command. [1993], *Air Concepts for Theater C^4I*

3 Andride, SJ. [1989], *Handbook for Decision Support Systems,* Tab Books Inc Blue Ridge Summit.

4 Nelson, MA. [1993], *Combat Requirements for C^2*, Plenary Address to 1993 Symposium on Command and Control Research, National Defence Ministry, Washington DC, USA.

5 Neal, D. [1995], *Effective Emergency Management: Reconsidering the Bureaucratic Approach,* Disasters, Vol.19, No.4, Blackwell Publishers Ltd., Oxford.

6 *As Chapter 6 reference 1.*

7 Perry, W.L., Moffatt, J. [1997], *Developing models of Decision-Making,* Journal of the Operational Research Society, 48, 457-470, Operational Research Society Ltd. Birmingham, UK.

8 Klein, G., Orasani, J., Calderwood, R. and Zsambok, C. (Eds).[1993], *Decision-Making in Action,* New York, Ablex.

9 Perry, W.L., Moffat, J. [1997], *Measuring Consensus in Decision-Making: an Application to Maritime Command and Control,* Journal of the Operational Research Society, 48, 383-390, Operational Research Society Ltd. Birmingham.

10 Neal, D. [1995], *Effective Emergency Management: Reconsidering the Bureaucratic Approach,* Disasters, Vol.19, No.4, Blackwell Publishers Ltd., Oxford.

11 Klein, G., Orasani, J., Calderwood, R. and Zsambok, C. (Eds).[1993], *Decision-Making in Action,* New York, Ablex.

12 Perloff,M. [1993], *Videoconferencing for Command and Control,* IEEE, 476-479.

13 Kaempf, G.L. Klein, G., Thordsen, M.L., Wolf, S. [1996], *Decision Making in Complex Naval Command and Control Environments,* Human Factors, 38(2), 220-231 Human Factors and Ergonomics Society.

14 Millar, L. [1996], *RPD on the Fireground. How to Avoid Blank Screen Syndrome,* American Fire Journal, Vol.48, No.4, Pages 37-42.

15 Steffens, J.T. [1994], *The RPD Model of Fireground Decision Making,* Firehouse Journal, Vol.19, No.4, Pages 75 - 85.

16 Klein, G., [1991], *Naturalistic Decision-Making*, San Francisco, American Pyschological Association Conference.

17 Flin, R., [1996], *Sitting in the Hot Seat,* John Wiley, Chichester.

18 Burke, E., & Hendry, C., [1995], *Decision-Making on the London Incident Ground*, Paper presented at the Fourth European Congress of Psychology, Athens.

19 Hendry, C.D. [1994], *Looking for Clues*, Brigade Command Course Project Report, Fire Service College, Moreton-in-Marsh.

20 Workhouse Limited. [1991], *Intelligent Command and Control: Acquisition Review Using Simulation*, Learning Technologies Unit, Employment Department, TSO.

21 Flin,R., Arbuthnot,K. [2002]. *Incident Command: Tales from the Hot Seat*, Ashgate, Aldershot.

22 Tubbs, R.L. [1991], *Occupational Noise Exposure and Hearing Loss in Firefighters*, American Industrial Hygiene Association Journal, Vol.52, No.9, Pages 372 - 378.

23 Bonney, J., [1995], *What Makes for Effective Performance? Fire Command Teams*, International Project Report, Brigade Command Course, Fire Service College, Moreton-in-Marsh.

24 Murray, B., [1995], *Incident Command Expertise*, International Project Report, Brigade Command Course, Fire Service College, Moreton-in-Marsh

25 Dobson, R., [1995], *Starting as you mean to go on. A study of compliance with operational procedures during the first 10-15 minutes of incidents*, International Project Report, Brigade Command Course, Fire Service College, Moreton-in Marsh.

26 Fredholm, L., [1995], *Decision-Making in Firefighting and Rescue Operations.* Paper presented at the Third Emergency Planning and Disaster Management Conference, Lancaster University, Lancaster.

27 Cook, J.A., Staniforth, D., & Stewart, J., (Eds.,) [1997], *The Learning Organisation in the Public Services*, Gower, Aldershot.

28 Fortune, J. and Peters, G. [1995], *Learning from Failure - The Systems Approach*, John Wiley, Chichester.

29 Issac-Henry, K., Johnson, E., & Pante, C., [1993], *Management in the Public Sector; Challenge and Change*, Chapman & Hall, London.

30 Home Office, [1997], *Dealing with Disasters*, 3rd Edition, Brodie, Liverpool.

31 Chief and Assistant Chief Fire Officers Association. [1995], *Fire Service Operating Procedure for Major Incidents*, CACFOA, Tamworth.

32 HM Fire Service Inspectorate, Publications Section, [1999], *Fire Service Manual, Volume 2 Fire Service Operations Incident Command*, TSO, London

33 Cheshire Fire Brigade [1996], *Report on the Pickfords Warehouse* Fire, Cheshire Fire Brigade, Unpublished Report.

34 Gunter, D., [1996], *Effective Crew Command*, Research Report, Fire Service College, Moreton-in Marsh.

[35] Canter, D., [1990], *Fires and Human Behaviour*, 2nd Ed., David Fulton, London.

[36] *As Chapter 6 reference 18.*

CHAPTER SEVEN

Using Technology To Enhance Decision-Making Systems

7.1. Information Technology Overview

The previous chapters have illustrated the value of well-presented information to the Incident commander and his team. That data needs to be captured, stored, retrieved and delivered in safe and robust ways if it is to be available for use on the fire ground. Chapter 5 indicated that any system provided to do this must be 'fit for purpose' and capable of meeting the demands of, and be compatible with, firefighting operations. The information delivered to the Incident Commander also needs to recognise the command decision process in which it is to be used. This process described in a new paradigm in Chapter 6 is most likely to include recognition primed responses and a higher-level situational awareness. Using a range of media that aids visualisation, either in real time or from archives or conventional text, is therefore an important feature. The essential information technology support system that offers the widest options in these circumstances is a computerised one, especially if immediately available in the first response appliance cab. Any mobile data system requires robust maintenance arrangements and will retain some reliance upon support, by radio and other information technology communication, to the fire brigade central control room[1].

Commercial software programmes provide numerous systems offering text and graphics[2] some capable, with modification, of meeting fire service requirements. Fundamental to any requirement is the construction of cost-effective, robust central databases[3]. Whilst there have been serious failures of bespoke tailored systems[4], present IT technology is judged[5] to be capable of operation in the vehicle cab environment and able to withstand the physical treatment likely to be received on the fireground. Current working systems are evident in a number of UK brigades and Vehicle Mounted Data Systems [VMDS] are now in widespread operational use.

The convergence of telecommunications technology; mobile computer hardware and software developments are especially valuable. The networking of mobile data is developing rapidly and to meet the needs identified in previous chapters, early research trials designed to test the applicability of information technology as required in the central hypothesis were initiated by the author between 1990-1996. These trials were directed and supervised by the author and consisted of the following trial evaluations.

- Investigations, using CCTV, to improve visualisation of an incident site for both local i.e. Incident Commander, and remote i.e. Fire Control, use;
- Provision of aerial observation;
- Consideration, through real incident use, of thermal imaging to identify fire development;
- Investigations, using a prototype robotic vehicle, of remote control and data gathering opportunities;
- Evaluation of a shared electronic data transfer system for incident management by different service users;
- Creation of a practical user's data package using media opportunities like three dimensional drawing, video and still photography, digital mapping and existing data stores, including risk information;
- Investigation and practical evaluation of vehicle mounted computers to store the user data package; and
- Consideration, following investigation, of the value of enhanced gas and vapour cloud modelling.

7.2. Video Technology

Visualisation is important to incident command and control and relaying video real time images to operational commanders using closed circuit television [CCTV] assists for example, at a complex site [enabling the Incident Commander to remain in a static command location]. CCTV as such is a valuable reconnaissance tool allowing, for example, monitoring of fire progression to improve tactical decisions without personal risk or assessment of the operational situation before deployments. Valuable additional information may be obtained by linking with thermal imaging. Integrating security CCTV, common in many town centres and industrial sites, is also a useful tool in extending the available information sources for the Incident Commanders. Digital compression techniques that have for example expanded this technology into mobile telephones illustrate the growing number of options that now exist.

The early projects initiated placed CCTV images within a mobile command vehicle and relayed them to fire control. Whilst difficulties were found in interfacing CCTV into the fire brigade command and control facility these were ultimately resolved. As part of these trials, aerial apparatus routinely used by the fire service for fireground observation and which can operate under most climatic circumstances apart from the most severe wind conditions, was fitted with a CCTV camera to provide a 'bird's eye view'.

Although in the early 1990s this was a new innovation, fitting the CCTV camera was not complex. The initial difficulties centred upon the fixing of the rotational guidance system and passing the relay cable, which was used rather than wireless, through the rotating 360° base of the aerial apparatus. These difficulties were resolved in 1996 and the equipment remains fitted on Cheshire Fire Brigade's four aerial appliances.

Using digitised wireless technology the captured visual scene was relayed to a mobile command vehicle working some distance away. This was the most flexible method of conveying the image using a radio signal since it avoided excessive cable lengths and the attendant risk of damage to the cable and degradation of the signal. It was found that a radio system capable of operating remotely in adverse weather conditions would cost in 1996 approximately £10,000 for each apparatus. The practical investigations demonstrated that live data transmission using radio presented technical problems due to atmospheric and physical disruption.

A draft specification, prepared for the project trial, identified desirable features as including: -

1. A full colour visual image;
2. An auto iris focusing lens to give best optimum view for variable light conditions;
3. Remote camera operation from ground level;
4. Operation initially at the base of the aerial apparatus, but possibly much further afield;
5. The camera to have a motorised zoom facility and wide-angle view. [14 to 1 magnification was adopted with a 7.5mm to 105mm wide-angle zoom lens]
6. A portable full colour supervision and viewing monitor;
7. Videotaping of the image to permit critical audit of operations;
8. All the equipment to operate in daylight and night conditions and in potentially extreme environments of high temperature, humidity, smoke, water and airborne chemical contaminants;
9. The apparatus needed to be capable of being cleaned relatively quickly without specialist knowledge;
10. The equipment to be constructed with reliability, maintainability, flexibility and portability as key requirements; and
11. If radio transmission could not be used an operationally acceptable distance between the camera and its monitor had to be established [This was later confirmed as 500 metres and radio linkage was not used at the trial stage].

This initial specification was subsequently modified to require the camera to be intrinsically safe for operation in flammable gas clouds.

Security Design Centre supplied a prototype camera in the summer of 1996 and the system demonstrated in October 1996. The trials were a success and apparatus was taken into operational use in December 1996.

7.3 Aerial Observation

Liaison with Cheshire Constabulary identified the possibility of using their airborne reconnaissance aircraft. Whilst this aircraft is not available 24 hours a day, cannot fly under certain weather conditions, and cannot remain static over a specific site because of its fixed-wing design, it has demonstrated valuable visualisation support.

Again it was proven using this technology a real opportunity exists to vastly improve the information sources available to firefighters on fire spread. Practical examples of the value of such facilities were seen in two incidents when a Police aircraft was able to advise the Incident Commander of fire progress. The first occurred at a major school, Brookvale Comprehensive, Runcorn[6], where the fire spread from a central well, not obvious at ground level, was identified by an overflying police aircraft. The Incident Commander altered his tactics to help contain the spread in consequence of the information supplied by the police. The second incident was the 1996 Chester warehouse fire[7]. Again, the police aircraft was available and offered the Incident Commander confirmation of fire spread from the warehouse to adjoining buildings.

7.4 Thermal Imaging Technology

Thermal Imaging became accepted by the fire service in the 1990s. The fire service routinely uses hand held or helmet mounted cameras to provide a portable tool enabling firefighters to "see through smoke". They are used to locate casualties and identify "hot spots" of burning materials, concealed within walls and cavities.

Police aircraft are often fitted with thermal imaging technology and this can be of major assistance to the Incident Commander. In the Chester incident, which occurred in darkness, the aircraft had a thermal imaging camera and accurate information of fire spread inside roof spaces was given from the air when it was not obvious from the ground. The use of such information for prediction of fire movement and command decision-making is confirmed by the two cases cited here. One major limitation observed in both incidents was that of relaying information from the aircraft to the fire service on the ground, due to interoperability difficulties between various radio systems and channel frequencies. It is intended that these difficulties will be resolved as part of a radio replacement strategy shortly to be undertaken that has one of the requirements to enable interoperability between all emergency services.

The utilisation of thermal imaging in this way has yet to be fully investigated. The provision of this equipment, on fire service aerial appliances offers the advantage of high immediate availability, so adding considerably to the visualisation sources available. Thermal imaging equipment is both robust and reliable and has the potential to form one of the more important information strands. Combining the localised CCTV and aircraft transmitted images offers the capability of securing, under virtually all-climatic conditions, aerial observation of an incident with extremely good clarity.

7.5 Robotics

Whilst this section is not a review of robot development, nor a review of robots available, it does provide a limited assessment of fireground robots as used by the Tokyo Fire Department and the joint development of a prototype fire service robot between the UK Defence Establishment Research Agency [DERA] and author. This is because it is considered that fireground robots have a specific capability to access hazardous places and situations so avoiding firefighter risk. Equipped with video or thermal imaging devices they can gather information and with the right tools possibly firefight and operate in highly toxic environments.

During an invited visit to Japan* opportunity to examine the range of robots used by the Tokyo Fire Department [TFD], which has invested substantially in the development of robotics[8]. Of particular note, and already in operational use, was a wall-climbing robot for ascending high-rise buildings, both to assist firefighting and to provide CCTV images. Other robots seen were for use in underwater situations, robotic vehicles for reconnaissance, recovery and firefighting. The TFD was also investigating the possibilities of air strike capabilities from a helicopter.

The TFD has not published any figures on the costs of these units but they are thought to be substantial. It is also very difficult to estimate the impact that these robots have had upon firefighting in Japan, as there is no precedent or published audit measure. However, observations support the proposition that robots do offer a further safety potential.

The trial project to develop a UK fire robot was undertaken by DERA in Cheshire Fire Brigade using a Ministry of Defence modified robot technology and expertise previously used with tracked robots used to handle explosives and frequently referred to as "wheelbarrows". Recognising these possibilities for functional fire service use,

* Between 18 and 22 October 1994, the Tokyo Fire Department hosted a conference entitled "Fire Safety Frontier '94." This conference was unique; as it was the first time that the Tokyo Fire Department had illustrated its robotic capabilities to the world at large. The overall impression was of a technically highly advanced department.

especially for reconnaissance, discussions were held at the DERA laboratories* during the summer of 1995, initiating development of a prototype fire service robot. DERA had developed a small diesel driven 6 miles per hour robotic platform able to climb a step height of 0.3 metres with a 100kg payload.

Subsequently, field evaluations of typical scenarios on an industrial site were conducted in Cheshire to evaluate performance. They included entry and remote control in a building containing pumping machines, movement through a rail tanker area, and the projection of a foam jet onto a rail tanker. Approximately twenty experienced fire service observers then completed an evaluation sheet so assessing potential fire service use. The evaluation confirmed that the officers present considered the robot viable for fire service use, especially reconnaissance, obtaining environmental samples remotely, e.g. when toxicological, biological or radiation hazards were present. Improvements were also suggested such as including intrinsic safety+ requirements to allow operations within petro-chemical environments[9].

The trial project enabled a systematic evaluation and confirmed that was both feasible and practical to provide a small and affordable remote firefighting vehicle for use in highly hazardous operational environments. At present the study remains the only practical evaluation of small fire service working robots in the UK. [A larger tractor based firefighting unit is in service in the West Yorkshire Fire Brigade]. One outstanding unresolved question was that of radio frequency assignment[10] since the DTI and the Home Office have been unable to grant the necessary control channel[11].

* Defence Establishment Research Agency, 2K T16 DEE (Cobham Lane, Chertsey, Surrey)
+ Intrinsically safe electrical equipment is usually apparatus that either has sparking that is incapable of causing an ignition of any flammable gas or vapour or which contains such sparking, by its construction, to render it incapable of causing an ignition or explosion.

7.6 Electronic Data Interchange and Transfer

The availability of information affects the accuracy of decision-making. Zorkoczy and Heap[12] state that high-quality information enables the recipient to make sense of the environment and the more accurate information an Incident Commander can obtain, the better the decisions made. But in many cases it is equally important to secure necessary information at the right time. Electronic messaging overcomes this weakness and a messaging project was therefore undertaken.

Central to major incident decision-making is data manipulation and transfer of critical data between the involved agencies, recognising each holds data, which may benefit the others. Investigations into inter-agency electronic mailing* initially focused upon the feasibility of using a conventional office system[13]. While combined multi-agency systems of this type are not generally used for emergency management in the UK, many investigators[14] have identified the increasing importance of information and the use of information technology.

The project defined requirements for a common multi-user system determined like a real-time on-line incident record format, the facility to retrieve and to browse existing or closed incidents, and a message creation facility for transmission to other agencies using the network. Thus three different but overlapping and simultaneous actions were envisaged; Electronic Data Interchange (EDI), Electronic Data Transfer (EDT) and Database Access (DA), the relative importance of each determined by the magnitude and type of incident. Joining the network activated the system and the generation,

* That investigation related to the electronic mailing system used by Cheshire County Council, and referred to as Cheshirelink. This system links all County Council computer users and has the facility to extend its range throughout Cheshire to other agencies.

editing and sending of messages was menu driven with simple on screen icons since, during incidents, users would be entering the system at varying times with different stages of comprehension. Information was therefore rapidly distributed between crisis team members who could also work independently[15]. The system, running a timed log based on the work done by a particular user, and with a continuous log detailing all transactions and all user identities would then provide a subsequent audit trail* and method of debriefing to assist in future planning.

A trial multi-user EDI system was constructed with modified software to confirm the practicality of inter-agency joint operability. This practical small-scale operation in controlled conditions confirmed that the use of e-mail would be appropriate for some inter-service operations, though more complex data transfer would require other formats. The designated log and message requirements used a split screen with two working areas, with one side being used to convey the running log of the incident, whilst the other side contained all messages sent and received by the system in relation to the incident. These messages appear in chronological order, identifying the originator and text. The 'user side' of the screen contains a working area where messages were created, sent and received. The trial showed that a split screen or Windows* style configuration was practicable in providing a multi-user information system.

The Internet provides the least expensive messaging system. Although insecure this global medium makes use of software tools and methods that are widely standardised, increasingly understood and accessible to non-technical users[16]. The low costs and easy

* Subsequent discussions noted an increase in reluctance to have an auditable log following the trend to apportion blame for legal reasons.
* Windows is the registered trademark of the Microsoft Corporation, USA.

accessibility are major advantages of Internet–based EDI and while there are no technical reasons that prevents EDI transactions from being sent over an Internet carrier, provided that prior to the incident, all the emergency services had reached agreement on the introduction of a common EDI/EDT [17]. Security and reliability issues preclude the emergency services from adopting this route at present.

7.7 Mobile Data Trial

Turban et al[18] report an increasing importance being placed on information, and recognise that simultaneously, there is increasing difficulty in processing that information due to the amount available and its complexity. These authors agree with the conclusions reached earlier in that:

1. Many decisions are made under time pressure. Frequently, it is not possible to manually process the required information quickly enough for it to be effective.

2. Due to increased fluctuations and uncertainty in the decision environment, it is frequently necessary to conduct a sophisticated analysis to make an acceptable decision. Turban suggests such analysis usually requires the use of IT.

These general points hold true for the fire service. There is a considerable volume of useful and essential information already in existence and whilst some is carried as hard copy it is clearly impractical to provide all such information on a firefighting appliance[19], with a risk that harm to firefighters or poor incident management may result. Hence the fire service command and control centre becomes the central depository for operational information. Ideally, however, any information database should be directly accessible, in a user-friendly manner to the firefighter[20].

ACTIVITY	COMMENT
LOCATION	Geographic footprint, vehicle route from fixed [fire station] and mobile [vehicle tracking] locations.
ACCESS	Best point of entry, perimeter gates, floors. Photographic or video assistance for difficult routes.
SPECIFIC RISKS	1(1)(d) data, CAD and 3 dimensional layout drawings. Colour coded risks.
HAZARDS	Identification, action codes, inter-active hazardous material, equipment, resource availability, standard operational procedures databases
ASSESSMENT	Intelligent risk analysis diagnosis tools, resource deployment information, personnel role, incident log of messages and actions.
ACTIONS	Access to extinguishing agents like water, geographic and demographic infra structure data, incident visualisation, diagnosis tools for fire and damage spread, modelling of predicted actions, transport infra structure details, climatic data.
FUNCTIONS	Database support for functional staff, e.g. foam, water, breathing apparatus, etc.
ENVIRONMENT	Geographic recognition of area sensitivities including inter active sampling and modelling.
REFERENCE	Best practice general guides on operational matters, e.g. Manuals of Firemanship, fire science, training notes.
REVIEW	Recording of actions for audit and debriefing purposes.

TABLE 7.1 USER REQUIREMENTS

The availability of fire service and allied information sources is significant and, prior to investigating the use of mobile computers, consideration was given to likely useful data and this is summarised in Table 7.1. The table identifies a range and examples of the data available but not the likely need at any specific incident. Defining use is therefore a significant part of any information process that envisages the use of mobile computers with users on a fire appliance. The requirements listed do help, however, identify the data that can and is sometimes used at incidents and therefore provided a development template for a fire service hazard management system.

Translating these issues into the working environment for firefighters that may be extremely stressful[21] and climatically harsh with little time available to follow through any complex cataloguing or index process it was concluded access should be of a simple menu type. Zuboff[22] supports the earlier observation that the introduction of IT had to be accompanied by new intellectual skills. The simplicity of the retrieval process was therefore an important consideration and significant in determining which of the proposed systems to employ[23].

The rapid and effective transfer of data to the fireground using voice radio or hard copy facsimile is tedious [some fire brigades have only one major radio channel in operation], which some argue that radio is inherently unreliable being hearing dependent with a repetitious checking process. The transmission of digitally coded information via the radio vastly improves this situation, as evidenced in mobile telephone texting, but it was judged that the best solution to large-scale data needs[24] was a portable computer, which could hold relevant headline information to guide initial actions. Other researchers[25] have concentrated on identifying how the considerable amount of written and pictorial information used could be stored, in a user-friendly way, to support firefighting crews.

