FIRE INVESTIGATION ROAD MAPS
AND
DECISION TREES
TO ASSIST
FIRE CAUSATION IDENTIFICATION
AND IMPROVE
ARSON PROSECUTIONS

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This thesis is dedicated to my father 'Tony' Mansi who has always been in my thoughts throughout the many years of this research project. His presence has given me the encouragement to continue, even though I have been consumed in the investigations of several major fires during this time.

Abstract

One of the lowest prosecuted crimes in western civilisation is arson. Defence ‘experts’ may be able to discredit a prosecution charge by demonstrating that there are alternative causes for the fire that their defendant was being accused of setting, which were not investigated thoroughly, nor disproved. Unlike many other crimes, a fire may not be detected as arson until the final stages of an investigation, whereas with most other crimes, there is an obvious victim of a crime in the early stages of an investigation. The investigation of fires can be extremely complex. Fire investigators need to ensure that they have conducted their investigation using a systematic and rigorous methodology so that their findings can with-stand any challenges. At the beginning of this project, it was identified that there was a fundamental lack of a systematic methodology to investigate the cause of fires and a need for one to be developed.

To address this need, a series of 23 Fire Investigation Road Maps (FIRMs) have been designed, developed and tested at real fire scenes and also during cold case fire investigation reviews to assist a competent fire investigator conduct a thorough, rigorous and systematic investigation to determine the origin and cause of a fire. It is the cause of the fire, that being the ignition source, first combustible material to become ignited and the mechanism that brought the two together which will determine whether the fire was started accidentally or deliberately. The FIRMs are based on the application of the Scientific Method and are divided into groups and categories to ensure a rigorous and thorough process is carried out during an investigation.

Some examples of applications of the FIRMs during fire investigations when working with the police, forensic scientists and insurance investigators are the Bethnal Green Road two fire fighter fatalities; ‘Operation Refit’, reviewing the murder of Wayne Trotter; the Iron Mountain data storage depot in East London and the fire in the high rise flats, Lakanal, where six occupants lost their lives. The outcomes of these examples, and many other fire investigations, when applying the FIRMs have demonstrated to the relevant authorities, including several Coroners, that a complete and accurate fire investigation has been conducted.

Utilising the FIRMs during a fire investigation will benefit society by enabling existing data to be gathered, documented, analysed and made available for many interested parties, such as Coroners, civil and criminal prosecutors or used to identify any fire safety issues which need addressing. The accurate identification of the cause of a fire, with supporting forensic evidence, will assist the courts in making decisions as to whether the fire was accidental, deliberate or the result of a design or system failure. In the circumstances of deliberate fires, the FIRMs will support any subsequent prosecutions and help increase the low arson prosecution rates that currently exist.

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Chapter 1

Introduction to Fires and their Investigation

The detection rate for arson in the UK (ODPM, 2004) and in the USA is approximately 8%, with a successful prosecution rate of about 3%, i.e. the lowest prosecution rate of all UK reportable crimes (Association of Chief Police Officers, 2001). This is an extremely poor return on investigative endeavours compared with the appropriate statistics on all other reportable crimes. Many books (Almirall and Furton, 2004, NFPA and International Association of Arson Investigators, 2003, Cole, 2001, NicDǽid, 2004, DeHaan, 2007c, Icove and DeHaan, 2004a, Lentini, 2006a, Redsicker and O'Connor, 1997, NFPA, 2008b, NFPA, 2011c) have been written to educate, guide and assist fire investigators to carry out their role in determining the origin and cause of a fire or non-terrorist explosions.

Some books advocate the 'Scientific Method'* to develop a hypothesis when investigating fires (NFPA, 2011c, DeHaan, 2007d); this approach can lead to one hypothesis being developed to reflect selected data, i.e. the hypothesis can drive the data collection. A more scientific approach would be to collect all the evidence and then test a series of hypotheses to arrive at a prime cause or series of necessary circumstances, which resulted in the fire and its consequences. Many hypotheses are 'mentally' tested and eliminated without rigorously recording the analytical process. This programme of work addresses the development of a systematic methodology to continually assess the investigative procedures for accidental and deliberate fires. This enables fully supported hypotheses for the cause of each fire to be tested and proved with the elimination of all hypotheses that have failed.

This introduction outlines fire science, the crime of arson, the fire scene in relation to fire investigation and the reasons for its investigation. It also looks briefly at human agency influences affecting its initiation.

**The systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of a hypothesis' (NFPA, 2011c)*

1.1 Fire and Fire investigation

In simplistic terms, an investigation of a fire usually involves the identification of an ignition source, the first materials to become involved and the mechanism which brought them together to start a fire, followed by a detailed analysis of the fire spread mechanism in relation to larger fires and the roles of people involved at the ignition and different stages of the fire development. This research focuses on a new methodology that will assist a fire investigator identify the origin and cause of a fire. A similar methodology to assist in identifying fire spread will be the subject of further research.