In 1995, trials were initiated of an in-cab delivery system[26] supported by a central data system using a conventional laptop computer and commercial software programmes modified to integrate visual, pictorial and text data. One early outcome of the trial was the recognition that it would be helpful to display the information being viewed to the whole crew and a slave screen in the rear cab would be beneficial. Trialing this technology enabled the initial firefighting users to tailor the information they required enabling a first attack at complex sites to be mounted successfully.

The issues then remaining were whether a data link to the fire control database should be used or whether the in-cab computer holds its own database which is regularly updated using radio or a hard-wired connection, for example in the appliance room. Secondary issues include the software used to access this information and the methods used to produce output under operational conditions. The trail was successful and contracts were issued for the supply of vehicle mounted data systems. VDMS, which this pilot project was a forerunner, is now widely accepted as the way forward although at the time it was regarded as an unnecessary complication to introduce technology of this kind into vehicles.

7.8 Gas Plume Modelling and Vapour Release

The importance of being able to model and predict the behaviour and consequences of accidental releases of gases and other contaminants has greatly increased as a consequence of public recognition that industrial plant, including that situated in the vicinity of dwellings, can no longer be assumed to be safe. Bhopal, Chernobyl and Flixborough are extreme examples of major accidents

As a consequence detailed research was undertaken to assess the value of accessible plume modelling for fire service use. This research is detailed in the Appendix. The outcome drawn is that a considerable amount of equipment and computer aided software exists and there are therefore a number of predictive tools available. However, matching these tools with skilled staff, remains currently problematic for the few occasions that this enhanced capability is needed. It is feasible to introduce and as concerns grow related to environmental pollution arising from fires generally then it is possible these tools will become more widespread in fire service use. In the interim it is suggested that existing 'rule of thumb' calculations be transferred onto VDMS laptops to provide a better predictive analysis.

7.9 Geographic Information Systems

Cartography has long been used within the fire service as a method of noting where risk premises are and obtaining good access routes to those premises. Keates[27] argues that at least three particular uses of maps may be considered. The first is seeking a named feature where little pre-knowledge is required and scale is unimportant. The second is highly selective searching within a limited area, its use is typically as a problem solver and the maps used will require detailed scales. The third use is to conduct an extensive search, perhaps across a whole area and here again the scale is not important.

For some time, digitised maps have been available, and are now generally subsumed within the general title of geographic information systems (GIS). GIS provides a high quality map with the improvement of information overlays so permitting the reduction or increasing of the amount of information shown. It also enables customising for use such as that required by local authorities for highway or survey purposes. Digitising and developing maps has enabled three-dimensional terrain imagery to be undertaken. These are particularly useful when considering gas plume movement or, at a more local level, physical structures of buildings. Computers have the ability to create spatially related data sets with layers of inter-related information and this has permitted GIS[28] to provide an information management system useful to the fire service[29]. This is not entirely new; work has previously been undertaken within the retail sector to use data in this way and the growing importance of integrated risk management increases the fire service use of the spatial data capabilities offered by GIS.

The introduction in 1970, by Ordnance Survey [OS], of the digital map system has greatly aided this process[30]. There are various types of maps from OS. Some using raster data produce overlays of 1-50,000 or the 1-10,000 in black and white. Vector mapping using bitmap computer projections and dot colouring permits 1-1,250 urban and 1-25,000 rural files to be created which can be held under licence for CAD and control and command systems. Consequentially digital maps are used as input for major incident management and planning, for example, the OS Land-Form PANORAMA™, ADDRESS-PONT™ or OSCAR Route-Manager® series. Many of these digitised map systems are already used by utilities such as water, gas and pipeline companies for recording their information. Hydrological maps, from the Hydrological Survey, exist for drainage and ground water risk assessment.

Inter-related with the GIS system are those satellite navigation arrangements introduced by the US Department for the Defence Global Positioning System (GPS)[31]. This has relevance as mentioned under user requirements for improved vehicle tracking, and hence improved attendance times based upon identification of the nearest appliance. A very similar system was developed by the Russian military referred to as the Global Navigation Satellite System (GLONASS). Both these systems offer opportunities for fairly accurate ground fixing using low-cost hand held receivers. The accuracy is typically within ten metres although even closer positioning can be achieved with more sophisticated equipment. The receivers are unaffected by rain, fog or other weather conditions provided that they can sight a number of satellites which are in fixed orbit around the earth.

Typically the GPS satellite system requires six satellites in near circular orbits and a similar number of satellites are required in the GLONASS system. Both these satellite systems are around 20,000km above the earth's surface using very accurate atomic clocks and two carrier signals. Synchronisation is obtained by the hand-held receiver, which has a reference point to a land-based control station. The monitoring station for GPS is based in Colorado and for GLONASS near Moscow.

Unfortunately GPS does have a selected availability deliberately introduced by the US military to prevent its misuse by other powers. Various options exist to counter this selective availability including commercially available correction services. The GLONASS system does not have selected availability and therefore offers the civilian a fairly regular real-time information system. To obtain a fix, it is necessary, as mentioned, to receive a signal from five or six satellites. This arrangement will allow vehicle tracking and equipment control in real-time.

It will be seen from this very brief review of GIS and GPS that by placing the two systems together, a considerable computer-aided risk assessment and resource-layering system with geographic imagery is possible. It is also possible to create three-dimensional models that will greatly aid visualisation of terrain or fixed objects. Inter-linking of the resource data given by GPS or GLONASS into a GIS system will also enable real time monitoring of plumes or the updating of displays through tracking systems as vehicles move towards particular risks.

7.10 Summary

The investigations and project trials undertaken indicate that there are clear possibilities of improving fire service decision making through data management by utilising information technology and associated equipment. It is concluded that there are sensible and pertinent arguments to proceed although this would need to be in a measured way so that the introduction of such technology onto the fireground did not jeopardise firefighter safety or operational effectiveness. It is desirable that the service moves in this direction sooner rather than later.

Visualisation, a key component in operational command, could be improved with established equipment from other sectors. This is, however, not feasible for robotics, which require considerably further development if they are to be available at reasonable cost and usefulness.

The quantities of information handled and interaction with databases identified is also manageable, in a user-friendly format, using existing information technology operating systems and software. Most of the data required is already electronically stored and it is therefore utilisation and organisation of the present electronic storage systems that is desired. Also as cited earlier in this work organisations outside the fire service hold significant amounts of useful data and, as this chapter illustrates, accessing that data offers further potential opportunities to improve areas like visualisation, mapping and hazardous material handling. Individual premises hold some of that useful information, on-site, in a number of formats and accessing the relevant areas of those systems is worthy of further exploration.

The use of the data is compounded by the real time need for responsive action to match the dynamic nature of an incident. And as an incident progresses, so many new factors may become relevant, such as the release of materials into an airborne plume, rupture of a containment vessel, collapse of a building or wall and changes in the chemistry of products or materials stored.

Features such as security and robustness become important, as does the ability of the storage system to expand and extend. Data sources also continue to grow in flexibly and scale making interface to their operating systems, some which include graphical interfaces, an area for further research.

Since the fire service response itself is extremely mobile, any data storage and retrieval support system must match that mobility. There are difficulties in achieving a successful bearer system to link a central data bank to a mobile unit. This indicates that the short-term approach of providing the storage facility within responding fire appliances, where it would be directly accessible during the journey to the incident, is for the time perhaps the correct one. This does not remove the requirement for support by a more complex arrangement. Rather, it suggests that in the interim, that is whilst better data transfer arrangements are investigated, there is considerable outstanding research to be done in organising and acquiring data.

Plume modelling and GIS mapping are helpful and would improve the decision-making approach. GIS has already shown its value as a vehicle mounted resource. Plume modelling is more likely to be used as a central resource. However, considerable further development will be required before it becomes a viable inter-active fireground resource useful to the Incident Commander.

Overall these technologies reduce personal and public risk by increasing knowledge in real time operational environments. The following matrix demonstrates areas of enhancement afforded by each technology.

ENHANCEMENT AFFORDED BY TECHNOLOGY	VIDEO	AERIAL	THERMAL	ROBOTICSS	DATA TRANSFER	VDMS	GIS
General situational awareness	♦	♦			♦	♦	♦
Improved inter agency response	♦				♦	♦	♦
Improved assimilation of complex data	♦	♦		♦	♦	♦	♦
Reduction in time imposed pressures	♦			♦	♦		♦
Real time evaluation	♦	♦			♦	♦	♦
Improved anticipation and prediction	♦				♦	♦	♦
Reduction in personal risk to gather data	♦		♦				

TABLE 7.2 TECHNOLOGICAL ENHANCEMENTS ON DECISION-MAKING [DAVIS]

CHAPTER 7 REFERENCES

1 Wilson, D.A. [1997]. *Managing Information,* 2nd Edition, Butterworth - Heinmann, Oxford.

2 Kinnie, N. and Arthurs, A. [1993], *Will Personnel People Ever Learn to Love the Computer?,* Personnel Management Journal, Vol. 25, No.6, Page 46.

3 Clare, C. and Stutely, G. [1995], *Information Systems - Strategy to Design,* Chapman and Hall, London.

4 South West Thames Regional Health Authority. [1993], *Report of the Inquiry into the London Ambulance Service, February 1993.* S.W.T.R.H.A. London.

5 Rodden, T., Cheverst, K., Davies, N. and Dix, A., [1999], *Exploiting Context in HCI Design for Mobile Systems,* Workshop, http://www.comp.lancs.ac.uk.

6 Cheshire fire Brigade. [1996], *Brookvale Comprehensive School Fire,* Unpublished Fire Report.

7 Cheshire Fire Brigade. [1996], *Pickfords Warehouse Fire,* Unpublished Fire Report.

8 Nakamura, [1995], *Development of Firefighting Robots Tokyo Fire Department,* Fire Engineers Journal, Institution of Fire Engineers, Leicester.

9 British Standards Institution, [1977], *Electrical Apparatus for Potentially Explosive Atmosphere, BS 5501, 'Intrinsic Safety' Part 7,* TSO, London.

10 Radio Frequency and Communications Planning Unit, Radio Equipment Group. [1994]. *Type Approval Technical Specification MG-20 Issue 3,* Home Office.

11 *Unpublished Correspondence between Department of Trade and Industry,* Home Office and Cheshire Fire Brigade.

12 Zorkoczy, P. and Heap N. (1995), *Information Technology: An Introduction*, 4th Edition, London: Pitman Publishing

13 Cheshire Management Consultancy. [1994], *Hazard Management Systems,* Internal Report, Cheshire Fire Brigade.

14 Heeks, R. [1999], *Re-inventing Government in the Information Age,* London, Routledge.

15 Laudon, J.P. and Laudon, K.C. [2000], *Management Information Systems: Organisation and Technology in the Networked Enterprise*, 6th Edition, London: Prentice-Hall International

16 Mak, H. C. and Johnston, R. B. [1997], *'Infrastructure Architectures for EDI using the Internet'*, Business Systems Research, Vol. II, Flitman, A. (ed), School of Business Systems, Monash University, Australia.

17 Ritchie. [1994], *A "Road Map" to EDI,* Honours thesis. Department of Computer Science, Curtin University of Technology, Australia.

[18] Turban, E., McLean, E. and Wetherbe J. [1996], *Information Technology for Management*, USA: John Wiley and Sons.

[19] Albinson, B. [1993]. *Information Support for a Fire Officer,* Fire Engineers Journal, Vol. 53, No. 171, Pages 26-30, Institution of Fire Engineers, Leicester.

[20] Gregory, G. [1998]. *Design Analysis,* Pitman, London.

[21] Fullerton, C.S., McCarroll, J.E., Ursano, R.J. and Wright, K.M. [1992], *Physchological Response of Rescue Workers: Firefighter and Trauma,* American Journal of Orthopsychiatry, Vol.62, No.3, Pages 371 - 378.

[22] Zuboff, S. [1988], *In the Age of the Smart Machine*, Basic Books, New York.

[23] Goldfarb, T. [1993], *The Portable Command Post,* Fire Engineering Journal, Vol. 146, No. 9, Pages 53 - 55.

[24] Meldrum, G. [1992], *Data on the Move,* Fire Engineers Journal, Vol. 53, No. 171, Pages 31 - 32, Institution of Fire Engineers, Leicester.

[25] Kasasbeth, Y.A., Howells, D.C., Carter, B. [1997], *Hampshire Fire and Rescue Service Information Technology Study,* Fire Engineers Journal, Vol. 57, No.190, Pages 28-31, Institution of Fire Engineers, Leicester.

[26] Goodwin, P. and Humphries, S. [1997], *Vehicle Mounted Data Systems - Building on Success, Fire* Engineers Journal, Vol. 57, No. 190, Pages 39-41 Institution of Fire Engineers, Leicester.

[27] Keates, J.S., [1996], *Understanding Maps,* Addison Wesley Longman, Harlow.

[28] Lloyd, P. [1989], *A Study of Geographic Information Systems,* Brigade Command Course, Project Report, Fire Service College, Moreton-in-Marsh.

[29] Reynolds, C. [1995], *The Home Office Fire Cover GIS Package,* Dear Chief Officer Letter Number DCOL3/1995, Fire Service Inspectorate, Home Office.

[30] Bannister, A., Raymond, S., and Baker, R., [1998], *Surveying,* Addison Wesley Longman, Harlow.

[31] Leick, A., [1995], *GPS Satellite Surveying,* John Wiley, New York.

CHAPTER EIGHT

Conclusions

8.1 Outcomes

The overall outcome of this research is that decision making by the fire service at major incidents can be improved. To achieve that outcome requires the adoption of:

1 Clearer understanding of how decisions are made and how that process may be advanced. To assist in this a new decision making paradigm for use in crisis situations is proposed.

2 Cultural and organisational changes can also assist by

- Creating organisational values that are less hierarchical and incorporate a more positive learning culture

- Recognition that intelligence and information management must be given the same prominence at operations as physical resource management

- Using technology to reduce tolerance of personal risk to gain crucial observations and data

- Extending further the capabilities of integrated communication technology on the fireground and at central command locations to improve data handling, information presentation and inter and intra service communications

3 A series of associated developments have also been derived during this research that aid the fire service.

8.2 General Observations

This research has shown that fire service Incident Commanders face increasing challenges in their decision making. Reaching sound judgements requires assessment of a range of data, often under time pressure, in a systematic and prioritised way. Data may be offered in large volume and be incomplete, misleading or conflicting. Simplification would assist improved analysis and operational value. It is envisaged that data availability will continue to grow proportionally as technology advances in science, commerce and industry.

The importance, therefore, of having an effective management information system, as part of the command system, is apparent from the key case studies outlined and the literature reviewed. What has also emerged is the importance of simulation [in this context situational awareness and the visualisation of the incident as a dynamic event] and this questions current protocols of fire service command and control. Current models of command decision making using recognition primed decisions are seen as a part, not the complete substance, of this process.

These views are supported by the review of the three key case studies in Chapter 4 where information gaps obviously existed and which concludes by detailing 20 activities that have the potential to improve operational decision making. Using the improvement activities derived from the case studies a number of proposals are made to enhance the decision making system currently in use with specific emphasis on information management.

The importance of information management to the decision support system is outlined in Chapter 5 where improved approaches to capturing data prior to any incident Figure 5.1], assembling data as system support components [Table 5.1] and then placing that data in the command process [Figure 5.3] whilst seeking to avoid inter service tension [Table 5.3] are explored and defined. The conclusion is that a more systematic approach [Figure5.6] would help.

From this researched foundation the option is then outlined of a new decision paradigm [Figure 6.2] that places intelligence, the collective term used here to refer to data, management information systems, information synthesis and analysis and simulation or situational awareness, in equilibrium with physical resource management, the latter being generally very well rehearsed, frequently practiced and substantially funded.

Finally, to meet the decision support requirements of the Incident Commander, it is argued that a core communication system is essential that does not concentrate upon spans of control, but rather focuses upon a progressively expanding information highway, which retains resilience and complements the fire service prioritisation of decision making by ensuring that all participants in the evolving major incident can contribute effectively.

8.3 Improved Decision Making

Investment in decision making systems is crucial if the overall process of managing fire service intervention is to improve. The acceptance that current practice cannot be improved is wrong and potentially harmful. Gains have been made from the substantial investigations made in understanding the command decision processes in military organisations. The fire service is not isolated or especially distinctive in terms of its operating environment that it cannot also benefit from the advantages now offered by these advancement of studies in other allied services.

The rapid growth in computerised intelligent systems and simulation trainers and the general study of the factors influencing the choice of decision options in crisis situations all point towards possible improvements. This becomes more significant given the assertion that large loss incidents are diminishing and experience in actual command at large or major incidents will become less common. Young inexperienced commanders will still need to learn how to operate and translating existing experience from case studies into practices that can be replicated and understood will have to receive higher priority. Likewise colleagues in the other agencies and emergency services need to understand the fire service decision process if they are to interact effectively. It is also proposed that there be less emergency command centres. This emphasises the requirement for common operating protocols to allow efficient mutual aid arrangements and again improved understanding of the decision process and all important data needs.

The lessons of September 11th have profoundly affected crisis managers around the world as they seek to understand weaknesses in the response and develop more robust and resilient systems to cope with this type of exceptional scale event. Decisions made under such circumstances can affect many people and it is important that in the operational planning for these worst case and novel situations the previously assumed concept of escalating existing practices is thoroughly evaluated. This research has indicated that improvements remain to be made.

8.4 Organisational Culture

The traditional values of the fire service exist, in part due to history [Chapter 2], but more importantly because they represent empirical knowledge often learned at a high human cost. Those values have also produced results in crisis situations, when the Incident Commander has achieved a satisfactory, if not necessarily the ideal conclusion.

The fire service operates in a complex environment and is subject to a litigious society [Chapter 2] where risk control relates not only to physical harm but economic losses. Risk assessment requires balanced judgement with recognition of these wider perceptions. Given these circumstances, it is understandable to limit the immediate response in a crisis, to that which may be obtained from a known repertoire of skills and equipment, conforming only to the acceptable standard and best practice - the safe option. Such a repertoire gives the essential speed of action, safe practice and known outcome, without over-exposure of the individual firefighter to excessive risk of failure.

In the review of fire service management system development and its comparison to some international fire service organisations [Chapter 3] it became apparent that the development of a culture, which is based around the values of a learning organisation, has positive values for operational, as well as routine resource management.

These developments enhance analytical decision-making skills onto the fireground and are beneficial to the strategic function of command. Operating in this way represents, for some, a fundamental shift in overall fire service management affecting all levels of command, from the most junior to the most senior rank. Open cultures of this kind tend to be more resilient to the stress so frequently created by short timescales for action and lack of information, which previously could only be resolved by utilising naturalistic or recognition primed decisions [Chapter 6].

It is observed the Incident Commander utilises a range of options in a task-orientated manner and conducts analysis in a strategic way in the derivation of the necessary actions and tactics. The Incident Commander also uses political and humanistic skills to meet and obtain from individuals the necessary information needed to help communicate as necessary to others, including the public, so they might identify the best course of action.

Information, either in complexity, adequacy, scarcity or volume, is identified as a key stressor. This likely harbinger of failure can, it is believed, be relieved by the utilisation of technology. Technology is explored in Chapter 7 and studies concerning hazardous materials and plume modelling for critical incidents is detailed in the appendices. Changing fire service organisational culture enables the individual to better adopt and adapt to this technology. Since technology can support operational decision making this "leap in the dark" can be undertaken with some confidence.

8.5 Researched Allied Developments

In addition to the research relating to the decision-making system, a number of new practices have been evaluated and in some cases implemented. Six examples include:-

1. Enhanced gas plume and fireball studies directly related to fire service use and risks derived from acts of sabotage or other catastrophic events. This study was undertaken following terrorist activity at a natural gas storage site. This work has revealed the significant implications for future disaster planning.

2. Improved visualisation on the fireground using conventional CCTV equipment in new ways. The use of video media and possible interaction with existing security systems is also discussed as a method of providing visualisation for firefighters without personal risk.

3. Early studies related to the designated use of cab based computers and similar trials using data transfer for inter-service collaboration were undertaken. Using conventional laptop computers, fireground data management was reviewed to illustrate the practical value and implications for information management. Commercial development in the area of VDMS has now overtaken the cab based systems but the issue of inter-service data exchange still remains to be exploited.

4. Collaborative work with DERA followed by on-site trials produced a prototype robotic vehicle suitable for fire service operations. The trials suggested that it is both practical and economically viable to introduce robots into fire service operations, thereby reducing the threat posed to firefighter safety.

5. In addition, as part of the analysis of the information needs at major incidents a study is reported that directly related to a large-scale public evacuation at a major fire, which has not previously been available in the public domain. This is a significant matter since information failures can lead to deaths [This was demonstrated in the Dusseldorf Airport fire when the wrong evacuation messages were relayed by the public address system with devastating consequences]. This study, amongst relatively few in the UK, (as studies are not undertaken routinely into public response) has highlighted how important it is that information flow is speedy and accurate to both the public and the emergency services.

6. The introduction of a new policy approach that of using shelter as the best protection for the general public at some major accident situations rather than evacuation, is also described. This new approach was based on experience and empirical knowledge that fundamentally challenged previous public policy in this area. The shelter policy introduces a new and practical method of protection for the public whilst reducing resource demands upon the emergency services.

8.6 Further Research

Little real quantification was found to have been undertaken to identify the most reliable and applicable decision methods used at fire service operations. Existing empirical practice has therefore become the method. Whilst this undoubtedly has the strength that the practice reflects previous operations judged to be successful it carries a risk that better practice from other organisations is being ignored. Further detailed research into the effectiveness and psychology of the decision making process is therefore likely to have long-term benefits. Incorporating these outcomes into computerised or artificial intelligence systems with the associated links to simulation training is also likely to show benefit.

Technology can also help. There are illustrations throughout this research of areas in which modest technological investment aids the decision process and thereby reduces risk. Actual effectiveness, as exemplified in the key case studies in this work is still very reliant upon individuals at special risks taking the relevant actions at the time of the emergency, and upon the public authorities responding in an appropriate way. It would therefore appear sensible to separate out these special premises or areas of higher risk from the general response-planning processes and to have specific data stored, relating only to such premises. A higher degree of detail of the manufacturing process, both diagrammatically and in text is necessary to aid understanding at the time of any emergency. Researching the wider use of media and interactive plume monitoring would be appropriate in these circumstances.

The data required by Incident Commanders is shown to be extensive, held in various locations and different formats. Creating a central, simplified, easily accessible database that can respond dynamically would greatly assist future development of fire service information systems. And, since a great deal of the information needed is already held available on electronic systems the continued integration of this data into a mobile data system is a key component to successful fire service operations.

The quality of any judgement depends upon all those holding information being able to contribute to the decision process. A universal and comprehensive network would provide a means of meeting this need and that requires further development. Similarly developing a system to supply information to the public through the news media would be helpful in reducing any over-burdening of the Incident Commander and advising a concerned public.

Areas for further investigation also include relevant technologies, like video capture and robots that can reduce the risk of individual physical harm and provide insight into the outcomes of particular operational tactics. The robotic research mentioned is exceptional in fire service terms, even though it did not progress to full implementation.

A communication highway, between the activity zone and logistical centre of the organisation, is critical to the success of a disaster or emergency-management process.

Sustaining the information highway, whilst trying to ensure that it enables access to source documentation, will considerably help to avoid overburdening emergency managers. The identification of common thinking between and across emergency services, both nationally and internationally, in this area also helps to clarify the real, as opposed to the assumed, information access needs. These objectives do form part of the current UK radio replacement strategy and so will hopefully be attended to in the near future.

8.7 Summary

This research has argued the hypothesis that the fire service, with its hitherto traditional hierarchical structure, is increasingly becoming a service that meets a very broad spectrum of operational demands with a dynamic and flexible open learning culture. That culture in turn enables better decision-making at operations by using the widest range of managerial techniques, tools and practices.

In effecting what is therefore a transfer of skills, the fire service Incident Commander continues to grow as a sophisticated manager who is able to change his management style in an equally dynamic way to fit the working situation being confronted. However, the pressure will remain to ensure that any "best fit" action occurs within the shortest time scale.

Information, the dominant factor in good decision-making, requires that those tools previously reserved for the safe working environment of the office be adapted for use on the fireground. Filling the remaining information gaps with user-friendly, reliable, robust and secure data and improving visualisation equipment and systems, remains the ongoing challenge.

If the approach proposed in this research were vigorously adopted it is highly likely that a step change could happen to the benefit of the public and firefighter safety alike.

APPENDIX

SUBJECT TITLE

The Future Fire Service

During 2002 there was considerable unrest in the UK fire service that culminated with industrial action. The action involved members of the Fire Brigades Union seeking a substantially pay award in recognition of their perceived change in role and contribution to safety. Initially the Employers resisted this demand and a series of intermittent rather than continuous strike actions occurred.

This action substantially affected the more urban areas of the UK where union membership was both strong and unified. In many rural areas existing fire cover continued although restrictions did apply around mutual aid and specialist support. Alternative emergency cover provided by the Military was therefore evident in most towns and limited specialist support for both serious structural firefighting and other rescues or involving hazardous materials existed.

In the weeks leading up to the first action period extreme efforts were made to avert any action and although action did occur these efforts prompted a wider reappraisal of the fire service role and contribution. As a direct result of this reappraisal and in part as an unsuccessful process to avert industrial action the UK Government at the request of the Employers instituted on the 20 September 2002 an independent review of the fire service under the chairmanship of Professor Sir George Bain assisted by Professor Sir Michael Lyons and Sir Anthony Young. The process of trying to avert action was unsuccessful in part because the Fire Brigades Union would not submit evidence to the inquiry team. This review group assembled evidence and reported in December 2002[1].

Their conclusions were quiet fundamental in character and offered criticism of all the participants involved over many years in fire service matters. More importantly the review group called for urgent action and suggested a new approach based upon risk reduction through prevention with new institutional structures and higher regard and greater expertise in human resource management. A range of proposals was made about pay with links to personal competency and comment on efficiencies and transitional funding.

The report was generally well received although the union had published its own alternative report[2]. The Government has consequentially published a White Paper[3] that spells out how it intends to take the accepted proposals of the independent inquiry forward. In Scotland an earlier White Paper[4] had been published with many complimentary features to the England and Wales paper.

In addition the Employers and Fire Brigades Union have in 2003 concluded an agreement that allowed industrial action to cease and the emergency cover arrangements provided by the Military to be withdrawn. Referred to as the 'Heads Agreement'[5] this agreement binds both parties into an integrated modernisation process that has associated staged payments for the uniformed workforce between 7 November 2002 and 1 July 2006.

In England and Wales and in Scotland the Government has now clearly indicated that a legislative programme will be undertaken following consultation on proposals outlined in further papers. These intended legal steps are due to be introduced into the legislative programme during the 2003 2004 Parliamentary session. New arrangements will then be in place for the future. In the interim period action has been taken on a number of matters not requiring legal change, such as the introduction of risk management, the progression of the integrated personal development system and establishment of some new institutional structures, so commencing an extensive modernisation process for the UK fire service.

Cultural Change-The Cheshire Case Study

The process of cultural change referred to in Chapter Three resulted in a major initiative being instituted and managed by the author. After considering these issues, research was instituted into the practical impacts of changing the management culture in Cheshire Fire Brigade[6].

The aim was promoted that the service should not just accept the commercial decision models that had evolved, but should seek to develop a decision process specific to the fire service. The rationale here being that operational command and normal working practice had already created a clear two-dimensional model, with station management being seen as distinctly separate from fireground operational management. The question that arose was whether one management approach could work as effectively in the fire station as it could upon the fireground. Evaluation of these current concepts of management approach led to the conclusion that a two-dimensional model, i.e. fireground and office, was unnecessary. It was considered practical to change the fireground 'command' management processes into one more aligned to everyday management processes without creating functional difficulties. The key was to retain the Incident Commander in a strict hierarchical management position on the fireground, even though in normal work the individual might be a specialist team member not be directly involved in operational planning.

Two local debates occurred at the early stage, both apparently centred on protecting the existing fireground decision-making process and the functions of central command. The first argument focused upon the high operational risk involved in adopting untested new ideas. The second suggested it was essential to retain the structural line management system within the fire service, rather than the flexible models of industry. Again it was suggested that change might involve significant risk of failure to deliver at critical times if clear accountability and robust practices were not present.

On further reviewing fire service managers at work, it was concluded that these risks were overstated. The fire service already had a relatively sophisticated management system and that the resistance to change was common to that found in most organisations i.e. individuals feeling threatened by possible loss of status and control when confronted with a more flexible approach.

One consequence was to indicate that a flexible model of management where the fire service manager could change his decision-making style rapidly to suit the working environment was more appropriate. The author describes this concept as 'participative' and subsequently introduced a cultural shift in this direction into Cheshire Fire Brigade.

To introduce this general empowerment philosophy senior staff reorganised the management process and structure so that it might reflect the general concept of participative management. In order to assist, describe and explain the new thinking and to argue, ultimately, for a structural change within the organisation, it was necessary to involve significant numbers of staff in discussions[7].

Information management was also identified as a key factor in enabling the devolution of responsibilities. Unfortunately there was insufficient existing infrastructure within the Fire Brigade's organisation to enable the right information, especially in such activities as budget management, to be placed in the hands of the responsible managers and enable them to discharge their accountabilities. This limitation created an urgent desire by the Brigade's management to rapidly expand the existing management information systems.

Teams of officers having similar responsibilities produced 'real world' objectives and common goals and performance measures were introduced to assess successful practices and procedures. This reflected the growing importance of benchmarking introduced into the fire service by bodies such as the Audit Commission.

Part way through the change process a consultant conducted an independent diagnostic review designed to evaluate whether the new participative culture was effectively empowering the organisation or simply being absorbed and ignored. This diagnostic study revealed that despite the comprehensive nature of the change and the degree of stress created, there was a clear and demonstrable commitment, by those staff consulted, to the new style of management, it being seen as more effective in providing the desired public fire service. One identified weakness of the new approach was poor internal communication between working levels, an area where IT was likely to assist.

This Brigade study was aimed deliberately to investigate the establishment of a new style of organisation, which constantly sought to learn[8] by measuring its delivered outcomes and so develop best practice and thereby continuously improve the organisation. It also paved the way for a structural review to enable any process introduced, to be placed within a better and more comfortable system of quality assured management[9]. The underpinning philosophy was the provision of a flexible management process, which reconciled the needs of operational command, functional objectives and was able to support management within the Brigade's operational geographic area, whilst ensuring a high quality of service. This created an integrated yet flexible organisation.

Integration included responsibilities for overall corporate achievements linked to improved communications between all levels of management and management systems, utilising personal knowledge and experience. Functions and activities were integrated within overlapping elements designed to increase flexibility and meet changing demands, whilst avoiding depersonalisation and fragmentation.

Considerable work was undertaken to create a learning organisation within Cheshire Fire Brigade since this was judged important in helping establish Incident Commanders who could challenge in a very constructive and analytical way any information upon which they would subsequently take decisions. Approaching organisational management in this way also encouraged individual confidence in the use of information communication technologies, common in both daily fire service and business activities. Achieving and successfully embedding this new management culture was therefore an important step in progressing the overall concepts of improved operational decision making.

Evidence that, as a consequence of the work undertaken, a change in culture was successfully achieved was demonstrated by the Cheshire Fire Brigade becoming the first brigade to achieve the Investors in People Award*, which recognised the cultural change, and achieve a Charter Mark* for its relationship to those it serves.

The Process

Fire, like all public services, needs periodically to review its approach to delivering its service to the public. Customer care, a common aim within industry and commerce has an equal relevance in public life even though the commodity sold or purchased belongs to the public and therefore the process is one of transfer or exchange of professional skills. As local authorities began to change their role of providing less direct services and sought to enable services to be obtained from other agents so the fire service, with its direct provision role, looked to see if it should change. All of local government must be accountable. The public rightly expects this both of the corporate 'Fire Brigade' body and of the individual officers. They also expect responsible attitudes to prevail rather than play a game of hide and seek to find the right responsible person.

These simple ideas required cohesion to work. Fire service work is far more complex and decisions have to be reached quite often which involve a number of specialised persons combining their talents. It is critical however that the service did not become a red tape organisation - rather a blue ribbon was the aim.

With these ideas in mind thought was been given to the future operating process,

* Investors in People awards recognise employers who develop, train, recruit and evaluate employees to achieve the highest standards of business performance. A series of assessment indicators are used against a portfolio of evidence supplied by the applicant. The assessor, appointed by the local Training and Enterprise Council, reports to a Recognition Panel who make any award. The Government Department responsible is the Department of Education, Employment Skills and Enterprise Section.

* Charter Mark is the Government's award for organisations that provides an excellent service to the public. The criteria are designed to measure and improve service. Charter Mark awards requires evidence of performance standards to be judged and once awarded is valid for three years. The Cabinet Office is the responsible government department.

management style and structure within the Cheshire organisation. At the first stage they were conceptual, since the idea was to forward plan, in what had become a more, rather than less, confused operating environment. The basic need was the bringing together of the skills of individuals, in a culture, which enabled each to contribute fully in decision making, which in turn was to be as near as possible to the point where the decision would have to be implemented. The commonly used phrase 'Closer to the Customer' summarises this part of the approach.

The Brigade process at that time placed a great deal of decision making at the only point where resources, skills and information combine - Divisional Management. The suggestion was that this bridging point could move more closer towards local areas with the majority of day-to-day decisions being made and implemented at that level.

To do this required a new structure, which enabled discussion and debate amongst groups of involved officers. It also required a change in culture to ensure accountability did not become a moving target with no individual holding true responsibility for the decision, or worse, avoiding a decision.

If decisions were to be made closer to the local station ground there had also to be a supporting and review process of management, which facilitated and monitored decision-making. Policy direction and resource allocation remained the primary tasks of Brigade managers and therefore arrangements, to allow policies a degree of interpretation to reflect locally identified needs yet also capable of being monitored and supervised, had to be developed.

The fire service has traditionally used a ranking system to control supervision and take decisions. This emphasis needed to move and ranks, which it was accepted were totally essential for the operational firefighting and rescue function, had to become the value terms of recognition for contribution and responsibility. In other words there was recognition and acceptance of the essential difference in using rank in operational command and when using ranked posts to define the alternative responsibilities of technical and managerial duties. It was also accepted that to introduce change within any organisation and its staff fundamentally takes time. Training and education were considered and then undertaken in a change transformation period that lasted 3 years.

The philosophy suggested did not envisage less managers, it actually suggested more but of different types. Decentralisation, when useful in economic terms and as an aid to the public and officer, was another aim. There was an attempt to bring together at the centre the key elements of strategy, resource allocation and ultimate responsibility for success or failure. Management support it was thought would be demonstrated in this way and leadership, team skills and individual contribution, which fundamentally make all things work, would have better processes, structures and cultures to improve performance still further.

Structure

The General Philosophy

The designed structure provided a flexible management process to reconcile operational command, functional objectiveness and supportive management within a territorial environment, whilst ensuring quality of service. The structure aimed the following benefits:

- A fully integrated Brigade management team with more emphasis on the Brigade's corporate needs and less on the function of day-to-day management.

- Improved communications within and between each level of management.
- Working based on participation, rather than rank.
- Clear levels of authority and responsibility.
- Equity in relation to workloads.
- Sensible overlapping of functions or activities to avoid unnecessary segregation.
- An increased flexibility to meet frequently changing demands.
- A more personal approach.

Three primary management levels were introduced:

• Local	Customer based and action orientated
• Territorial - based	Interpretive, supportive to local management, area
• Brigade	Responsible for organisational strategy

Operational Command was observed as a distinct management process and as such had separate, rank related and specific functional applications.

General functional objectives were seen as assisting development and achievement by establishing performance measures, clarity of purpose, specific research and development and defined targets. Similarly they were not seen as exclusive but mutually compatible with each and between each function. Territories were seen to aid both staff and customers acting as the bridging point between all functions and the local and Brigade management systems. Actual territories for practical purposes were co-terminus with existing geographical references such as station grounds, District Council areas and the overall Brigade operating area.

Practices

Effective management at a local level already existed and it was determined refinement might assist whereas wholesale change would not. Operational Command was also good. The appropriateness of Officer response had however sometimes been questionable and was therefore deemed worthy of review. Territorial management was widely dispersed and therefore in need of co-ordination. The questions that arose here were:

- Was the current divisional territory appropriate, given the specialisms and range of activities?
- Could the current structure meet the envisaged growth and frequency of change?
- Should an individual be expected to link so many activities and was it desirable that one communicator had to operate at such a sensitive and isolated position?

Change therefore appeared inevitable if functional separation was to be avoided, to allow for greater flexibility and to develop the potential of staff to contribute to a quality service.

At Brigade level the challenges were frequent and wide ranging. Areas of activity could not be effectively managed due to resource shortages of the right skilled staff. Activity increases and more management time were needed within finite resources. The translation of strategy into policies and action plans was becoming more complex as the activities increase. It was observed that it became more imperative to look forward to avoid crisis management. Communication between all groups had similarly become more demanding, with risk of isolation for groups at a time when integration is needed. Again, therefore, there was a need to reconcile structure.

Activity Review and Future Needs Analysis

A review of current activities had clearly identified that some elements of Brigade activities received less attention than others. Whilst this had not been a great concern, there was always a doubt, that in some aspects of work, quality was not being delivered. An activities review showed areas of need as follows:

Firefighting

Operational Planning, Operational Delivery, Despatch [Command and Control] and Communications

Emergency Planning

Planning and Technical Support

Management Support

Corporate Board Management, Finance, Personnel and Training, External Affairs, Technical Support, Performance Review and Property

Fire Safety

Inspectorate, Technical Support, External Affairs and Education

Quality Management and Structure

It was argued that the provision of any service should include a "level" or "standard of delivery" which whilst sometimes difficult to define, also needed to be immediately understood, for example "first class" and "high quality". Quantitative targets or indicators would wherever possible, support these statements. It was accepted that this cannot always be the case and therefore professional subjective judgments had to be made about the quality of service, for example, how to differentiate between a well-performed operational activity and an excellent one.

The concept of the quality circle, a small work-based group, or preferably a team of specialists working together, providing mutual support, developing performance awareness, maintaining service integrity and quality of service, was used. This process in fire service terms needed to bring together the four identified functions viz firefighting, fire safety, emergency planning and management. Each quality circle, or team, needed a leader who acted as the essential communicator, forward planner and link with the local community. The leader had key responsibility and accountability for the overall quality of performance for the team. Additionally, in the new structure, the leader acted in the capacity of Area Manager within multi disciplined environment sharing decision-making and avoiding functionalism. In this role the leader acted as the convener [or facilitator] not a commander of the resources.

It had been found that increasing demands for internal and external services had tended to be met by creating new specialist groupings closer the centre rather than the front line - service delivery points. Rather than centralise the quality team approach was used to reverse this trend and provide locally the ability to evaluate performance and monitor output in terms of quality of delivery to the public. The service then became output focused.

There was also a desire to have managerial flexibility through generic job descriptions to reduce the inherent hierarchical structure created by grading by rank across the service. More importantly jobs had to be evaluated against tasks, responsibility, accountability and scale. Additionally, leadership, command and management activities were considered together with their individual consequences. Some officers need to be trained in leadership skills as well as in how to determine resource allocation for command purposes. However, both tasks are primarily about firefighting response albeit that leadership has an important team-building element in the management process. The primary business demanded a management activity, which was high on communication and technical decision-making. There was therefore an element of transferable skills. The fact that the daily core business demanded different activities was not allowed to minimise the perception that daily management was less important than operational command - it simply affected the grade for primary firefighting purposes. This created the opportunity to use different ranks for the same generic job.

A key issue was to avoid top-heavy management. No deputy posts were to exist except at the very top of the structure were it was considered essential that there should be no confusion at any time as to who was fulfilling the operational role of Brigade Commander. All the management process and structure re-evaluation was set against quality output - not status driven concepts that more senior ranks mean a more important post or Brigade. The emphasis was of all the workforce's contributions counting. Quantity, how many people there, did not matter so much but where those people where, what they were doing and how cost effective they were, thereby placing emphasis on quality. This objective resulted in placing support staff, firefighters and inspectors together where they did the real job and management "on costs" were minimised with decision-making moving closer to the public and the community.

Identification of territorial decision-making teams was therefore critical. The objective was to allow decision and action to be as close to the public as possible. That required local managers with authority and the minimum local to centre communication about decision-making. A decision made closer to the public was accepted at some risk since policy precedents might be set but it was deemed an acceptable risk if local managers were to be clear about their authority in just the same way as the Chief Fire Officer.

The size of the local territorial unit was also critical. It needed to be of sufficient size and composition to be fully effective and economic - how else could the local firefighter match public need in a qualitative way but it was recognized equally that support "on costs" might become significant if the territorial or local unit chosen was too small.

The proposition was therefore for:

- Area teams to have responsibility for the quality of all day to day working
- Supportive managers leading and co-coordinating each area team
- Interlinked groups of operational managers who had a review, forward planning and evaluation role with functional responsibilities.
- A level of senior managers who had functional accountabilities and corporate responsibilities for strategic determination and resource allocation

Impacts

Generic job titles and descriptions were adopted in the well-understood areas of:

Operations Manager	Responsible for a corporate function
Area Manager	The local quality team leader
Team Manager	Responsible for delivery of a function at local level

The relationship that emerged was one of strong local initiative and action, enabled and supported by a group of more senior managers who shared the responsibility of identifying the future trends and plans, whilst monitoring and reviewing current performance.

Conclusions

A quality assured system of management was seen as an approach, which would aid better service delivery, whilst ensuring that best value is extracted from the available resources. Its emphasis therefore was about placing decision-making close to the public and reducing management overheads. The cultural shift was significant with rank having less to do with day-to-day management and more operational role related. Adoption of critical post holders who did not wear uniform became widely accepted and organizational goals moved to an output focus rather than input and quantitative. By 1994 the Brigade was experimenting in many managerial approaches and innovating practices with qualified risk-taking being corporately accepted. Economically in-year expenditure control performance improved as devolved budgeting was established and practical achievements in procurement activities continued despite tight financial restrictions. The participative style, whilst it made individuals feel they were responsible, did so in a positive atmosphere since they controlled the resources, influenced the policy and made the decisions. The organisation set out the direction, provided essential information and management networks and ensured the supply of skilled and competent staff.

SEPTEMBER 11, 2001

The World Trade Center

This catastrophic event caused the death of 2830 people. The north tower was hit by American Airlines, Flight 11, a Boeing 767-223ER, estimated to be carrying around 34,000 litres of fuel and traveling at 470 miles per hour. The second aircraft United Airlines Flight 175, a Boeing 767-222, again estimated to be carrying 31,000 litres of fuel at about 590 miles per hour hit the south tower. The 767-200 series planes had an overall length of 48.5 m, a wingspan of 47.6m, a fuselage diameter of 5.3m, and a tail height of 15.8m.

At 8:46 AM EST, the first plane, banking to the left, collided with the north tower very close to the center of the north face between floors 94 and 99. Exterior damage to the north extended over all six of these floors. At 9:03 AM, the collision of the second plane with the south face of the south tower took place, with damage between floors 78 to 84. Each damage pattern resembled the outline of the Boeing 767 lying at nearly a 30-degree angle. The World Trade Centre was a complex of major buildings of which the twin towers, 110 storeys high, were a prominent feature. There was partial or total collapse of 10 buildings within the complex, which resulted in one million tons of material falling on a relatively contained site.

Each tower was 110 stories, with the north tower being 417 m and the south tower being 415 m high. Each floor was approximately 3.66 high, with the ceiling height of 2.62 m and an intervening floor thickness of 1.04 m. Each tower was square with sides of 63.1 m. Within each tower was a service core about 24 m by 42 m composed of 47 box-section load-bearing columns. The core and facade columns constituted the load-bearing structures for each tower, including the potentially high loads produced by winds. Along each exterior face, there were 59 box-section facade columns spaced at 1.02 m centers.