1.1.1 Fire

Generally fire occurs when a heat source comes into contact with an organic material. An organic liquid or solid will evolve vapour when heated and when the concentration of the vapour is sufficiently large enough it will form a flammable mixture with air (i.e. above the lower flammability limit). When this flammable mixture is heated further to its ignition point, combustion occurs (spontaneous ignition) or an ignition source can be applied to a part of the mixture and if it supplies sufficient energy, then combustion (pilot ignition) can occur at a lower temperature.

Basically then, fire requires three components; a fuel, oxygen (from the air) and an energy source in the form of heat (i.e. the ignition source). If one of the components is removed, then the fire will cease. The three components are usually depicted as a triangle:

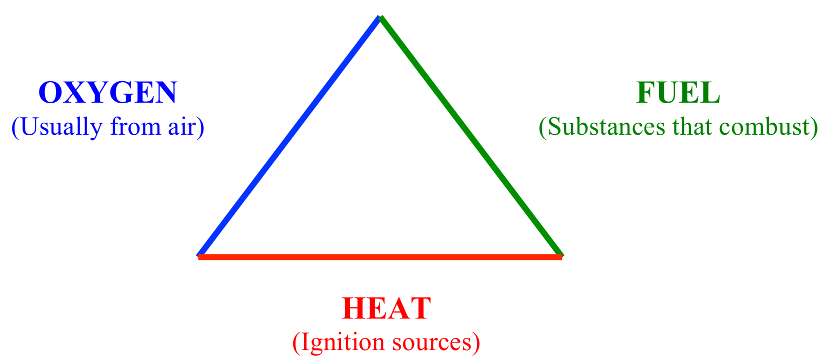

Figure 1.1 The Fire Triangle

A slightly more sophisticated approach suggests a 'Fire Tetrahedron' which adds another side to the fire triangle, and that is of an uninhibited chemical chain reaction, i.e. combustion reactions involving free radicals.

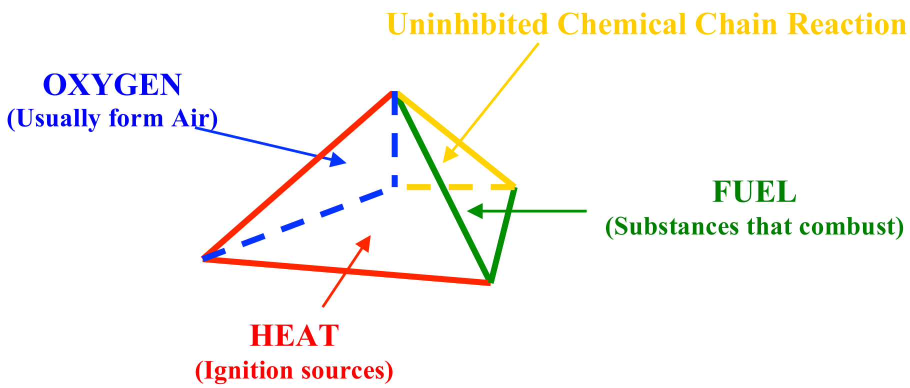

Figure 1.2 The Fire Tetrahedron

Combustion is a series of chemical reactions involving the oxidation of a fuel. These chemical reactions produce heat, light, carbon-dioxide, water and chemical by-products of which carbon monoxide is one. Self-sustained combustion occurs when enough heat from the exothermic reaction radiates back to the fuel source (i.e. thermal feed-back) perpetuating the production of vapours which continuously feed the flame. A simple example of this is a candle. Controlling any one of the four sides will prevent combustion from either occurring in the first instance or continuing once started.

1.1.2 Fire growth and spread

Fire grows and spreads by heat transfer and by the travel through air of burning materials (embers).

Heat is thermal energy that is transferred from one location to another and is dependent on the temperature differences at each of those locations. Heat will travel down the temperature scale, from a higher temperature to a lower temperature.

As far as the investigator is concerned, 'heat' is that part of the tetrahedron which represents heat energy above the minimum level required to release fuel vapours and cause ignition (NFPA, 2004g). Heat transfer is measured in units of energy flow per unit of time (e.g. kilowatt = kilojoule per second) (NFPA, 2004i).

1.1.2.1 Burning velocities

Fire will develop and spread at different rates depending on several factors, such as the material involved, the orientation of that material and the ventilation available.
The most simplistic example of this is a burning match; tip the burning end downwards and the fire quickly develops upwards along the length of the match. Hold the match upwards with the flame above the match body and it will burn slowly back down the length of the match. If held horizontally, the match will burn at a rate between the two latter orientations.