At 9.59 EST Tower 2 collapsed and Tower 1 at 10.29 EST. The collapse of Tower 2 destroyed the Incident Command Post established in West Street forcing officers to find alternative command location and the Tower 1 collapse destroyed the Operations Post for that tower. The collapse of Tower 1 killed amongst other officers the Chief of Department who was the Incident Commander and it was not until 11.28 EST that he was replaced. The loss of so many firefighters, emergency medial service personnel and police officers had a profound effect upon operations to evacuate and rescue the thousands of workers already in the World Trade Centre.

Estimates[10] made using mathematical models based on preliminary assumptions and analysis suggest the aircraft collision and release of fuel, which resulted in a fireball and started fires in each tower, supplied energy from the fire to the plume of one gigawatt.

Despite the collision and fire load damage resulting from the strikes of two Boeing 757 aircraft these structures didn't collapse immediately enabling significant numbers to evacuate. It is postulated that the external steel frames and central utility cores suffered extensively from the fuel fires and may have weakened installed passive fire protection on the steelwork, which was then subjected to severe heat. The progressive failure of the steel frame part way up each tower subsequently resulted in the collapse as the considerable unsupported structural weight of each tower overcame the residual strength remaining in the unaffected parts of the towers. The speed of the final collapse gave little hope for those trapped inside either below or above the floors directly affected by both aircraft initial impacts. Fuller studies are being conducted in the USA and elsewhere into the important features of building collapse and evacuation. These studies will provide important information to designers, civil and fire engineers.

The scale of the subsequent rescue operation was unprecedented in a modern urban environment. A recall of all off-duty firefighters linked to local and government responses, made as part of the established mutual aid system and the Federal Emergency Management Agency scheme, was only one part of this operation. This operation subsequently became a recovery and criminal investigation of enormous proportions. A visit to the site in March 2002 indicated that the FDNY were still recovering their lost colleagues on a regular basis in a most dignified and appropriate way whilst simultaneously rebuilding their fire department and meeting the emergency service needs of New Yorkers.

In addition, and as a result of the attacks, the United States Government has created a new strategy for homeland security. President George W Bush stated in Executive Order 13228, Section 2, October 8, 2001 that "The Mission of the Office (of Homeland Security) shall be to develop and co-ordinate the implementation of a comprehensive national strategy to secure the United States from terrorist threats of attacks."

A key element of the strategy is to support the first responder community. That community includes over one million firefighters of which approximately 750,000 are volunteers. Other parts of the strategy relate to defence against biological terrorism, securing America's borders; using the defence capability of technology' improving aviation security; and other security based initiatives.

The McKinsey Report[11] and Chief Cruthers[12] reported that the New York State mandated command system, which has variations to the ICS processes described, did function effectively. ICS strengths were common terminology, manageable spans of control, modulated organisation and integrated communications. Chief Cruthers believed the local variation of having one leader rather than unified command was preferable. Fire Department deployments on site were undertaken using magnetic boards and grease pencils, although the department is now experimenting with a prototype ruggidised computer.

Military assistance in logistics, communications and technology, like robots and geographic information systems, greatly aided operations. Aerial and thermal photography and use of global positioning systems also proved invaluable in the very extended post incident phase when identifying and accurately plotting locations on the extensively damaged and very large site, to support tasks such as recovery of human remains, was required.

ICS was seen to need more institutionalisation within routine operations with better preparedness [training, preplanning, hazard assessments] and improved scalability [matching the dynamics of such large scale events by maintaining critical decision and safety systems]. The ability to conduct risk assessments in real time, matching personnel accountability, information management, incident communications [radio traffic, staff deployments, logistics] and inter-agency functionality [unified command, mutual aid, information sharing and inter communications], were crucial learning outcomes for the decision making processes.

The McKinsey Report emphasises these communication difficulties concluding that they hindered the fire department's chief officers as they co-ordinated the response. Initially little reliable information was available and some portable radios failed to work within the high rise structures due to repeater malfunctions [repeater systems amplify and rebroadcast the radio signal]. There was a lack of information to the chiefs on what was happening in and to the structures so, for example whilst television was broadcasting extensive coverage, some officers within World Trade Center 1 were unaware of the incident's progression. Consequently they had little precise background, such as the aircraft hitting the second tower leading to the fire and ultimate collapse of that tower, with which to manage their assignments. The complexity and quantity of information flows, compounded by the difficulties of inter-agency working [there was spasmodic police and fire communication and a significant uncoordinated response of volunteering mutual aid, for example], resulted in serious resource management problems.

The Fire Department's outcomes recognise that ICS use therefore needs expansion. This will target support for Incident Commanders so that crucial decision functions can be undertaken in a comprehensive, well-defined and flexible way. McKinsey also suggests that highly trained specialised teams may be needed to manage the larger and more complex type incidents with the Department's Operation Center being extended into a fully functioning emergency operations centre. Planning is also seen as an essential component and so are improvements in communications infrastructure and the deployment of technology.

The Pentagon

Arlington County is the smallest county in the United States with a population of around 190,000 people of which the Pentagon workforce alone is more than 23,000. Arlington County is located across the Potomac River from Washington, District of Columbia. American Airlines Flight 77, a Boeing 757 aircraft with 58 passengers and a crew of 6, crashed into the Pentagon at 9.38 EST with a loss of 189 lives. Arlington County Fire Department (ACFD) responded to what eventually became a 10-day operation.

The construction of the Pentagon, which somewhat ironically commenced on 11 September 1941, involved a five-sided design [chosen primarily because of the existing road layout]. The building is essentially of a reinforced concrete construction having a floor area of 7 million square feet. The accommodation consists of 5 continuous rings of offices each 5 storeys high. Contingency planning for the site rests with the Commanding General of the Military District of Washington. The aircraft's speed when it struck the west side was estimated at 400 miles per hour, with a mass of 270,000 pounds, and it penetrated three of the five rings of the of 5 storey offices.

The After Action Report [AAR][13] prepared on the response by Arlington County to the September11 terrorist attack on the Pentagon, as well as describing the activities of a number of agencies, identifies a number of learning points. Importantly Chief Plaugher of the Arlington County Fire Department [ACFD] reported[14] and the AAR concurs that the ICS and unified command was understood, implemented effectively and operated successfully. This is notable given some participants, for example the military, were unfamiliar with ICS yet were able to work closely with the identified Incident Commander, who was then able to offer explicit information in support of an holistic response.

However difficulties did emerge in communication support operations, central to ICS, in that the ACFD did not have a dedicated mobile command unit and, from initial response to tactical operations, almost all aspects of communications were problematic. Cellular telephones and radio channels became saturated and even handheld portable radios were not interoperable [between fire departments and other emergency responders]. Logistically the scale of the event was overwhelming with short-term shortages occurring in critical high demand items like breathing apparatus. Mutual aid helped overcome these logistic issues as the incident progressed.

Other areas worthy of improvement were found to be better control of those individuals or organisations who responded on their own initiative to the incident, improved physical facilities to harden and better equip control and communication centres to handle emergencies; better interoperability in field communications, stronger and more organised logistics management; and improved co-ordination in managing health related issues, including emergency medical services and receiving hospitals.

It can be postulated that although these incidents, particularly in New York, had unique features there is clear evidence that the well-defined command decision-making process was essential in maintaining action impetus in what could have been chaotic and disestablishing situation for the fire service. What is also evident is the decision system is dependent upon an equally crucial and reliable information communication system.

GAS DISPERSION MODELLING

Introduction

The importance of being able to model and predict the behaviour and consequences of accidental releases of gases and other contaminants has greatly increased as a consequence of public recognition that industrial plant situated in the vicinity of dwellings can no longer be assumed to be safe. Bhopal, Chernobyl and Flixborough are extreme examples but many other instances exist. Considerable quantities of flammable and toxic gases are being produced, stored and transported throughout the world and at every stage there is the risk, to a greater or lesser extent, of accidental release.

When hazardous materials escape the usual case is that a gas or two-phase cloud is formed, either as direct release of gas into the atmosphere or vaporous media escaping as a two-phase mixture. Of course, liquid may escape and form pools, which will then evaporate to form a cloud. Many of the gases of greatest interest, including the hydrocarbons such as natural gas, will be lighter than air and buoyant. Safety considerations necessitate the assessment of the hazards that could ensue from an accidental gas release usually through the modelling of the gas dispersion process.

This appendix is concerned the practical response of firefighters and how they can be more effective if faster, more efficient models are available used to predict the likely patterns of dispersion of gaseous releases into the atmosphere. It is concerned with release of toxic contaminants, which pose a threat to health, and, in particular, the release of combustible clouds which may ignite to form a fireball exposing surrounding objects to a sudden heat radiation load. In this latter respect an analysis of the hazards of gas release from two low-pressure gasholders is reported.

If the cloud is not combustible (a radiation leak, for example) or combustion does not take place the cloud will be dispersed in the atmosphere by the normally turbulent airflow (e.g. wind), spreading and diluting the materials and persons in its path may be exposed to a health damaging toxic load.

There are possibly over a hundred computer models now being marketed for use in the calculation of the dispersion of hazardous chemicals released to the atmosphere. In the US the United States Environmental Protection Agency [EPA]* has developed numerous models that are accessible from the EPA Internet web site*. Most are derived from its source programme ISC3 which is the industry standard as all commercial software packages seem to be derived from it, almost certainly because it is used as a regulatory requirement in the USA. A variety of commercial software uses ISC3 as basis, with a bespoke user interface to what is otherwise an 'unfriendly' program. These models provide an extensive range of useful pollution control models and information[15].

When hazardous materials escape, the usual case is that of a gas or two-phase cloud being formed, either as a direct release of gas into the atmosphere or a two-phase vapour mixture. Of course, liquid may escape and form pools, which will then evaporate to form a cloud although the fire service may be able to reduce the extent using water curtains. Research by Bara and Dusserre[16] concluded that for heavier gases (ammonia was the gas studied) this was a quick and reliable method, accepting that the use of water with ammonia clouds may present an environmental problem. Many of the gases of greatest interest, including the hydrocarbons such as natural gas, will be lighter and

* The EPA was established on 2 December 1970 to protect the nation's health and environment. It's role includes clean up and prevention of pollution, ensuring compliance with law, assisting efforts to protect, research and educate on environmental issues

* United States Environmental Protection Agency http://www.epa.gov.scram.001/E22.htm.

more buoyant than air. Safety considerations necessitate the assessment of the hazards that could ensue from an accidental gas release, usually through the modelling of the gas dispersion process, and a large number of pollution surveys over the years have been carried out in the power generating industries. For example, studies by Pasquill and Smith[17] cite work by Culkowski, Munn and Cole who have shown that the height of a source above the surrounding ground can be disregarded for most practical purposes.

Research in the United States has identified that many plume models have shortcomings, particularly where two-phase jet releases are involved[18]. Similar problems exist with low wind speeds and current approaches fail to predict plume movement accurately in these circumstances being designed to give only a general overview. Indeed low wind speeds can make dispersal prediction difficult as the dispersal distance[19] increases. This does not diminish the value of such models to first attendance crews but it does for ongoing operations.

The initial characterisation of a release is critical for estimating concentrations of gas in the cloud[20]. As a consequence, models that contain similar treatments of atmospheric dispersion and use the same meteorological parameters can differ in their predictions by orders of magnitude. A number of models of heavy gas cloud formation and dispersion have also been assessed by a consortium that contained representatives from British Gas, CEGB, HSE and a number of French organisations including Gaz de France, Electricite de France and the French Nuclear industry[21]. The assessment compared simulations using seven widely available models with controlled input parameters. It found that the differences between the model predictions of concentration and cloud width are, for "large" volume releases (> 2000 m^3), within a factor of 3 to 5, but that at low wind-speeds and with increased surface roughness the factor could be an order of magnitude or more.

For the Incident Commander there are two distinct areas where such modelling will be useful, or even critical, these are in the modelling of emission and dispersion. The properties of the substance released will have a direct bearing on both aspects, but external effects such as meteorology and topography are relevant only to dispersion. Significant factors relating to emission must be incorporated accurately into the model; otherwise, any subsequent dispersion model based on the release data will carry forward and may exacerbate errors incorporated in estimating the emission. It has to be remembered that however good the technology the primary requirement is for accurate and complete data.

Work has been undertaken in the UK and two studies by Johnson[22] and Pettit[23] recorded relevant incidents attended by the fire service. These considered both liquid and gaseous releases and gave considerable attention to the Guassian and box models. Johnson concluded that the CHEMET* scheme[24] appeared to offer the best way forward and could be extremely valuable to the emergency services [The Meteorological Office has since made useful additions to the scheme in the form of guidance to meteorological forecasters[25]].

The main difficulty Johnson noted was that an estimate of the area at risk could not be provided quickly enough for first attendance crews and did not account for dense gas or complex topographical situations. He believed that the best way forward would be to

* CHEMET Service provided by the Meteorological Office, free at point of consumption to emergency services, to provide a service of expected weather conditions in a defined locality.

upgrade the CHEMET system by introducing something similar to the North American Emergency Response guidebook[26].

Reviewing this earlier study it was concluded that any fire service prediction model is likely to be significantly different from those used generally by government agencies and industrial companies to predict likely consequences of accidental release of hazardous materials. Firstly, it has to be fast, and secondly it must be capable of producing - whether directly or interpreted through a handbook - sufficiently accurate predictions for consequent actions to be confidently taken. It should also be capable of incorporating accurate local weather and other relevant data gathered by the fire service at the scene, including measurements of concentrations of pollutants.

Such a process requires careful review, as there are situations at major hazard installations where considerable volumes of dangerous materials are stored and the duration for release may be hours rather than minutes. The possibility therefore of improving the CHEMET prediction system would be very attractive and provide an increased level of prediction with existing reliability.

One major weakness with CHEMET is the perception that pollution from fires is less of a problem than those of hazardous materials. This is very questionable as products of combustion are frequently very toxic and smoke palls can be of long duration with large volumes of material[27]. Flammable gas clouds can also have a devastating impact as Unconfined Vapour Cloud Explosions (UVCEs) and the obvious case of fireballs (Diffusion flame) shows. Here the main parameters necessary for hazard prediction are; the fire ball diameter, fireball duration, thermal flux at the fireball surface, heat radiation from the fireball at different distances, and the proximity of humans and property[28].

Over the past fifty years there have been at least two fireball or UVCE incidents every year in which the damage occasioned by the blast was the major concern[29].

The most prestigious and widely used source of information on the prediction of likely physical effects resulting from the release of hazardous materials was the so-called "Yellow Book" prepared by TNO in the Netherlands for the Committee for the Prevention of Disaster with the support and approval of the Directors General of Labour, Environmental Protection, Transport, Public Order and Security and published in 1979[30]. However, rapid advances were made in the modelling of the escape and dispersion of gases and the "Yellow Book" was extensively re-written by 1988 with a substantially revised second edition published in 1992. Within its remit this remains the generally accepted guide for engineering solutions for sources at or close to the ground, but it was by no means comprehensive, lacking a section on the dispersion of heavy gases which was to be dealt with in a later edition, and weak on how the concentrations of the cloud fluctuated as it progressed through the atmosphere.

As mentioned significant work has been undertaken in the United Kingdom by the Fire Research and Development Group, a department of the Home Office responsible for fire service research, to identify gas dispersion modelling and predication systems which might be capable of use by first attendance appliance crews. Primary amongst this work are two studies by Johnson[31] and Pittit[32], which recorded the general range of incidents attended by the fire service and considered both liquid and gaseous releases.

These authors noted that various standard models had been developed for liquid and gas spills together with jet releases and those arising from pool evaporation or flashing fractions from particular leakage. The authors also played considerable attention to the

Guassian model (see below) and box models created for specific research work. Johnson concluded that having reviewed the models he found that the CHEMET [33] which is the scheme provided by the UK Met Office, appeared to offer the best way forward and could be extremely valuable to the emergency services.

The difficulties he noted was that the estimate of the area at risk could not really be provided quickly enough for first attendance crews and did not account for dense gas or complex topographical situations. The difficulty here was twofold. CHEMET is a free service offered to the emergency services and no funding exists for an improved service. Secondly the service is delivered from Regional Met. Offices using wide area forecasts and so cannot take account of local microclimates. In addition there were at the time of its adoption few public sector systems and to date it remains the only system supported 24 hours per day by professional meteorologists. Johnson believes that the best way forward would be to upgrade the model by introducing something similar to the North American Emergency Response Guide Book[34] [NAER'96 Guide], which was then available in French, Spanish and English.

The NAER'96 Guide is specifically related to transport emergencies and although the guidance given is generally quite comprehensive for a very wide range of chemicals the difficulty is that there are a significant number of incidents which arise in chemical and other fixed plants with specific problems. Even though an overspill or leak may not have a volume in excess of that likely to be transported in a tank, the duration of the leak itself that creates specific difficulties. In addition the topography of the site (adjacent buildings, other hazards in the vicinity) may pose serious risks both to humans and to other plant processes.

The prediction model that the fire service requires is significantly different from those used generally by government agencies and industrial companies to predict likely consequences of accidental release of hazardous materials. First it has to be fast, the incident commander on site has a responsibility to protect life and property and in an incident the time for decision-making can be the order of minutes. Secondly it must be capable of producing - whether directly or interpreted through a handbook, sufficiently accurate predictions for consequent actions to be confidently taken. It should also, of course, be capable of incorporating weather and other relevant data both unknown and available. But importantly, the fire service has a capability of gathering local information on wind speed, direction and other relevant data at the scene, including measurements of concentrations of pollutants to allow a continuous updating of the model.

Such a scenario, if it could be applied through a defined model or template, would offer better prediction than that currently available within the NAER Guidebook.

This consideration requires careful review, as there are situations at major hazard installations where considerable volumes of dangerous materials are stored and the duration for release may be hours rather than minutes. This is particularly relevant with regards to CHEMET the service supplied free to emergency services by the Meteorological Office. CHEMET regards releases from fires as less of a problem than those of hazardous materials but this is doubtful as products of combustion are frequently very toxic and are not destroyed in the heat of combustion.

The CHEMET scheme is operated by the police or fire service telephoning the appropriate regional meteorological office and ensures that a short-term forecast is given which will help predict the plume behaviour. Recent work has been carried out to improve the nature of the information provided on the standard reporting system.

One similarity between the CHEMET approach and NAER Guide is that of defined area at risk which, in order to allow for a meandering plume from a ground source, adopts a 30^0 spread on either side of the source point.

This wide variation in spread, in an urbanised area, could create considerable difficulties, requiring the police and fire service to give serious operational consideration to the evacuation of large numbers of the public if this leak was to continue for any extended period.

The possibility therefore of improving the CHEMET prediction system so offering an improved way forward might be very acceptable and provide an increased reliability in the overall output parameters achieved.

FUNDAMENTALS OF ATMOSPHERIC DISPERSION.

General

It is important for responsible persons in the fire service to understand the fundamentals of atmospheric dispersion and of the processes used for modelling it. The fire service perspective includes not only concern about the spatial and temporal distribution of releases of flammable gases, but also smoke or toxic cloud movements and the possibility of the long-term harm that toxicological products could create for individuals

The pollutant concentrations in any atmosphere can vary considerably and for any individual pollutant those variations are invariably determined predominantly by meteorological factors. They are also related to the type of source; the ground contours; the physical or chemical properties of the particular pollutant; the geography of a particular area; and can vary considerably throughout the seasons of the year. It is the physical and chemical features that determine the actual distribution of the pollutant in the given atmospheric conditions, the two characteristics, of density and reactivity, being particularly important for cloud behaviour and dispersion.

The density of any gas is used to categorise the meteorological circumstances according to the corresponding particular atmospheric conditions. Gases that are described as passive are regarded as having a density that is equal to the prevailing air density and so would generally follow the ambient air movement without any major disturbance.

Equally, there are gases that are lighter than surrounding air and these will clearly disperse a great deal easier moving rapidly upwards in the atmospheric layer. Gases are also able to be transformed very easily if they are reactive, that is they can react with other pollutants within the atmosphere or with atmospheric components, such as moisture or solar radiation, which will effect how the pollutant moves forward as a cloud.

There are also gases regarded as heavy where the gas collapses to the ground and through the normal diffusion process then disperses.

METEOROLOGICAL INFLUENCES

Wind

When undertaking an assessment of the consequences and dispersal of an accidental release of a given hazardous substance two of the most important parameters are wind speed and direction. The wind speed is particularly important when considering the dispersion of toxic or flammable substances in the atmosphere and will have an important effect on the hazard ranges associated with the scenario. The majority of dispersion models use the wind speed as a key input but it is generally accepted[35] that for wind speeds lower than about 2 ms^{-1}, available models are insufficiently detailed or accurate. This is somewhat surprising since the mean wind speed at Manchester Ringway for the decade 1983 to 1992 was recorded as 1.5 ms^{-1} for about 20% of the time.

Meteorological Office wind speed data is almost always collected at a standard height of 10 m. But those releases within or adjacent to, urban areas (which are of greatest concern) will often be at, or close to the ground. Wind speeds for the lowest levels have, therefore, to be estimated.

Both Pettit and Johnson identified that the duration of releases, and the general gas density were significant factors in determining the likely down wind distances at which pollution could be significant.

These consequences of wind are also affected by physical location, particularly in a country like the UK, surrounded by seas. For low wind speeds sea breezes can be important. On a fine summer's day these will start at about 10.00 am and may penetrate inland by as much as 90 km by sunset. For stable conditions, with little convection the sea breeze will remain local to the coast. In the UK a sea breeze in the daytime can be seen to come in from the sea as the landmass becomes warm from the sun and the colder air moves in off the sea to replace the warm air. This air then rises to the lower layers in the atmosphere. In the evening this breeze process is often reversed as the land cools and the winds move out towards the warmer more stable temperature of the sea. Local wind systems may be set up within valleys. Anabatic winds occur where the air flows up slopes that have been warmed by solar heating. The vertical profile of wind speed will not follow the normal boundary layer conditions and maximum wind speeds will occur within a few metres of the surface of the slope. The situation is reversed during nocturnal cooling, giving katabatic winds. Where there is no external forcing the valley will experience significant diurnal variation in both wind speed and direction -

Simple conditions are those such as the change that occurs between day and night. During the day warm air when heated moves off the ground and causes thermal turbulence. In the colder nighttime air unstable conditions are created and create atmospheric influences. Conversely there can be very unstable conditions where pollutants either readily mix or may accept moisture, which then primarily affects dispersion creating different dispersion characteristics.

Amongst these conditions different forms of approach to modelling that have developed are lacking in accuracy for wind speeds of less than about 2 ms-1. This is important because most transport phenomena of interest to the brigade officer commanding an incident are on a meteorological micro scale, in the order of km rather than hundreds of km. The transport behaviour of, say, plumes from accidents are normally within the Atmospheric Boundary Layer, the lowest 500 to 1000 m of the earth's atmosphere. Dispersion of pollutants within this layer will depend strongly on local wind effects and stratification. Depending upon the local conditions the plume could be brought down to ground level within a few kms or remain aloft for many tens of kms.

Air Temperature

An important property of the atmosphere is stability. This is primarily a function of the temperature variation in the lowest part of the atmosphere, and given an indication of the tendency of vertically displaced parcels of air to move within the atmosphere. In neutral conditions, which generally occur for moderate to high wind speeds, the temperature lapse is adiabatic (in practice this is about $1^{o}C/100$ m), if a vertically displaced parcel of air moves up or down. The air temperature then adjusts to its surroundings and it will neither rise nor fall any further. Such conditions result in strong mechanical mixing with negligible convective effects.

In very stable conditions the temperature may actually increase with height. This results in the tendency for any displaced parcel of air to return to its original position and reduced mixing occurs. In very unstable conditions the lapse rate is supra adiabatic causing any vertically displaced air to continue its movement setting up large convective cells and enhancing mixing.

Temperature differences likewise create major air movements, being particularly important in terms of cloud movements where inversion characteristics may arise. This inversion process often restricts the depth of any pollutant layer almost putting a lid on the atmosphere and at night time, when ground cooling has occurred, can produce quite static and clearly defined layer conditions. The envelope of air surrounding the earth, the troposphere, is where the majority of the weather is formed. The top part of this is about 5 miles high over the poles and 11 miles over the equator and varies in temperature quite significantly. Within this area its temperature determines the density of the air. Warm air is less dense than that of cold and will always therefore tend to be forced upwards by the surrounding colder air. The temperature is derived in one of two ways. The first is by contact with a surface having a different temperature; consequently air that lays on hot surfaces warms by conduction becomes less dense, and then rises. The whole process has to be in balance so as soon as warm air rises cooler air moves into the vacuum created and the series of vertical up currents or thermals are consequently replaced or balanced by compensating down currents with the whole process of convection then being underway.

Equally air that is in contact with any colder surface is cooled by conduction, gains density and if it is the ground that is cold then the air would tend to settle and cool still further. In this way cold air can remain very close to the ground for long periods, the fog of the winter being an obvious example.

Temperature may also be affected by pressure, independent of any outside source, since air like any gas warms on compression and cools on expansion. In the atmosphere, where pressure is exerted by the column of air overhead, then a transfer process will begin to work and becomes inter related with the warm air of conduction rising. The cool air of reduced pressure enters from the atmosphere and when the cold air travels down to the ground it starts to warm and the entire process becomes repeated.

A very important part of this process in the study of cloud movement arising from fires or toxic leaks is that of inversion where the temperature acts, as already mentioned, as a lid on the thermal of rising air as soon as it reaches surroundings warmer than itself and ceases to be buoyant. A good practical example of this is in the stillness of the winter when smoke from a garden bonfire can quite clearly be seen to rise, reach the inversion point after rising rapidly on the thermals created by the fire but then spreads out horizontally.

Pressure differences created by thermals are important and have to be recognised as do local weather conditions which may create their own distinct features of high and low pressure zones which will directly affect the movement of any smoke plume. The UK typically has westerly winds which are the depressions moving east across the Atlantic clashing with the higher pressure that usually exist over the landmass. It is worth being aware that whilst these conditions generally are static, in the sense they will not change rapidly during the duration of an incident, they are totally dependant upon the local processes already touched upon. Likewise thermals, arising from fires can convey products considerable distances upward into the atmosphere before they disperse and will often deepen on sunny days but as the sun sets it is usual to expect that the dispersion will conversely slow. This occurs since the joint effect of the sun and the fire will cease.

These thermals are particularly important to the fire service officer and as a general rule the height of the axis of any plume of hazardous material the more the dilution by the vertical and cross winds spreading which must occur before any effect is noticed at ground level.

Practical Impacts

Smoke palls can create major health hazards and the ability to predict the likely spread due to atmospheric temperatures and wind conditions can be an extremely important part of determining suitable responses for public evacuation. Local winds play a significant part in the understanding of fireground effects. Winds such as zephyrs, moving from cool areas into warm ones, are not particularly strong but will have some impact around the fireground. The most significant observed fire phenomena in this regard were the firestorms created at Dresden during the Second World War. Large numbers of the population suffered death, apparently not from direct burning but from air movement created as these zephyrs intensified and moved into the thermals created by the massive fires. Subsequently insufficient oxygen was left in the surrounding areas unaffected by fire leading to a loss of human lives.

Whilst this is a worse case scenario, similar effects can occur particularly where large areas of cool air may exist close by the fire scene.

The temperature ranges that occur in urban areas may also be important. Urban areas are measurably different to those in open country; certainly urban temperatures reach significantly values than those of any surrounding rural district. The range can move from a few tenths of degrees Celsius to several degrees. The maximum effect of this can often be found on calm clear nights in the summer when a heat sink effect occurs within the city or urban area. These impacts are quite important in that the balancing processes already mentioned created by radiation, have to be satisfied by conduction and turbulence transfers occurring between the two areas.

Surface temperatures may also reach an appreciably higher value in towns and cities arising from man-made heat. Consequently open country effects, such as the deep frosts of a clear winter night, may not be seen within the urban environment where boundary layers can change and create inversions. This may become important when fires create thermal plumes.

Topography

Dense concentrations are inversely related to the speed of any ground level release. Wind direction will directly affect any dispersion and the direction is also related to any ground contours, or what might be termed surface roughness, which will cause collapse or conversely rapid movement of any clouds. Most industrial sites from which gas dispersion could be expected will contain a number of buildings and other structures. These will vary in height and will significantly affect the airflow at, say, head height (approx. 2m above ground level). Channelling and sheltering effects will be present, significantly altering airflow patterns at lower levels in a non-predictable way. In addition there are likely to be heat sources and differences in ground cover (tarmac, grass, etc.), which will ensure a distribution of temperatures that may drive significant local convection currents. Little has been done to quantify such effects[36].

For the built environment within urban cities these contours may well be created by high rise buildings or factories forcing the air to move through passages which may be narrower and therefore increase the speed and the concentrations of any toxic products. Buildings can significantly affect atmospheric dispersion[37]

There are an infinite number of possible configurations of release and obstacle arrangements and no general theory exists to predict the dispersion of gas releases for all conditions. Wind tunnel data reported by Duijm and Webber is confined to street canyons consisting of simple cubed shapes with the wind parallel to the two lines of cubes and the source midway between the lines. No validated simple methods exist that describe dispersion around arbitrary arrangements of two or more obstacles, but the general approach (where the cloud depth is much greater than the height of the individual obstacles) is to use a roughness length appropriate to the obstacle arrangement.

Within the physical environment there is also the need to consider the impact of any ground contours, which may include contours created by buildings that introduce high wind speeds or turbulence in localised areas. The opposite of these wind speeds can be almost stagnant conditions where buildings act like the walls of a valley restricting any real dispersion within the valley area.

As with all these natural phenomena considerable variations can arise due to local geography. Ground contours will clearly distort any wind patterns in a very similar way to how they would disturb water if it were flowing across similar ground contours.

Humidity

From a firefighting point of view there is also the need to consider humidity, as air, which contains high amounts of vapour, will again introduce conditions that directly affect the ability to disperse any products. Saturated air, that is air which is containing the maximum amount possible of any vapour, will create special conditions which if such air meets any absorbent materials used in building constructions or outside goods storage areas could produce circumstances which rapidly increase concentrations of any product. This is important in fireground conditions where harmful products entering the air stream may have already been subjected to high levels of water used in the firefighting and example here may be the use of water sprays on ammonia leaks.

Consequently if this polluted saturated air finds itself in a situation below dew point, that is where the temperature is just below the saturation point, some droplets will inevitably occur. A practical example here may be droplets of a high level pollutant falling some distance away from a fire creating possible harm to pets or animals but more likely corrosion or similar problems to vehicles and paintwork of buildings.

This sort of condensation is very important since it can almost reach the stage of creating a fog very similar to the natural fog of condensation. Fog exists until either a temperature rise lifts the air and clears it away or an increase in wind speed creates sufficient movement to disperse the fog. Under fireground conditions the condensation fog at ground level could contain very high level pollutants and the consequence of risk to the population. In the winter there is also the possibility that real fog may be combined with the fire process and liquid droplets again at low temperatures might occur creating quite difficult conditions.

One particular fog, advection, could pose particular difficulties as it arises from warm air being cooled on a cold area. If the fog happens to contain harmful levels of condensate, which do not clear easily, dew point and saturation become quite important, especially in the cold winter temperatures of the UK, and it is worth being aware of such difficult conditions.

There is also the possibility of such specialised conditions occurring with clouds of gas or smoke that become dominant around particular geographic features such as large hills. The natural phenomenon involved is referred to as an orographic cloud, but effectively results in a cloud forming and evaporating over the relatively humid part of a hilltop.

These natural phenomena would normally be seen as the cloud that becomes stuck on the top of a hill or to the rear of a particular high point but it has the ability to cause deep concentrations, which is more interesting to the fire service officer.

INDUSTRIAL EXPERIENCE

Studies into effluents from industrial processes generally use the simple model that ground level concentration from a source of a fixed height is inversely proportional to that height. This in turn means that considerable importance is attached to the height of the source of a plume centre line since this will be the result of any buoyancy created in the process.

However the physics of the problem are not so simple and studies into gaseous effluents, such as those coming from power stations, has been seen to be a complex process dominated first by the rise and influence induced in any plume, as a consequence of its upward movement and secondly, the buoyancy, which is subjected to the natural dispersive actions of the atmosphere.

These complexities have resulted in a large number of surveys over the years particularly by those involved in the power generating industries and studies. Pasquill and Smith cite work by Culkowski, Munn and Cole who have for example identified that the height of a source can be disregarded for most practical purposes[38]. Consequently these studies have generally shown that despite these complexities it is still a reasonable policy to use a ground level source as the input to any calculation and prediction of safe estimates of concentration. This is particularly relevant to the fire service who have a capability and capacity to measure ground level dispersion but little expertise in the utilisation of complex modelling data.

It has already been mentioned the general degree of aerodynamic roughness of any area could create distinct problems predicting the transfer with any source gas. The work by Culkowski cited by Pasquill and Smith has also indicated, that for practical purposes of estimating likely down wind concentrations it is quite often adequate to calculate an upper limit by neglecting the elevation of the source and any initial rapid down stream dispersion caused by aerodynamics.

Some of the areas identified that are important have been indicated in an idealised representation for a continuous leak or smoke plume. Variations in the position and magnitude of the concentrations that might cause difficulty arise from changes in wind direction and the rates of vertical spread. Variations therefore in concentration relating to a fixed point source may be considerable and this has to be borne in mind when trying to create

Modelling or plume approaches capable of interpretation for the fire service. An idealised plume developed from studies into environmental pollution would typically show features where the cross and down wind isopleths are indicated as powers of 10 when normalised as proportions of apparent cross and down wind values.

OPERATIONAL RESPONSE

Translating some of this more generalised information into practical conclusions for the fire service is particularly difficult. Recent research conducted at the Home Office into gas release systems by the Fire Research and Development Group has focused extensively upon the North American Emergency Response Guide Book previously mentioned. This is a guidebook produced for first responders during the initial phase of hazardous materials and dangerous goods incidents and relates particularly to those products rather than to general harm caused by smoke.

The guide seeks to help identify dangerous materials and provide advice upon how best to approach them. It does however also include particular guidance on the identification of zoned areas, which may present harm to individuals. Guidance has been collated from Canada, the United States of America and Mexico and represents the conclusion of work undertaken by a group of representatives who provide the transport emergency response within these countries.

The NAER Guidebook was therefore a development of the Transport Department of Canada, the US Department of Transportation and the Secretariat of Communications and Transportation in Mexico and is specifically designed for use by fire-fighters. The document contains a particular reference to what is described as a table of initial isolation and protective action distances. This table suggests distances useful for the protection of people from vapours resulting from spills of dangerous goods that are considered poisonous or toxic by inhalation. It is designed to give consideration for the first 30 minutes after any material has been spilled and recognises that changes could occur and increase risk with time.

The guide defines an initial isolation zone as an area immediately surrounding the incident in which persons may be exposed to dangerous and life threatening concentrations where the dangerous conditions which are life threatening exist both up and down wind of the source. A protective action zone is then defined as an area, which is downwind from the incident where any person may become incapacitated or unable to take protective action and could incur serious or irreversible health effect.

The table provides specific guidance for small and large spills occurring during the day and night periods. It recognises that some adjustment for distances for a specific incident may be required with independent variables that should be made by personnel technically qualified to make any such adjustments.

Factors that are particularly identified as needing to change the protective action distances are clearly those relating to the nature of the material especially where it becomes involved in fire. Similarly if a spill involves more than one or two vessels then the tables may need to be extended and increased. Also recognised are materials that may be identified as requiring protective action distance up to 7 miles or 11 kilometres under certain atmospheric conditions. These in turn may have to be extended quite considerably or if a dangerous vapour plume is channelled down a valley or between high buildings. Spills in regions where there is strong inversion, which often occurs in the countries mentioned, through snow near to the source centre with steady winds, may also demand similar changes.

Materials reacting with water are also touched upon as being particularly difficult and of course could influence environmental requirements for protection. All these various factors have to be considered alongside the protective action decision factors that relate to the protective options that may be available. Evacuation, which is one possible protective action, is frequently not available and persons may be required to remain in a shelter condition rather than being placed at particular risk from dangerous goods. The sort of influences that need to be considered, apart from the volume and rate of release are the actual degree of risk to health and the speed of vaporisation.

Similarly under evacuation conditions the location and number of people involved will influence how long it may take to evacuate or conversely how short the dispersion may take offering the option that it may be better to shelter people. The ability to control and move people and the availability of shelter and specific risks such as those of health care premises also need to be considered.

The model produced defines the initial isolation zone with its core being the spill with the protection action zone placed in a downwind configuration with the outer limits of the spill generally seen to be half the downwind distance to allow for a meandering plume.

The practical impact of the guidance given is that it requires tremendous isolation areas and whilst it does seem to offer significant potential linked to the table of various conditions great care is needed in its application.

Using the table for a practical example of a chlorine spill the initial isolation zone diameter is 20 metres or 200 feet for a small spill and 185 metres or 600 feet for a large spill. The downwind protection zone during the day extends to 0.2 miles or 0.3 kilometres from the source with 0.5 mile or 0.8 kilometre at night for a small spill. A large spill requires a 0.5mile daytime distance with a 1.9-mile night-time limit.

It must be realised that this work has been produced for the North American Continent using average temperatures from 61 US cities. The average temperature recorded was 35^0C considerably above the UK average. The definition of a small spill relates directly to the US 55 gallon or 0.1kgs storage drum. A large spill is 3kgs. By using the downwind distance and halving it for the outer parameter, what is in effect being created is a 30^0C spread on either side of the initial isolation zone with everyone regarded at risk within this particular zone.

The UK temperatures are considerably different with a 25^0C day and a 15^0C night temperature. Humidity within the UK is often at 70% and when UK consultants considered this matter they used stable weather as classified by Pasquill that is with winds below 5 metres per second. They also assumed a surface roughness of 0.12 the equivalent of a wooded area. To illustrate the practical circumstances involved at actual incidents the following case study based on a chemical release attended by the author is included for reference.

CASE STUDY INCIDENT

13 June 1987 At The ICI Rocksavage Works Runcorn

This incident provides a case study of a toxic gas release. The incident commenced about 1030 a.m. on the chlorine distillation plant when it was noted that there was a problem on a mild steel condenser. The condenser was used to condense chlorine that had been boiled off from the brine process as a method of removing any bromine, which is an impurity within the brine process of gathering chlorine.

The chlorine bromine mix is placed within the condenser and operations are at around 10-bar pressure. Chlorine derived in this way from brine is known to carry other impurities and on occasions a chlorine iron fire can occur. That is what is believed did occur and caused corrosion on the condenser, which eventually allowed chlorine to penetrate through the internal jacket into the water contained within the outer jacket. This water in turn then went to the cooling towers where, in the process of air stripping, a chlorine release into the atmosphere inevitably arose.

The ultimate impact was that a chlorine iron fire also became established within the condenser jacket that ultimately penetrated the outer condenser wall and allowed what was then relatively hot stock chlorine to be vented into the atmosphere through what was now the weakest point within the condenser. It is estimated the internal temperatures caused by the chlorine iron fire were around 1400^0C within the condenser.

Serious conditions were noted at around noon on the 13 June and when it is believed the chlorine-bromine-ferric chloride mixture was actually emitted through the body of an inlet carrying water flow from the condenser water control valve. The estimates of the released quantities were between 0.5 and 1.8 tonne. This was based upon estimates of the remaining inventory within the condenser system and the increased weight of the chlorine bromine dump tank, which was isolated at the start of the emission.

Eyewitnesses at the time saw flames by the condenser and a large amount of ferric chloride was subsequently found following investigation. The water exit on the pipe work was estimated to be very hot with analysis of paint subsequently indicating that over 200^0C temperatures must have been prevalent around the pipe work.

The release to the atmosphere was probably made at around 9 - 12 bar pressure at a temperature around 48^0C and as part of the reaction a chlorine hydrate was developed that subsequently would break up thereby increasing temperature. Other reactions might arise forming iron chloride and in an exothermic reaction hydrochloric acid and hydrogen. Again these reactions would be exothermic.

Ultimately all the chemistry possibilities were examined. The possibility of a chlorine-hydrogen explosion could not be discounted since there was a violent pressure stage at the time of the gaseous chlorine emission. This was however probably due to a high temperature vaporisation from the condenser water jacket. The condenser had been in a static condition i.e. not circulating for around 90 minutes before the incident.

What is also interesting about this incident is that there was, in the area outside the condenser plant and some distance away, a qualified chemist working as an environmentalist. He was able to provide an eye witness account which demonstrated that white and a pale brown fume cloud rose to a height to between 300 - 400 feet and also formed a dense brown and white cloud which rolled away from the plant. He also noted the developing cloud stayed very low and started to move at a different angle to the initial puff release that formed the high cloud. Wind speed and direction were consistent with the cloud formation since the direction the low cloud took followed the wind direction and the rolling nature of the cloud was consistent with the wind speed that was estimated to be calm with very low ground speeds. The outcome was a two-stage plume with the two elements of a high and a low cloud moving in differing directions at different speeds.

What is interesting from this case study is that if a conventional isopleth had been utilised to predict a cloud of chlorine bromine it is most likely that it would have predicted a low cloud movement but not the high cloud that moved in a different direction.

Wind strength and direction also changed during the incident, an important point when it is realised some children were directly in line with the cloud. The duration of the incident lasted several hours following the noon release. The ability to track the cloud accurately, in the way the qualified eye- witness observed, would have been beneficial.

It would both have allowed a wide area to be returned too normal [in this case the motorway was closed for a protracted period even though it was unaffected]. And it would have better informed the site operator and fire service of the effectiveness of their combined onsite actions designed to control the release. [The fire service did have large volumes of water for cooling and water curtain spray purposes during the emission from the chlorine distillations plant].

Previous research in the United States has identified that many plume models have shortcomings particularly where two jet releases are involved and this case indicates the type of variability's involved in actual events[39 40].

Both the current CHEMET and NAERG approaches would have failed to predict accurately in these circumstances both being too broad in their overview. This does not diminish their value to first attendance crews but it does for ongoing operations. Useful additions to the basic CHEMET scheme are included in the guidance given to meteorological forecasters but this is not available to the fire service at the scene[41].

FUTURE DEVELOPMENT

CHEMET has been used by the fire service on a number of occasions. A more recent quoted example is that for a Napha leak in Cleveland on the 4 May 1997[42]. CHEMET was able to provide a series of predictions to match changes in wind direction as the wind moved its direction significantly during the period of the toxic leak. What was important however was that the cloud did not move as predicted throughout the period even though the three-quarter cloud cover that existed and the neutral stability of the atmosphere was correctly classified suggesting again, as at the Runcorn incident local factors were more influential.

The defined areas of risk for very urbanised areas are significant, in terms of the size of the population affected. Although general policies such as that of "shelter" may be adopted (i.e. people stay indoors and close all doors and windows) it was nevertheless necessary to expend considerable energy to maintain accurate identification of the physical levels of contaminant present due to the leak.

In this case for example it was necessary on a number of occasions to disrupt road traffic to ensure safety, and this is an element of incident management that creates, for the fire service particularly, serious difficulties.

Minimising disruption to road or rail traffic and the effected population demands that plume prediction should be as accurate as possible. Improved accuracy would be achieved if wind speed and direction obtained at the scene, together with on site measurement of down-wind concentrations occurring during the incident, were fed back into the model to give enhanced accuracy. The overall impact would be to improve the standard of prediction and so enable the predicted area at risk to become more closely realigned to that threatened by the actual leak. The basis of the process would remain the current CHEMET system with the 15 pre-determined idealised plume templates designed to estimate typical emission events across a range of anticipated atmospheric conditions.

As an example the use of diffusion tubes used to obtain pollutant densities tubes tend to over-estimate concentrations when compared to more chemically based analysers. Consequently models usually only permit general assessment rather than any particularly accurate assumption. They are nevertheless useful and can be, if accurate data is supplied, relatively precise. The difficulty is obtaining the right level of accuracy given that critical decisions will often have to be made within short time scales based upon those conclusions.

The Met. Office has consistently refined its CHEMET system. Detailed notes exist to allow identification of wind speed and direction, stability and the depth of any mixing layer in which the gas may occur.

This information approach now requires the fire service, or other user, to supply in a systemised way detailed weather and product data, which is then used by the forecaster. The result is often a facsimile plume prediction supplied direct to the requesting organisation within a period of less than 30 minutes. In each of these considerations the gas is considered neutrally buoyant and this is an important part of the prediction process. Further research conducted by the Met Office also enables calculations to be made upon the air projectory utilising standard models evolved over considerable time.

This is linked to the depth of the mixed layer, generally established as day, a stable night or a deep convection period, has enabled a nomogram to be developed. The nomogram provides an estimate of the mixed layer utilising wind speed, integrated heat from the dawn and the amount of cloud cover [measured in Oktas]. In addition the Met Office has developed its own defined Pasquill stability index and again converted it into a simple flow chart for use by their forecasters.

The quality of the forecast produced by the Met Office, it is argued, has been refined but remains highly dependent upon the quality of the input information. Improvement might be gained by ensuring that real local data, e.g. actual wind speed and direction is input into the model. This would apply particularly, for example, to a major chemical complex closely positioned to the sea where local winds are very likely to be at variance to those forecasted by the Meteorological Office. It is argued therefore that if a degree of improved information could be supplied by the fire service to the forecasters, then this in turn could improve the prediction available through

Extending the use of the templates to all engaged agencies would enable all the responding emergency services to apply the agreed appropriate standard template. Adopted for any specific event, the template, allows independent use so helping define actions appropriate to their service whilst ensuring all agencies had the same "at risk area".

NATURAL GAS RELEASES

A separate and a distinct area of concern to fire brigades are the risk created when flammable gas is released into the atmosphere. Dispersal patterns, under these circumstances, place the gas within its flammable limits. This can pose serious risks for those in its vicinity, and is considered here as a separate activity in gas dispersion models. This research is based on post event studies relating to two gasholders that were subjected to terrorist attack using explosives and is the major element of this report.

Work conducted with two low-pressure gasholders helps indicate the risks. Both gasholders are typical of many to be found in current use, and are water-sealed (water tanks are below the ground) containing natural gas (NG) at ambient temperature.

The first gasholder is column-guided and consists of two annular sleeves, known as lifts; the upper of these is roofed with steel plates to form the crown of the holder.

Average thickness of the walls is 5 - 8 mm. The lifts move telescopically so that the height of gasholder varies with the actual quantity of NG within it. Gas pressure within the gasholder depends on gas quantity and is determined by total weight of the lifts that are above the ground at any one time. Total gas capacity of the column-guided gasholder is 12,687 m^3; internal pressure corresponding to first lift being moved to its full height is 16.2 mbar, whilst when the full height of the holder is reached, the pressure is 19.9 mbar.

The second gasholder is spiral-guided and consists of three lifts. Total capacity of this holder is 16,935 m^3; pressures corresponding to moving to the full height of the first, the second and the third lifts are 16.2, 21.2 and 28.6 mbar respectively.

Natural gas consists mostly of methane and is lighter than air due to its lower molecular weight [see Table A1 below]. The critical temperature of methane is -82^{o}C hence at normal conditions methane cannot be liquefied by pressurisation.

Molecular weight, [g/mole]	16.9 - 19.0 mean: 17.18
Lower flammability limit (LFL) χ_{LFL}, [% vol]	5.0
Upper flammability limit (UFL) χ_{UFL}, [% vol]	15.0
Boiling temperature, [K]	109
Critical temperature, [K]	191
Heat of combustion, [kJ/kg]	50,010

TABLE A1 PROPERTIES OF THE NATURAL GAS

Maximum total masses of NG in gasholders at an ambient temperature of, say 15°C, can be calculated using the maximum pressure corresponding to the maximum volume of the gasholder. System parameters are summarised in Table A2.

Gasholder	1	2
Type of construction	Column-guided	Spiral-guided
Diameter of the gasholder, [m]	31.4	31.1
Maximum height of the gasholder, [m]	16.5	25.6
Maximum Volume, [m^3]	12,687	16,935
Maximum excess pressure, [mbar]	19.9	28.6
Maximum mass of NG (at 15 C), [kg]	9,390	12,530
Total mass of NG, [kg]	21,920	
Minimum distance between the gasholders, [m]	10	

TABLE A2. PARAMETERS OF THE LOW PRESSURE GASHOLDERS

SCENARIOS OF EVENTS AFTER DAMAGE/DESTRUCTION OF GASHOLDER

Before considering possible scenarios of an accidental breach caused by a rupture of the gasholders and analysing the consequences of such an accident, some reasonable assumptions have to be made. A whole variety of physical and chemical phenomena could be expected to occur depending on damage characteristics. Among these events the most serious (i.e., leading to the most hazardous effects) need to be chosen for analysis. Below probable scenarios are developed based on particular features of low-pressure gasholders. The following restriction is imposed: the accident is assumed to be sufficient to cause breaches in gasholder walls but small enough so that the main danger could be expected from the combustion or explosion of the gas released.

Both column-guided and spiral-guided gasholders are designed so that the lifts are supported only by the pressure difference between the holder interior and ambient air. Characteristic feature of this type of gasholder is relatively low values of excess pressure (about 0.02-0.03 bar). Since the internal gas pressure is linked with the mechanical behaviour of the gasholder construction, possible consequences of gasholder depressurisation after a breach in the wall or roof will also significantly depend on whether the lifts are still able to move telescopically as the gasholder deflates, or are locked tightly. Consideration is given only the case of the major hazard where the lifts are free to move so that the maximum volume of flammable gas enters the atmosphere mixing with surrounding air to form an explosive or combustible cloud outside the gasholder.

Depending on the characteristic size of the breach and on the quantity of the gas stored in the holder at the moment of depressurisation, different sequences of events may follow. If the breach is relatively small, the gas will be released into the atmosphere over a period, which is much longer than characteristic mixing time, and a quasi-steady-state jet will emerge and a jet fire will occur. However, if the breach is large enough and this is the scenario examined here, the release time is about or less than the mixing time scale, and the gas will form a cloud that can burn after immediate ignition as a fireball or disperse in the atmosphere giving rise to flash fire or (at least, potentially) vapour explosion in the case of delayed ignition.

The critical breach size is defined so that if an actual breach has size, which exceeds it, a rapid escape of the gas into the atmosphere might be expected, while in the case where the actual breach size is less than the critical, jet outflow occurs. If the fuel gas is released quickly enough into the atmosphere, it forms a cloud in which the concentration of the gas will exceed the upper flammability limit (UFL). Some layer of combustible mixture in which the gas is diluted so that its concentration falls between the upper and lower flammability limits will surround this cloud. After immediate ignition the fuel-rich core of the cloud will burn as a fireball. The volume of the gas in the fuel-rich mixture corresponding to the critical breach diameter can be assessed as this value can be considered as a minimum mass of the NG that can burn as a fireball. Thus, in case of a large enough breach, the mass of the fuel in the fireball can be assessed as 0.3 - 1.0 of the total mass of NG stored in the gasholder. Critical values of the breach diameter, area and the volume and mass of the fuel corresponding to them were calculated for the first and the second gasholders and are presented in Table A3 together with the total likely outflow time.

Gasholder	**1**	**2**
Maximum total volume, [m^3]	12,687	16,935
Critical diameter of the breach d_*, [m]	4.7	5.1
Total area of the critical breach S_*, [m^2]	16.3	19.8
Critical volume of the gas V_*, [m^3]	6,090	8,130
Critical mass of fuel M_*, [kg]	2,820	3,765
Total outflow time for critical breach t_r^*, [s]	15.6	17.1

TABLE A3. PARAMETERS OF THE CRITICAL BREACH

If the gasholder deflates completely, all the stored gas escapes into the atmosphere. The maximum mass of methane is released if the gasholder is filled to its full capacity before the breach. If the breach size exceeds about 5 m (which is about 3% of the roof area), the fuel gas will form a large cloud in period less than 15 - 17 seconds. After immediate ignition at least half of the released mass of methane will burn to form the fireball. The main hazards are associated with heat radiation effects

Fireball

If the vapour cloud is ignited immediately, it may burn as a rising sphere, usually referred to as a "fireball". Rapid combustion of vapour clouds as fireballs has been observed in a number of incidents. The fireball is usually formed if the flammable cloud is fuel-rich, so those non-premixed regions of it burn in a diffusion regime. The main parameters to be predicted for assessment of hazards from a fireball are:

- Fireball diameter
- Fireball duration

- Thermal flux at the fireball surface
- Heat radiation from fireball at different distances
- Hazardous zones corresponding to various thermal fluxes

The following cases were chosen for analysis with the gasholder supposed to be filled to its full capacity before the accident, after which it telescopes down until all the gas is released into the atmosphere:

- Case 1. Fireball with total fuel mass of 5 tonnes. This case corresponds very approximately to the lower limit of possible flammable fuel quantity after the rapid release.
- Case 2. Fireball with total fuel mass of 10 tonnes. This case corresponds to severe damage to either of the two gasholders so that all the fuel is released from the damaged gasholder into the atmosphere.
- Case 3. Fireball with total fuel mass of 20 tonnes. This is the worst possible case when both gasholders are damaged simultaneously. The separation between the gasholders is small compared to the typical fireball diameter (about 100 m), so it is supposed that fuel clouds escaping from both gasholders form a single fireball after ignition.

Characteristics of the fireball are summarised in Table A4. It can be seen that in all cases the fireball diameter exceeds 100m and fireball duration is about 10 s.

Case	**1**	**2**	**3**
Mass of NG, [kg]	5,000	10,000	20,000
Maximum fireball diameter, [m]	103	129	162
Total fireball duration, [s]	7.5	9.0	11.0
Height of the fireball centre, [m]	77	97	121

TABLE A4. PARAMETERS OF THE FIREBALLS IN CASES 1-3

Heat flux from the fireball diminishes with distance as shown in Fig.3. The more powerful the fireball is, the larger is the radiation flux at any given point and the longer is the exposure time.

Boundaries of hazardous zones can be obtained by comparing the calculated heat radiation flux with experimental data, which relate the radiation intensity and exposure time to damage caused[43]. The probit method can be used to determine the heat radiation causing various levels of lethality. It should be noted that actual consequences of heat radiation are determined by heat flux being absorbed by the target. This flux can be less than the incident radiation flux (calculated above) because some fraction of radiation can be reflected and the target surface may not be oriented square on to the incident radiation. Since these factors diminishing the received heat flux are often uncertain, analysis of the consequences of heat radiation is widely performed assuming that the received heat flux is equal to incident flux, (i.e., the target is assumed to be a black body normal to the radiation direction).

This approach gives the conservative (worst-case) estimate of the radiation effects and is adopted in the current study. The data obtained are summarised in Table A5 as eight hazardous zones corresponding to diverse effects of the heat radiation. For each zone the distance to its boundary is given. The heat flux at the boundary of each zone is also indicated in parenthesis.

These data show that the fireball constitutes a very serious hazard because its thermal radiation can be dangerous for people at distances of up to 160 - 350 m's'. Radiation-induced ignition of wood can occur at distances of up to 90 - 155 m.

Zone	Expected effect	Distance, [m] (Heat flux, [kW/m^2])		
		Case 1 (5,000 kg)	Case 2 (10,000 kg)	Case 3 (20,000 kg)
1	Wood ignition	91 (26.7)	118 (26.6)	155 (26.4)
2	75% lethality	-	-	35 (69.3)
3	50% lethality	-	31 (65.1)	65 (57.2)
4	25% lethality	23 (63.3)	54 (53.7)	90 (46.5)
5	10% lethality	43 (51.6)	72 (44.6)	109 (39.4)
6	1% lethality	66 (38.0)	99 (33.0)	144 (28.9)
7	First degree burns	126 (16.9)	179 (14.5)	252 (12.4)
8	Pain threshold for unprotected skin	165 (10.0)	250 (8.5)	345 (7.0)

TABLE A5 HAZARDOUS ZONES SUMMARY FOR NATURAL GAS FIREBALLS

UNCONFINED VAPOUR CLOUD EXPLOSIONS [UVCE]

If a gasholder is breached it is possible that escaping gas will be ignited immediately, and this case is covered above. Nevertheless, for the sake of completeness the case of delayed ignition of the gas cloud from the gasholder is considered here. The principal hazards from a vapour cloud in the case of delayed ignition are:

- Flash fire and thermal radiation effects
- Unconfined vapour cloud explosion (UVCE) and blast wave effects

For flash fire to occur, the cloud (or some part of it) must mix with ambient air so that the fuel is within the flammability limits. Also, a source of ignition is necessary. Fuel combustion in a natural gas flash fire is blast-free and the main hazards are associated with possible flame engulfment. The most significant factors determining the evolution of a natural gas cloud are atmospheric turbulence and the buoyancy caused by the difference in molecular weights of NG and air. The low molecular weight of natural gas causes the released cloud to rise rather than to flow down along the ground surface (as in the case of heavy gases). This diminishes the hazards of NG clouds substantially. To estimate the main features of evolution of the gas cloud after escape from the gasholder, it is necessary to consider cloud dilution by atmospheric diffusion together with buoyancy forces.

Bull and Elsworth in their work on the susceptibility of gaseous methane/ethane mixtures to detonate in air have shown that neutral and/or stable weather conditions the distance the cloud must travel to be diluted with sufficient ambient air to reach the UFL is about 100 - 200 m, and the time necessary to reach this distance is about 1 min for wind speed 2 m/s, and 0.5 min for the wind speed 5 m/s[44]. It follows that fast dilution in the zone near to the gasholder is probable only if atmospheric stratification is very unstable, which is the case on sunny, windy days. Thus it is likely that in average weather conditions the cloud has to drift about 50 - 100 m before it can become flammable.

Positive buoyancy of the cloud results in its relatively rapid (at least for the first few seconds) ascent above the site, possibly to a height of several dozen metres. If this combined with the absence of, say, tall buildings near the gasholder site then the probability of delayed cloud ignition very low. Even in the case of the ascending cloud being ignited, its burning is expected to be blast-free, i.e., deflagration regime of combustion will follow. There is now considerable evidence that vapour clouds of methane at normal temperature burn but do not explode. Experiments have been carried out in which attempts have been made to initiate explosion in methane clouds with quite strong ignition sources, but without success[45].

Summarising the above, it can be stated that delayed ignition of NG cloud constitutes much less hazards than immediate ignition after damage to the gasholder. British Gas experiments simulating accidental release of LNG into the atmosphere concluded that releases of natural gas in open terrain, if ignited would not give rise to a Vapour Cloud Explosion due to the low reactivity of the gas/air mixture. The types of event occurring would be either a burning plume or fireball depending upon the nature of the release[46].

Unconfined vapour cloud explosions [UVCE] are particularly hazardous and are often linked to aerial explosions. They arise when both fuel and air [or oxygen] are present in a gaseous form and may be either pre-mixed or not. Mists or droplets can form similar clouds and offer similar characteristics to UVCEs involving gases. The UVCE has the ability to create very high temperatures and significant increases in volume with the consequence of expansion forces capable of creating considerable damage.

The closer the gas is through premixing to the perfect or stoichiometric proportion the hotter the flame. This stoichiometric mixture is well documented for most common gases and considerable research has been done into all 'normal' gases. Of course all gases do not burn especially if they are towards their upper or lower flammability levels and again these levels are well defined using apparatus developed by the US Bureau of Mines. Turbulence or increased ambient temperature can enhance the impact of UVCEs and therefore the impact of the weather becomes important. Increases in ambient pressure also have an effect; gases such as methane have a slightly higher burning velocity with decrease in pressure.

Typically the vast majority of UVCEs will involve liquefied petroleum gas or at least its derivatives propane and butane. Hydrocarbons, initially at normal temperature and pressure will produce temperatures on combustion of between 1800 and 2000º C. UVCEs are particular hazardous because of the up to eight fold increase that may occur in volume and atmospheric pressure. With any actively moving flame speed it is normal for explosions to occur within confined areas. UVCEs by definition will occur in an unconfined space although there may be some physical limitations applied through the presence of buildings or chemical plant.

It is generally accepted that UVCEs are subjected to the normal deflagration flame and are not detonations. Nevertheless the standard measure of damage created by the blast waves is linked to that created by detonations. The standard link therefore is to explosives and conventionally trinitrotoluene [TNT]. TNT detonations are the method used for recording likely impacts of UVCE and the kinetic energy developed by such blast waves goes far beyond the boundaries of any thermal damage. It is necessary for mixing to occur prior to any significant UVCE Studies identifying incidence have observed that over the past 50 years there have been at least two fireball or UVCE incidents every year.

It therefore becomes extremely important in considering the weather to note its impact upon clouds likely to generate this phenomenon. In charting the fifty incidents quoted UCVEs killed over 700 people, quite frequently through the blast rather than through thermal injury. The primary weather influences on UVCEs are those of wind and temperature. Rainfall, atmospheric pressure and humidity tend not to have any major impacts although they can create situations, particularly where the density of the gas may be confined, which enables the gas to force its way against wind flows, because the cloud of gas is stabilised by the weather condition. In any study it is important for the fire service that the hazards of UVCEs be recognised in a similar way to that of fire balls and that the likely impacts as the down wind area be considered.

EMERGENCY ACTION PROCEDURES

Emergency Action Code

The principle UK method of marking hazardous materials is with an Emergency Action Code derived through the Hazchem system[47]. The transportation of hazardous materials in the European Union relies upon designation through the agreement relating to the carriage of dangerous goods by road[48]. Essentially the difference between the two systems is the UK EAC and the ADR primary hazard reference, since both systems include the United Nations substance number. The UK system effectively relies upon a routinely published Hazchem list that is a derivative of both United Nations and European classifications. These latter sources, whilst providing a very useful database, are not primary sources. These remain the observed and recorded physical and chemical properties of the individual chemical, substance or mixture, which are not open to misinterpretation. Information is also often available in schedules attached to enforced national regulations.

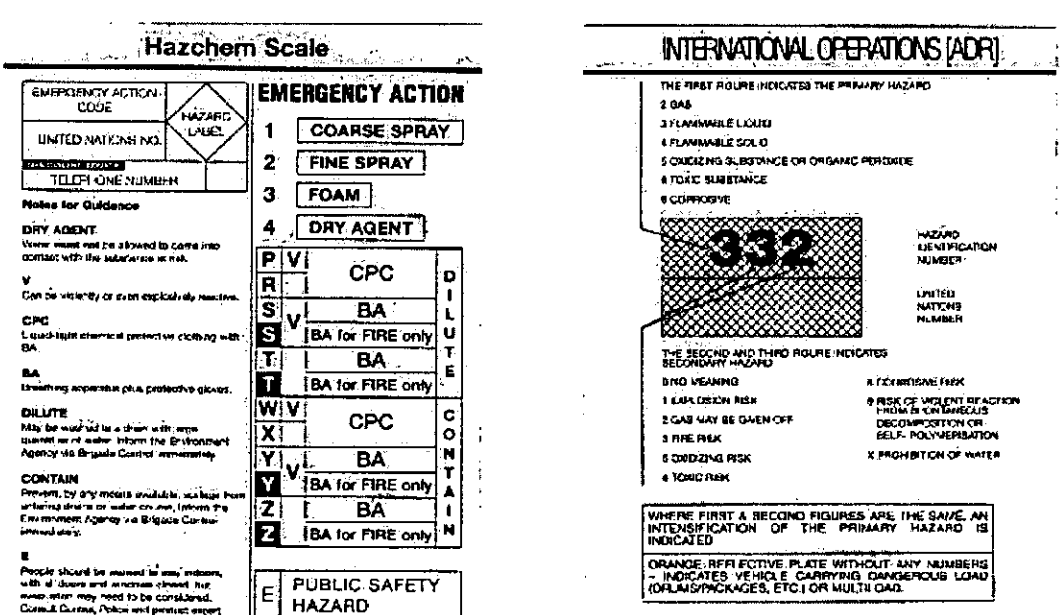

FIGURE A1 PERSONAL HAZMAT CARD
(FRONT AND OBVERSE OF A COMMERCIALLY PRODUCED CARD)

The Hazchem system therefore remains an EAC based system, not a risk assessment code, and the UK Hazchem List an advisory document without legal obligation, albeit derived from the Approved Carriage List 1996 which is a legally enforced document, i.e., clothing codes or extinguishing agents. Translating the EAC into action is simply managed through the issue to every firefighter of an EAC card; Figure A1 illustrates a commercial example.

It is re-emphasised that accurate primary data is required, particularly for chemical and hazardous material incidents. This transposition of data activity is not without its faults, as will be shown; yet it is crucial to ensuring the Incident Commander is provided with accurate information. Errors can occur in transposing any data from its primary source, e.g. typing and miss spelling, and such errors are not solely in the preserve of the local operator but also occur in national databases or legislation.

Computer transposition, whilst reducing simple mistakes will not necessarily prevent, and may magnify, the propagation of errors.

The secondary data often used in working systems is sometimes derived using specific decision criteria. Validation of the decision criteria is important since this determines the quality of the working data. In this context, understanding why certain criteria have been chosen, who the selected end user is and how the data has been validated become essential questions. The UK Hazchem system is very good example of this process of data system construction with the fire service, as the selected end user, making operational decisions at hazardous material incidents.

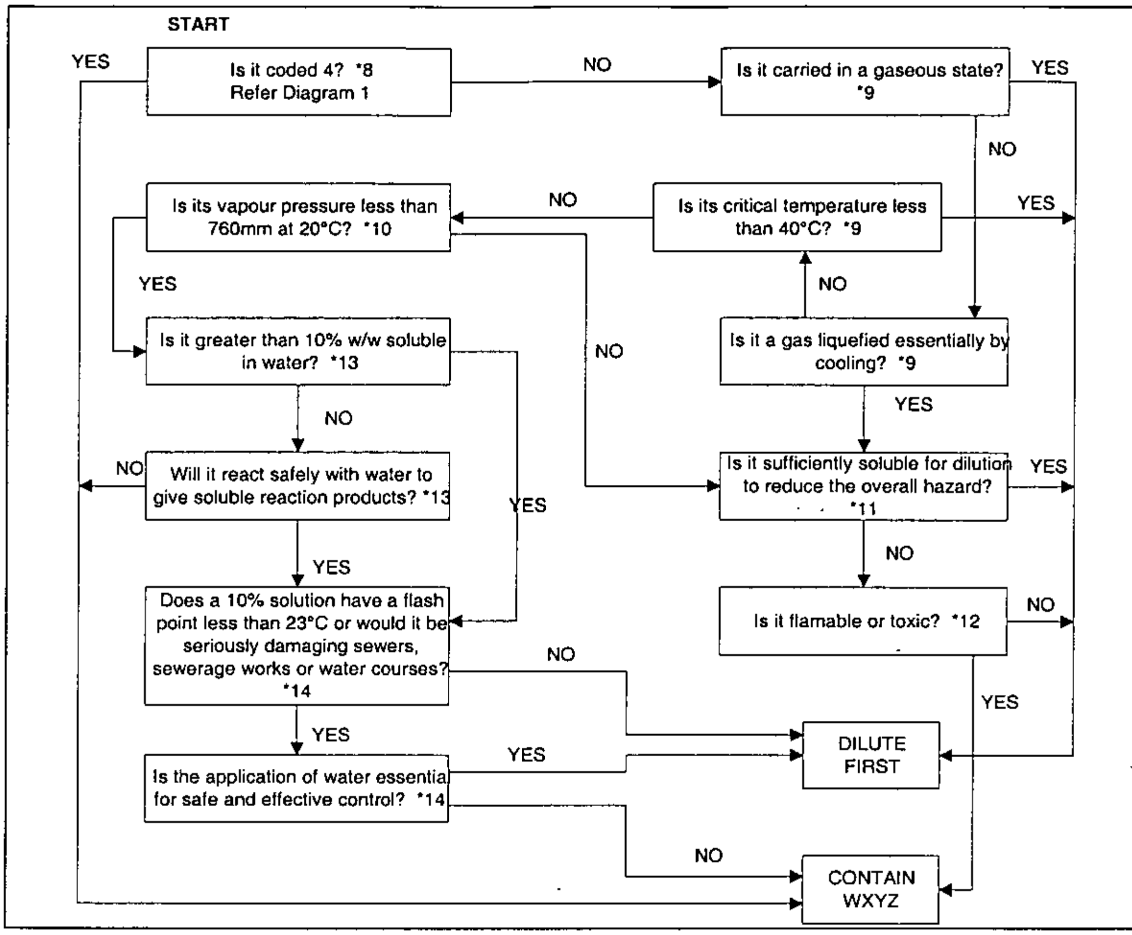

FIGURE A2 AUSTRALIAN DANGEROUS GOODS CODE[4] DECISION TREE FOR CONTAIN OR DILUTE?

Notes to Figure A2

1 The letters used indicate the precautions to be taken in the event of a fire or spillage, in this tree whether to contain or dilute any material. The letter 'E' is added when a neighbourhood evacuation should be considered. The letters are shown on the placard and firefighter's card [Figure 1]

2 The references *8 to *14 refer to the notes contained in the Australian Dangerous Goods Code Appendix 4 page 271. Note *8 for example reminds the user that a substance coded '4'must be kept dry and should not be diluted, Note *9 that compressed non liquefied gases can be dispersed quickly using water spray, Note *10 clarifies that a substance exerting less than 1 atmosphere absolute at ambient temperature is treated as a liquid or solid and Note *14 highlights the danger of flammable or toxic vapours in sewers. This flow diagram is one in a series of 5 the others covering Which Medium to use, Personal Protection, risk of Violent Reaction and the need to Consider Evacuation.

The Hazchem system has developed extensively over several years to provide the firefighter with the EAC. The EAC, printed on a placard attached to a container transporting hazardous material, defines the essential immediate actions that should be taken to secure safety both for the public and the firefighter, and also provides information as to how to handle any spill or fire that has occurred. Placarding of road and rail vehicles originating in the UK is a legal requirement under national and international legislation[49].

The decisions as to which extinguishing medium to use; whether to dilute or contain a substance; which type of personal protective clothing is appropriate; whether a violent reaction might be anticipated; or should public evacuation be carried out, are determined by using decision trees, based upon information used to formulate the EACs. A full description of the current EACs and the guidance used to derive an appropriate code for a specific chemical substance, developed by the UK Home Office Hazchem Technical Subcommittee, is not published in the UK although it is to be found in the current Australian Dangerous Goods Code Book[50]. As an example the decision tree for determining whether to contain or dilute a spillage of a hazardous substance is shown in Figure A2.

Ambiguities in Published Information on Hazardous Materials

It is important to avoid any ambiguities that can lead to operational confusion. However, such events do occur and two examples follow: -

Double Entries

As mentioned the Hazchem List, issued periodically by the Home Office, contains vital information for the fire service. However some duplication necessarily occurs as the properties of various forms of the same substance may pose different threats, each requiring a distinct EAC.

The example taken from the Hazchem List Number 10[51] illustrates that using the UN identity number, as done by Fire Control, results in the same EAC thereby creating confusion as to the level of Personal Protection unless the ADR code is also known.

UN	Proper Shipping Name	EAC	APP	HIN1	HIN2	ADR
2996	ORGANOCHLORINE PESTICIDE, LIQUID, TOXIC	2X	B	-	-	66
2996	ORGANOCHLORINE PESTICIDE, LIQUID, TOXIC	2X	-	-	-	60

TABLE A6 DOUBLE ENTRIES[5]

Notes to Table A6

EAC Emergency Action Code, 2X Fine spray and may react violently, APP Advice on Personal Protection, B Gastight suit, HIN Hazard Identification Number, ADR International Transportation-risk identification of primary hazard-60 Toxic, 66 Very Toxic.

The fire service would identify the substance at an incident by the UN Number but under current UK domestic legislative controls would not necessarily have the ADR code. The immediate problem for the fire service is whether gas tight clothing should be worn [as shown by the B in Additional Personal Protection column], since without access to the ADR code they would be unclear as to which substance they were handling. There are particular difficulties of mobility and comfort in using gas tight protection at a fire or under high ambient temperatures.

Dual Classifications of Explosive Substances

Some explosive substances appear in the Hazchem List with a UN number greater than the originating number of 1001, which is where the 'normal' list of dangerous substances starts. The same substance may also appear with a number less than 1000, so being classified as explosive. The only difference in chemical composition between the two substances is the amount of water or other diluent present. Such a substance could clearly present a serious operational risk to firefighters if it were to be in close location to a source of heat, as might occur at a vehicle fire. Table A7 illustrates this point with the substances ammonium picrate and barium azide.

UN Number	Proper Shipping Name	EAC	APP	HIN1	HIN2	ADR
0004	AMMONIUM PICRATE Dry or wetted with less than 10% water, by mass	1.3D				
1310	AMMONIUM PICRATE Dry or wetted with more than 10% water, by mass	1W	-	4.1	-	-
0224	BARIUM AZIDE Dry or wetted with less than 50% water, by mass	1.1A				
1571	BARIUM AZIDE Wetted with not less than 50% water, by mass	1X	-	4.1	6.1	-

TABLE A7 DUAL CLASSIFICATION[5]

The possible confusion could have serious operational consequences for firefighters. A substance classified as 1.1A is a primary detonating explosive, whilst a deflagration risk is classified as 1.3. A product search based on the chemical name only would not reveal this significant risk variation. Explosives also do not currently feature in the lists available to the UK fire service, although they do form part of the UN list[8].

Inconsistencies in Published Information on Hazardous Materials

It is important to avoid inconsistencies of classification, especially between related chemical compounds, which could lead to increased operational risks. Isocyanates are a useful example in helping to illustrate this point and appear in the following three tables and chart. Isocyanates are commonly used in the plastics industry and are widely transported emphasising the need to reduce or eliminate such inconsistencies as shown in the protective clothing classification in Table A8.

UN Number	Proper Shipping Name	EAC	APP	HIN1	HIN2	ADR
2480	METHYL ISOCYANATE	*3WE	B	6.1	3	-
2481	ETHYL ISOCYANATE	*3WE	-	3	6.1	-
2482	n-PROPYL ISOCYANATE	*3WE	B	6.1	3	663
2483	ISOPROPYL ISOCYANATE	*3WE	-	3	6.1	336
2484	Tert-BUTYL ISOCYANATE	*3WE	B	6.1	3	663
2485	n-BUTYL ISOCYANATE	*3WE	B	6.1	3	663
2486	ISOBUTYL ISOCYANATE	*3WE	-	3	6.1	336
2487	PHENYL ISOCYANATE	*3W	B	6.1	3	663
2488	CYLOHEXYL ISOCYANATE	*3W	B	6.1	3	663

TABLE A8 ISOCYANATES WITH EAC AND HAZARD IDENTIFICATION[5]

In Table 3 there are clear inconsistencies in that, despite all the substances listed having a high toxic risk, only some show the need for a corresponding level of personal protection. The APP [Personal Protection] code 'B' requires gas tight protection yet three of the isocyanates are listed as not requiring this level of protection, despite all of the substances shown having an occupational exposure limit[52] of 0.02 mg. m^{-3} or 0.07 mg. m^{-3} for short term [15 minutes] exposure. Such materials may cause sensitisation, so placing individuals at considerable future risk from very low-level exposures, as the trachea becomes hyper responsive and respiratory symptoms increase. Avoiding inconsistencies is not impracticable although at the planning stage information may be found using the US Chemical Abstract Service Registry Number [CAS RN or CAS Number]. This is a substance specific number and allows access to physical and toxicological information that is primary information, therefore providing some certainty upon which planning might proceed. The use of the CAS number also enables searches to be made of the considerable number of existing databases now available on the Internet. Accessing data in this way will help overcome the errors likely to arise from using generic or UN number based substance data, recognising there remains some caution always about the completeness of any list.

In Table 3 UN 2480, for example, is not registered as having an ADR classification, that is products posing a personal risk requiring gas tight protection for firefighters do not, apparently, require consideration of public evacuation, although responsible for the Bhopal disaster of 1985[*]. This latter point is further illustrated in Table A9 extracted from the North American Emergency Response Guide, where considerable evacuation distances are advised for UN 2480.

As can be seen from the table, UN 2487 and UN 2488 require large safety distances,. which in a UK context of urban communities would pose serious operational management issues. The practical arrangements necessary to evacuate established populations of many thousands of people, sometimes under adverse or inclement weather conditions and who might require physical and health support, illustrate this point. Considerations of this kind, for what might be short-lived events such as toxic gas releases, resulted in a review within Cheshire Fire Brigade of safety strategies and ultimately the adoption of a 'shelter' philosophy. This is reported upon later in this thesis.

Physical properties, as shown in the following Table A10, help illustrate how primary, uncorrupted, data can help remove the ambiguity, inconsistencies and duplication of error possibilities in the area of dangerous goods transportation. Unfortunately collecting and translating into practical use this data is not widely undertaken within the fire service and the ambiguities and inconsistencies outlined do therefore occur. The resources needed to undertake this level of work are extensive and it is therefore

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[*] 40 tonnes of the toxic substance Methyl Isocyanate was accidentally released at Bhopal, India on 3 December 1985 from the Union Carbide plant with the consequential loss of over 800 lives and 500,000 injuries. The Bhopal Gas Peedit Mahila Udlyog Sangathan estimate over 16,000 deaths have since occurred.. The US Chemical Safety Board estimate that in the US each year there are 60,000 incidents and 250 deaths directly related to hazardous materials.

perhaps understandable why this activity has not already been accomplished. These important physical factors show there are relationships, which can help with planning and interpretation. Boiling points for example show a definite relationship to evacuation distance with the more volatile substances requiring progressively less distance. Figure A3 is an interpretation, by the author, to show a clear relationship between boiling point, i.e. volatility and evacuation distance.

UN Number	Proper Shipping Name	Evacuation Distances (metres)					
		Small Spills			Large Spills		
		Isolate	Day	Night	Isolate	Day	Night
2480	METHYL ISOCYANATE	95	800	2700	490	4800	9800
2481	ETHYL ISOCYANATE	215	1900	4300	915	11 k	11 k
2482	n-PROPYL ISOCYANATE	125	1100	2400	765	6300	10.6 k
2483	ISOPROPYL ISOCYANATE	185	1800	3900	430	4200	7400
2484	tert-BUTYL ISOCYANATE	125	1000	2400	550	5300	10.3 k
2485	n-BUTYL ISOCYANATE	95	800	1600	335	3100	6300
2486	ISOBUTYL ISOCYANATE	60	600	1400	155	1600	3200
2487	PHENYL ISOCYANATE	30	300	800	155	1300	2600
2488	CYLOHEXYL ISOCYANATE	30	200	300	95	800	1400

TABLE A9 NORTH AMERICAN EMERGENCY RESPONSE GUIDE[53] EVACUATION DISTANCES (metres) FOR ISOCYANATES

Notes to Table A9.

1. A small spill involves a single, small package up to 208 litres, a small cylinder, or a small leak from a large container. A large spill involves a larger package or multiple spills from small packages.
2. Day is anytime after sunrise and before sunset.
3. The isolation distance is the initial immediate evacuation area for all non-essential and unprotected individuals.
4. The Day and Night figures represent a Protective Action Zone distance, in metres, on the downwind side of the spill. This is a zone in which persons are at risk from harmful exposure. The spill centre forms the point of origin of the zone distance given in the table.
5. The width of the zone is the same distance, so forming a downwind square, with the risk area equally dispersed on either side of the direction of spill centre line.

UN	Proper Shipping Name	Boiling Point ^0C	Freezing Point ^0C
2480	METHYL ISOCYANATE	39	-17.8
2481	ETHYL ISOCYANATE	60	-10
2482	n-PROPYL ISOCYANATE	83	-5
2483	ISOPROPYL ISOCYANATE	74	-3
2484	Tert-BUTYL ISOCYANATE	85	11
2485	n-BUTYL ISOCYANATE	115	11
2486	ISOBUTYL ISOCYANATE	106	22.5
2487	PHENYL ISOCYANATE	163	41.3
2488	CYCLOHEXYL ISOCYANATE	172	53

TABLE A10 BOILING AND FREEZING POINTS FOR ISOCYANATES[54]

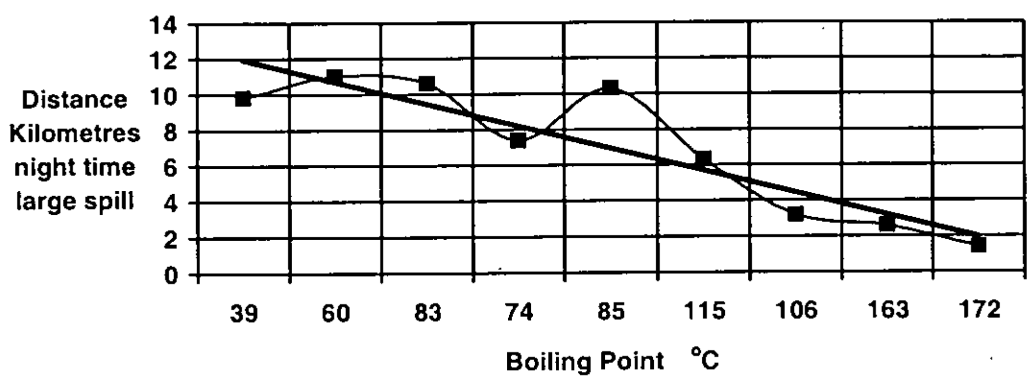

FIGURE A3 EVACUATION DISTANCE AGAINST BOILING POINT [DAVIS]

Data acquisition is not without difficulties, as Klein and Franklin, both involved in providing advice to the fire service have explained following exploration of the issues of validation and verification arising from the current UK approach[55]. This reinforces the very important point that there is frequently, within the legislative requirements, both a framework and prescriptive information base regarding harmful effects that can be usefully applied by the fire service as part of an overall database. For example, limits imposed to avoid harmful ionising radiation contained in UK regulations, derive from values allocated by the International Convention for Radiological Protection [ICRP].

This approach has benefits. The legislation detailing substances, levels or limits to prevent illness or harm, or concerned with monitoring and updating requirements, provides a ready source of incident management information. From legislation in most countries, four groups may be readily identified i.e. Chemical Substances, Explosives, Biological Hazards, and Ionising Radiations and Radioactive Isotopes.

With each of these classified groups information relating to containment, classification, marking, surveillance, explosive limitations, transport etc. is either prescribed or, through guidance and advice or reporting requirements, monitored and controlled. In some areas of activity, the fire service is a consultee and may even be the regulator.

Building upon the existing framework is, therefore, an effective method of meeting some incident management information requirements. In addition, procedural practice may reflect risk avoidance. Thus the wearing of breathing apparatus to prevent possible ingestion, for example, becomes essential in clearing-up operations at premises where asbestos or ionising radiation risks are known to exist. Allowing contents to burn in a controlled manner may be the preferred tactic at a biological laboratory or agricultural store to protect the wider environment from possible bacteriological contamination.

STUDY INTO EVACUATION OF RESIDENTS FOLLOWING A SERIOUS FIRE AT LIGHTFOOT STREET, CHESTER, CHESHIRE, 25 OCTOBER 1996

Introduction

The purpose of this study is to try and identify the behaviour of residents, since there are very few published reports following such incidents. The approach has been to try and identify at what time residents became aware of the incident and how they reacted initially. Linked to this is an understanding of their knowledge of fire safety and the local risk, which was involved, prior to the actual fire.

In addition, residents were asked to indicate how they were made aware of the incident. The survey method itself revolves around the use of personal calls conducted by firefighters who were involved with the actual fire. One outcome of the survey has been the positive statement made by residents and firefighters alike that discussing the incident has helped to come to terms with what was a truly traumatic event.

The structure of the twenty-one questions has been used to seek understanding in a number of broad areas. The questions themselves have been simplified to allow collation and to aid compilation, so that any lessons may be used in the future to improve the quality of the emergency services' response, especially by the fire service.

The survey results are quantified under a series of headings. The first, effectively groups people by their age, occupation, health and language. The second seeks to understand their prior fire safety knowledge and any local knowledge in terms of the building involved. Central then to the questioning is how individuals were alerted and what their first actions were. Finally, their considered opinion is requested regarding their own reaction and those of the emergency services and the opportunity is also given to suggest improvements.

It would have been impossible to conduct this survey without the willing participation both of the residents involved and of the firefighters of Red Watch who had been involved on the night of the fire. What is in strong evidence, as one considers the responses, is that essentially the community sought first to help itself, with a great deal of time and effort being placed into alerting others. Secondly, there is a clear wish to help improve the circumstances for others who may find themselves in similar traumatic events.

THE INCIDENT

At 01:30 hours on Friday 25 October 1996 Cheshire Fire Brigade Control received an automatic fire alarm call from the Chubb Control Centre in Manchester. Chubb are a Company handling automatic fire alarm calls.

Figure A4 Chester Warehouse Fire

The call stated there was an alarm operating at a Pickfords Furniture Depository at

Hoole Bridge, Chester. Attendances were made from Chester Fire Station to what subsequently became a serious incident involving eighteen appliances. The nature of the fire was that following an extremely rapid fire development in the warehouse, which was built in the early 1960s as a railway locomotive shed, a series of properties in Lightfoot Street were directly affected by fire spread. These properties were some 18 metres away from the main fire area. The large storage facility, containing possessions and furniture within the warehouse, created a significant fire in a building measuring 100 by 30 metres.

The building was located behind a solid brick perimeter wall and constructed from corrugated cement asbestos sheeting over a steel frame with a lower section of block work. It was not protected by a sprinkler system. The Lightfoot Street housing, which subsequently became involved in the fire, consisted of Victorian two storey terraced properties built around 1900 of traditional construction. A number of houses had been upgraded both internally and externally and in particular PVC rainwater goods and windows had been used.

To the rear of the terraced property was a communal passageway. The construction of the houses in a continuous terrace was subsequently found to have a significant effect on fire spread in that the roof void in a number of cases had been breached.

The incident development, following the arrival of the first appliances, was that despite an immediate check on site, no obvious fire was observed. However within a very short period of twenty minutes, a major fire had broken through the roof of the warehouse and was already seriously threatening the occupiers within Lightfoot Street. The first call indicating that residents were directly affected was made at 01:48 hours and was subsequently followed with over 100 calls.

METHODOLOGY

The survey was carried out, as mentioned, by firefighters and 29 questionnaires were returned. At the time of the incident it was estimated 50 residents were actually evacuated. 29 questionnaires have been from those directly affected in Lightfoot Street. There is no way of knowing whether an individual has returned more than one questionnaire, although I feel this has been avoided. This has particular relevance concerning children, since some may have been counted twice. Table A11 demonstrates the gender and age of the respondent. It will be seen that 55% were in the 30 - 60 age group. There were 17 children and the majority of occupants were female. Question 2 sought the occupation of the respondent, not necessarily the 'head' of the household. Two thirds of those responding were actually employed, the others being retired or unemployed.

Question 3 indicated the majority of residents were in good health and Question 4 that all used English as their first language. It will be seen, therefore, that the majority of residents were within the middle age group, female and English speaking

Age	No	%	Gender	No	Health	No
16-20	5	17	Females	17	Good	29
20-30	5	17	Families with Children	11	Visually impaired	0
30-40	3	10			Hearing impaired	0
40-50	6	21	Males	12	Physically impaired	0
50-60	7	24	Children present	17	Pregnant	0
60-70	2	7	**Employment Status**		Sleeping medication	1
70-80	0	0	Working	21	**Primary Language**	
80-90	1	4	Retired	4	English speaking	29
Totals	29	100	Unemployed	4	Other language	

Table A11- Demography of Respondents

Question 5 sought to identify where the residents had gained their fire safety knowledge and the results are shown in Table A12. The influence of television and local newspaper articles is seen as particularly relevant, as is the influence of those at work. What is more noticeable is the lack of information gained from local radio and this is perhaps an area which could be developed given that it is known, from other surveys, a significant number of the population listen routinely to local radio stations.

At work	14	TV advertisements	8
From child at school	1	Always known	1
Local newspaper articles	4	Other	3
Radio advertisements	0	None	1

Table A12- Source of Fire Safety Knowledge (Question 5)

Question 6 sought to identify whether or not the population in Lightfoot Street was transient or static. The respondents generally had over six years occupation and therefore were very knowledgeable about their street and local community (Table A13). However when considering the Pickfords building, it is clear that the vast majority of respondents had little knowledge of the building at all, with only four illustrating the most basic knowledge of the interior (Table A14). This raises the general question as to how informed communities should be of particular premises in their neighbourhood and how relevant it would be for the Fire Service to generally try and increase people's knowledge about particular premises.

0-2 years	5	12-14 years	4
2-4 years	2	14-16 years	3
4-6 years	0	16-18 years	1
6-8 years	2	18-20 years	2
8-10 years	0	> 20 years	9
10-12 years	0	Visitors	1

Table A13 Length of Residence in Lightfoot Street (Question 6)

Detailed knowledge of the interior	0
Basic knowledge of the interior	4
No knowledge	25

Table A14 Knowledge of the Pickfords Building (Question 7)

In this case it has to be said, it would have been doubtful under current arrangements for any specific advice to be given about this particular premises. However, given the outcome of the fire, there has to be a question as to whether local communities should have a better knowledge of premises that may present them with a risk from fire.

The next series of questions sought to identify how residents were alerted and at what time this awareness occurred. It also sought to identify whether in the initial alerting process they were able to gain sufficient information to assess the nature of the occurrence and the threat to their own circumstances. It is very evident from the responses to Question 8 that noise was the principal method of alert, combined with light (Table A15). These two methods appear to have been the primary alerting process for the early callers. Noise in particular in this case was especially relevant, given that the asbestos sheet cladding was fragmenting quite violently, creating a series of loud cracking noises. The light of the fire would also be quite intense. The role of the emergency services in providing the alert was relatively modest in comparison to these two other physical methods. There is clearly an indication here that for an alert to be effective, the use of noise and light, in the emergency services case perhaps the sounding of warning horns at night would be a particularly effective method.

Method of Alert	No.	%
Noise	16	55
Smoke	0	0
Heat	0	0
Police	3	10
Fire Brigade	1	3.4
Sensed movement	2	6.9
Family member	3	10
Boyfriend/other occupant	2	6.9
Light of fire	2	6.9
Neighbour	1	3.4
One respondent ticked two categories		

Table A15 Method of Alert to Fire (Question 8)

Turning to the time that people became aware of the circumstances Question 9 illustrates that within fifteen minutes of the occurrence the vast majority of people became aware. There is then a pause of some fifteen minutes before the final group were alerted. It is judged that this gap related to the time at which firefighters conducted a final evacuation search of Lightfoot Street to ensure that all residents had indeed left their premises. The importance of such a search is borne out by the respondents, which illustrate that five people were still in their premises at 2 am even though there was an extremely serious fire affecting the front of the building.

Time of Alert	No.	%
1.30 am	7	24
1.35 am	3	10
1.40 am	11	38
1.45 am	3	10
1.50 am	0	0
1.55 am	0	0
2.00 am	5	17

Table A16 Time to Realisation. (Question 9)

Question 10 demonstrates that the vast majority of people were asleep or at least in bed with no recorded persons being active and awake. Their understanding of the situation, as illustrated in Question 11, was that most people sensed that there was a serious situation underway with 43% of the residents recording it as extremely serious.

Location	No.	%
In bed awake	5	17
In bed asleep	24	83
Awake and active	0	0

Table A17 Location at time of Alert (Question 10)

Understanding	No.	%
Not serious	3	10 %
Slightly serious	7	23 %
Moderately serious	6	21 %
Extremely serious	13	45 %

Table A18 Initial Understanding of Situation (Question 11)

Answers to Question 12 –What was your first course of action? - Show that the first action of the majority of people was to alert others and commence an evacuation (Table A19). This form of response tends to support the notion identified by the United Nations studies that under extreme circumstances the first action of many evacuees is to actually assist and help themselves rather than to seek help from others.

Action	**No.**	**%**
Tried to determine what was happening	2	6.9
Prepared to leave the house	8	28
Evacuated	10	34
Alerted others	12	41
Helped others	3	10
Sought help	1	3.4
Waited	1	3.4
Sought protection from the fire in the house	0	0
Move car	1	3.4
Other	2	6.9
Respondents ticked more than one category		

Table A19 First Course of Action (Question 12)

The community of Lightfoot Street demonstrated this human behaviour in a very focused way with over 40% of their actions directly related to alerting others. The results of Question 14 demonstrates that this included making emergency calls, alerting neighbours and friends either by telephone or directly and waking other occupants within the building (Table A21) while those to Question 13 supports the response made to Question 8 that the majority of respondents did indeed hear the fire rather than identify any other indication that a fire was underway (Table A20).

First Indication of Fire	No.	%
Saw smoke	2	6.9
Smelled smoke	1	3.4
Told by others	2	6.9
Saw firefighters	1	3.4
Opened the front door	1	3.4
Heard the fire	15	52
Saw flames	2	6.9
Heard alarms ringing	0	0
Noise	2	6.9
Saw fire	6	21
Other	0	0
Respondents ticked more than one category		

Table A20 First Indication of Fire (Question 13)

During these initial actions the vast majority of people evacuated although as Question 15 illustrates two remained inside their house believing it was safer (Table A22). The two that stayed watched the fire progress until they too thought it was necessary to leave (Table A23). In leaving their homes, residents predominantly entered the street and vacated, either to the public house or the church hall (Table A24).

Method of Raising Alarm	No.	%
Dialled 999	8	28
Dialled a neighbour/friend	2	6.9
Alerted neighbours	8	28
Alerted other occupants	6	21

Table A21- (Question 14)

Reason for Staying in House	No.
I was too frightened	0
It was too smoky	0
I was too hot	0
I felt safer inside	2
I was not sure what to do	0
Other	0

Table A22 Reason for Staying in House Rather Than Evacuating (Question15)

Action in House	No.
Got dressed	0
Closed all doors	0
Moved to the rear of the house	0
Watched out of the window	2
Gathered personal items	0
Other	0

Table A23 What Did You Do If You Stayed In The House? (Question 16)

Action	No,	%
A friend's house	5	17
Other family member's house	3	10
Into the street	20	69
To the pub	15	52
To the Church hall	6	21
To the car to leave the area	1	3.4
Just ran	0	0
Northgate Arena	3	10
Other - went to own home	1	3.4
Respondents went to more than one evacuation centre		

Table A24 Evacuation Destination (Question 17)

Whilst it may seem unusual to state the role of the public house fulfilled as a natural focus for evacuation and assembly it is something the emergency services should seriously note. This is not the first time in the Author's experience that 'the pub' has served as the focus and focal point for a community at times of stress and indeed many publicans, because of their involvement with the community, naturally offer support and shelter to those who are distressed. Such buildings invariably are warm, well known and at prominent accessible positions.

Moving towards the response it will be seen from Question 18 that the role of police and fire service officers, in providing information and announcements is important (Table A25). 33% of the respondents heard nothing and had to take their own course of action. This suggests that at every emergency where an evacuation is needed the most careful consideration has to be given to providing direction to the evacuees. Where this is likely to occur without support then the simple precaution of placing notices for the public informing them of where to assemble or find information is something that needs to be taken into account

Advice From	No.	%
The Police/Fire Officers	13	50
From other residents	2	7.7
Heard nothing and took my own course of action	10	38
Other - family member	1	3.8

Table A25 Source of Advice (Question 18)

Question 19 provides a clear illustration of how the Lightfoot Street residents felt at the time (Table A26). It is to their immense credit that whilst they were anxious the majority felt in control of the situation or calm and able to function. It is also important to realise that three individuals were seriously confused by the situation and therefore in need of direct personal help. This is a very important point, which needs further consideration.

Feeling	No.	%
I was anxious, but in control	17	59
I panicked and felt confused	3	10
I felt calm	8	28
I was unable to think	0	0
Other - no problem	1	3.4

Table A26 Feelings at the time of the fire (Question 19)

Question 20 was answered despite the loss that occurred to the individual and could therefore be seen as an extremely satisfactory performance by the emergency services. The response of the emergency services is generally seen as satisfactory or extremely so. But the emergency services no doubt can draw some satisfaction from this comment.

Satisfaction Level	No.	%
Extremely satisfied	12	40
Very satisfied	8	27
Satisfied	6	20
Dissatisfied	0	0
Very dissatisfied	0	0

Table A27- Level of Satisfaction with Response of Emergency Services (Question 20)

The responses to two further questions about 'how could we help in future' and 'what could we do better' illustrated that there is room for improvement. The responses are not included in this paper.

To summarise, they appear to indicate that the concern over the loss might have been less had better provision existed in the first place. There is also a clear message about recognising the dignity of the individual and the need for more information. Practical support to help relieve the pressure created by bureaucracy in dealing with paper work and at meeting individual needs following such a stressful situation are also shown.

CONCLUSION

This survey has clearly illustrated, that at times of immense stress, the general reaction of the public is far better than the myths often associated with such evacuations tend to lead us to believe. On this occasion, despite an extremely frightening fire, the first actions of the majority of residents were to ensure their neighbours and family were alerted and that they were all moving to a place of relative safety. The majority did this by their own unaided efforts operating through a system of community understanding. The role of public information in such circumstances is amply reinforced by the indications that further information would have been helpful and was needed.

There is also an illustration of a need to be aware of local circumstances and to improve general knowledge on fire safety issues through local media. The residents of Lightfoot Street have, by simply responding to the questionnaire and study, provided a very rare insight into how people feel and react under such circumstances.

REFERENCES

1 Office of the Deputy Prime Minister. [2002], *The Future of the Fire Service :reducing risk, saving lives*, ODPM Free literature, Wetherby.

2 Fire Brigades Union.[2002], *The Fire Brigades Union Position Statement on the True Modernisation of the UK Fire Service*, Fire Brigades Union. Published by Fire Brigades Union, Bradley House, 68 Coombe Road, Kingston upon Thames, Surrey, KT2 7AE

3 Office of the Deputy Prime Minister. [2003], *Our Fire and Rescue Service*, TSO, Norwich

4 Scottish Executive. [2002], *The Scxottish Fire service of the Future*, TSO, Edinburgh.

5 National Joint Council for Local Authority Fire Brigades. [2003], *Fire Service Reform Fire Service national Employers' proposed Heads Agreement*, NJC, London.

6 Davis, D.T. [1991], *A Change in Management Style,* Cheshire Fire Brigade, Unpublished

7 Jenkins, D. [1996], *Managing Empowerment,* Century, London

8 Senge, P. M. [1993], *The Fifth Discipline. The Art and Practice of the Learning Organisation,* Century, London

9 Walker, D.C. [1996], *The Learning organisation and its Relevance to British Fire Services,* Brigade Command Course Report, Fire Service College, Moreton-in Marsh

10. Rehm, R.G., Pitts, W.M, Baum, H.R., Evans, D.D., Prasad, K., McGrattan, K.B., Forney, G.P. [2002], *Initial Model for fires in the World Trade CenterTowers,* National Institute of Standards and Technology, US Department of Commerce, Maryland.

11 McKinsey and Company. [2002], *Studies of New York Police Department's and New York Fire Department's response to the World Trade Center Attack,* City of New York, NY.

12 Chief Cruthers. [2002], *Presentation to CTIF XXIII International Symposium 19 September 2002,* Vienna, Austria.

13 Titan Systems Corporation. [2002], *Arlington County After Action Report on the Response to the Pentagon,* United States Department of Justice, Office of Justice Programs, Office of Domestic Preparedness, Washington, DC.

14 Chief Plaugher. [2002], *Presentation to US/UK Symposium 18March 2002,* Alexandria, VA.

15 Society of Industrial Emergency Services Officers and Emergency Planning Society. [1997], Seminar Papers, *Toxic Release Dispersion Data, April 1997,* Lancaster.

16 Bara, A. and Dusserre, G., [1989], The Use of Water Curtains to Protect Firefighter in Case of Heavy Gas Dispersion, J. Loss Prev. Process Ind. Vol. 3.

17 Pasquill, F., and Smith. F.B., [1983], *Atmospheric Diffusion, Study of Windborne Material from Industrial and Other Sources. Windborne Material from Industrial and Other Sources,* Ellis Howard, Chichester.

18 Hanna, S.R., and Drivas, P.J., [1998], Guidelines for Use of Vapour Cloud Dispersion Models and Smith, M., [1968], Recommended Guides for the Prediction of the Dispersion of Airborne Effluents. Am. Soc. Mech.Eng. Am. Inst. Chem. Engs.

19 Lines, I.G. and Deaves, D.M., [1997], *Practical Modelling of Gas Dispersion in Low Wind Speed Conditions, for Application in Risk Assessment,* W.S. Atkins, Warrington. J. Of Hazardous Materials No. 54, p201-226.

20 Touma, J.S. et al, [1995], *Performance Evaluation of Dense Gas Dispersion Models.* Jnl. of App. Meteorology, Vol. 34 p 603 - 615.

21 Brighton, P.W.M., et al, [1994], *Comparison of Heavy Gas Dispersion Models for Instantaneous Release,* Journal of Hazardous Materials, 1 Vol. 36 p193 -208.

22 Johnson, B.P., [1994], *An Overview of Gas Dispersion Models for Possible Use by First Attendance Crews.* Publication No. 13/94, Fire Research and Development Group, Home Office.

23 Pettit, G., [1996], *The First Stage in the Development of a Gas Dispersion Prediction System for Fireground Use.* Publication No. 7/96, Fire Research and Development Group, Home Office.

24 CHEMET. [1997], *An Explanatory Brochure,* Meteorological Office, Bracknell.

25 Bennetts, D.A., [1990], *Guidance Notes on the Spread of Pollution.* Meteorological Office, Bracknell.

26 U. S. Department of Transportation [1996], *North American Emergency Response Guidebook,* Research and Special Programmes Administration, Washington D. C.

27 Bootier, L.E. and Janke, B. [1997]. *Air Emissions from Petroleum Hydrocarbon Fires During Controlled Burning,* American Industrial Hygiene Association Journal, Vol. 58, No.5, Pages 359 - 365.

28 Center for Chemical Process Safety, [1989], *Guidelines for Chemical Process Quantitative Risk Analysis,* IChE.

29 Gugan, K., [1979], *Unconfined Vapour Cloud Explosions*, Institution of Chemical Engineers, Rugby, Warwickshire.

30 Committee for the Prevention of Disaster, [1992], Methods for the calculation of the physical effects resulting from the releases of hazardous materials (liquids and gases), In English, PO Box 4323300 Apeldorn AH, The Netheerlands.

31 Johnson, B.P,, [1994], *An Overview of Gas Dispersion Models for Possible Use by First Attendance Crews,* Publication No.13/94, Fire Research and Development Group, Home Office.

32 Pettit, G., [1996], *The First Stage in the Development of a Gas Dispersion Prediction System for Fireground Use,* Publication No. 7/96, Fire Research and Development Group, Home Office.

33 The Meteorological Office, [1997], *CHEMET, An Explanatory Brochure,* Bracknell.

34 U.S. Department of Transportation, Research and Special Programmes Administration, [1996], *North American Emergency Response Guidebook*, Washington D. C.

35 Lines, L.G. et al., [1997], Practical modelling of gas dispersion in low wind speed conditions, for application in risk assessment, Journal of Hazardous Materials, Vol. 54 pp 201-226.

36 Robins, A.G., [1994], Flow and dispersion around buildings in light wind conditions. 4th IMA Conference on Stably Stratified Flows, University of Surrey, Sept, Clarendon Press.

37 Duijm, N.J. and Webber, D.M., [1994], *Dispersion in the presence of buildings,* Loss Prevention in Process Industry, Vol. 7(2) pp 118 -122.

38 Pasquill, F. and Smith, F.B., [1983], Atmospheric Diffusion, Study of Windborne Material from Industrial and Other Sources, Ellis Howard, Chichester.

39 Smith, M., [1968], *Recommended guides for the prediction of the dispersion of airborne effluents*, Am. Soc. Mech. Eng.

40 Hanna, S.R., & Drivas, P.J., [1988], *Guidelines for use of vapour cloud dispersion models,* American Inst. Chem. Engineers.

41 Bennetts, D.A., [1990], *Guidance Notes on the Spread of Pollution,* Meteorological Office, Bracknell.

42 Barometer, [1997], Issue No. 3.July, The MET. Office.

43 Center for Chemical Process Safety, [1989], *Guidelines for Chemical Process Quantitative Risk Analysis,* American Inst. of Chemical Engineers.

44 Bull D.C. and Elsworth, J.E., [1979], Susceptibility of Methane/Ethane Mixtures to Gaseous Detonation in Air - Comb and Flame, 1979, v. 34, No. 3, p. 327 – 330.

45 Lees, F.P., [1998], *Loss Prevention in the Process Industries, 2 vol.,* Butterworth, UK.

46 Private Communication J. Roberts 1997.

47 Hazchem is a generic title used to incorporate a system of guidance to provide information on hazardous materials that may become involved with accidental releases or fires. The Home Office has established a technical sub-committee with representation from the fire service, science, regulatory bodies and the chemical industry that have expertise in this field. The committee produce codes for new substances or substances approved for transportation in bulk. These codes are listed and the lists are published routinely by the Home Office Fire and Emergency Planning Department.

48 European Parliament, [1957], *European Agreement Concerning the International Carriage of Dangerous Goods by Road, (ADR) and Protocol of signature done at Geneva on 30 Sept., 1957,* as revised and updated, 1997.

49 *The Carriage of Dangerous Goods by Road Regulations 1996* [Statutory Instrument No.2095] with *Amendments* [Statutory Instrument1998 No.2885] and [Statutory Instrument 1999 No.303] and The United Nations Recommendations on the Transport of Dangerous Goods as adopted in European Member States through national legislation implementing European Council Directives concerning the international carriage of dangerous goods by road [ADR] and by rail [RID].

50 Federal Office of Road Safety, [1998], *Australian Code for the Transport of Dangerous Goods by Road and Rail [ADG Code], Sixth Edition, Vol.1 and Vol.2,* Department of Transport and Regional Development, Canberra, Australia.

51 HM Fire Service Inspectorate, Publication Section, [1999], *Hazchem List 10,* TSO, London.

52 Health and Safety Executive, [1999], *Occupational Exposure Limits 1999 EH40/99,*TSO, London

53 U. S. Department of Transportation [1996], *North American Emergency Response Guidebook,* Research and Special Programmes Administration, Washington D. C.

[54] *United Nations, Recommendations on the Transport of Dangerous Goods,* (6 Ed., Rev., United Nations Committee of Experts on the Transport of Dangerous Goods, 1989)

[55] Franklin,B. and Klein,R. [1997], *Hazchem List and Hazchem Revisited,* Fire Engineer's Journal, Vol.57, No.187, pp48, and Vol.57, No.88, pp5-7, Institution of Fire Engineers, Leicester.

Published Articles and Conference Reports

1. Davis, D.T., [1987], *Inter Service Integration Between the Police and Fire Service,* Association of Chief Police Officers Conference, Blackpool.

2. Davis, D.T., [1989], *Oil and Chemical Pollution in the Petrochemical Industry - A UK Approach,* Asia Conference, Singapore.

3. Davis, D.T. [1992]. *Hazardous Materials Information and Response*, Conference Proceedings, pages 103 - 111, Bahrain Society of Engineers, BSE, Manama, Bahrain.

4. Davis, D.T., [1993], *Fire - A Change in Management Style",* Cheshire Fire Brigade.

5. Davis, D.T., [1993], *Pollution Aspects of Disasters*, Emergency Planning College Conference.

6. Davis, D.T., [1994], *Mersey Oil Spill - A Practical Response,* Chemical Industries Association Conference, Glasgow.

7. Davis, D.T., [1994], *Interface Between Emergency Services & Emergency Planning;* European Conference on Integrated Risk Assessments, Cambridge, Report pp. 133 - 140.

8. Davis, D.T., [1995], *River Mersey Oil Spill - Lessons for the Future,* Emergency Planning Symposium, Emergency Planning College, Easingwold.

9. Davis, D.T., Chueng, B. and Morris, E.,[1996], *Hazard Management Systems: Information Management at Major Incidents*, EuroFire '95, Fire Engineering and Emergency Planning Symposium, Nime, France, Report pp. 415 - 425 1995. Fire Engineers Journal pp 19 - 24.

10. Davis, D.T., [1995], *The Offsite Incident,* Major Hazards IBC Conference, London.

11. Davis, D.T., [1995], *Fire Service Provision in the UK,* US/UK Symposium, Orlando.

12. Davis, D.T.,[1995], *Europe as a Scene of a Large Scale Accident*, Finfire Conference, Tampere, Finland.

13. Davis, D.T., [1995], *Hazard Information Strategies*, Fire East '95 Conference, Hong Kong.

14. Davis, D.T., [1995], *Fighting Large Scale Fires*, Association of Building Engineers, Conference, Buxton, Derbyshire.

15. Davis, D.T., [1996], *Shelter or Evacuate - Policy Decisions*, Cheshire Chemical Symposium, Winsford.

16. Davis, D.T., [1996], *Information Systems for Supporting First Response*, 2nd International Conference, Local Authorities Confronting Disasters and Emergencies, Amsterdam.

17. Davis, D.T., [1996], *Risk Assessment for the Fire Service*, US/UK Symposium, Stratford-on -Avon.

18. Davis, D.T., [1996], *Exercise Europe [Sweden]*, Report for CACFOA and Home Office.

19. Davis, D.T., [1996], *Fireground Staffing Considerations*, US/UK Symposium 1996 and published report to CFBAC.

20. Davis, D.T., [1997], *Pickfords Warehouse Fire & Lightfoot Street Survey*, Report to Cheshire Fire Authority and CACFOA Emergency Planning Sub Committee.

21. Davis, D.T., [1997], *'Risk Assessment'*, Fire Engineers Journal, Vol 57, No 187, Pages 12-17, Institution of Fire Engineers, Leicester.

22. Davis, D.T., [1997], *Sudden Releases to Water Courses*, Societies of Industry Emergency Service Officers Conference, Lancaster.

23. Davis, D.T., [1997], *Sudden Releases to Atmosphere*, Societies of Industry Emergency Service Officers Conference, Lancaster.

24. Davis, D.T., [1997], *Community Fire & Safety Education*, Fire Africa '97 Conference, Johannesburg, South Africa.

25. Davis, D.T., [1997], *Urban Terrorism*, Fire Africa '97 Conference, Johannesburg, South Africa.

26. Davis, D.T., [1997], *Chemical Risk in Industry and Transport, Environment and the Fire Service, Hazard Management Systems*, Conference of Association Professional de Tecnicos de Bomberos, Castelleon, Spain.

27. Davis D.T., [1997], *Information Needs at Major Incidents: Information, Communication and Management*, University of Central Lancashire.

28. Davis, D.T., [1998], *Fire Service use of Gas Plume Modeling*, Chartered Engineer Submission to Engineering Council.