1.1.2.2 'V' Patterns and fire plumes

Because of the burning velocities of materials, upward burning material in the fire plume adjacent to or against a vertical surface will produce a 'V' shaped burn pattern on that surface of varying angles, normally 90 degrees or less. The fire plume is the column of hot gases, flames and smoke rising above the fire due to buoyancy (see [1.1.3.2] below), which entrains air into the flame mixing air and oxygen with the fuel gases. If the fuel is on a slope, like the match described in [1.1.2.1] above, its burning velocity will be quicker if the fire started at the lower end of the material and vice versa. These patterns will not conform to fires started by using an ignitable liquid as the fire spread and fire patterns are dependent upon the distribution and vertical surface contact of the liquid when ignited, sometimes as a deflagration. All of the ignitable liquid may be alight before the materials below it start to burn, therefore it may appear that the materials were ignited all at the same time, which in effect, they may have done.

Burn patterns on a vertical surface from a downward burning fire present themselves with less acute angles against a vertical surface. This is due to the burning velocity of materials that burn downwards being less than those that burn upwards.

1.1.2.3 Flame spread ratings of materials

Materials are rated by classification of their surface burning characteristics, which have been assessed against set standards. This is to prevent materials being installed in areas where they do not conform to the overall purpose and safety of that area. An example is the requirement for a Class 0 rated wall lining for a fire escape route, in accordance with BS476 Parts 6 and 7, indicating that the surface linings of that escape route should not burn and add to the fuel load should a fire occur within that escape route.

1.1.3 Heat transfer

Heat may be transferred by convection, conduction or radiation and is the energy that is required to maintain or change the temperature of an object. Temperature is a measure that expresses the degree of molecular activity of a material compared to a reference point, such as the freezing point of water.

1.1.3.1 Conduction

Heat is transferred either along a solid or between connected solids due to the movement of heated molecules within the solid material. The rate of heat transfer per unit area depends on the temperature differential and the material's thermal conductivity (k). Fourier's Law stated that the rate of heat flow through matter is directly proportional to the temperature difference.

The temperature gradient is the temperature change with distance through the material. The higher the conductivity and steeper the gradient, the faster the energy transfer takes place.

A simple representation of Fourier's Law of conduction is, in what is called the 'steady state' flow of heat i.e. unchanging with time, consider a fire on one side of a wall and heat is conducted through this wall to the other side. The equation that can be used is:

$$q = kA\,(T_2\text{-}T_1)/l \quad \text{(Quintiere, 1997a)}$$

where

q	=	rate of heat conduction (energy per time)
k	=	Thermal conductivity of the material (w/m^2) (energy/time x distance x temperature)
A	=	Area of the path through which the heat is transferred (m^2) (perpendicular to the heat flow)
T_2 & T_1	=	Respective temperatures of each face of the wall (^{0}C)
l	=	Wall thickness (m)

The rate of heat flow (q) expressed in kJ/s or kW between T_1 and T_2 is proportional to the property's thermal conductivity (k) expressed as kW/m.K. Heat transfer will increase when the area of the path perpendicular to the heat flow and/or the thermal conductivity of the material are increased.

Two examples can be given to demonstrate this steady state flow through two walls made of different materials (Quintiere, 1997a).

Example 1:
A wall is built from polyurethane foam 0.05m in thickness with a temperature of 20^{0}C on one side and 40^{0}C on the other side. Substituting $q = kA\,(T_2\text{-}T_1)/l$
with $q = (0.034\ \text{W/m-K x } 1\text{m}^2)(40^0\text{C} - 20^0\text{C})/0.05\text{m} = 13.6\text{W/ m}^2$ or $0.013\ \text{kW/ m}^2$
Example 2:
A wall is built from steel 0.05m in thickness with a temperature of 20^{0}C on one side and 40^{0}C on the other side. Substituting $q = kA\,(T_2\text{-}T_1)/l$
with $q = (45.8\ \text{W/m-K x } 1\text{m}^2)(40^0\text{C} - 20^0\text{C})/0.05\text{m} = 18{,}320\text{W/ m}^2$ or $18.32\ \text{kW/ m}^2$

These equations demonstrate how heat will conduct easier through steel than polyurethane foam. It also demonstrates why materials like polyurethane foam are used as insulating materials.

1.1.3.2 Convection

Convection is the term used to describe the transfer of heat between a solid surface and its surrounding fluid. Two forms are generally recognised:

(i) Forced: where the fluid is flowing as a continuous stream past the surface e.g. Drysdale (1985) provides an example the heat transfer to the fusible element of a sprinkler head from the flow of hot fire gases under a ceiling.

(ii) Natural: buoyancy effects initiate fluid flow. The density of virtually every fluid depends on temperature; when some of the fluid is heated by an adjacent hot surface, that fluid becomes more buoyant with respect to the rest of the fluid. Buoyant forces cause the hotter fluid to move from the surface to be replaced by cooler fluid.

The convective heat transfer coefficient, h is defined by the equation first discussed by Newton (Drysdale, 1985):

$$q'' = h\,\Delta T \text{ W/m}^2$$

or

$$h = q'' / \Delta T$$

where h is a function of:

(a) the fluid properties
(b) the flow parameters
(c) the geometry of the surface

and where q'' = rate of heat transfer (W/m^2)
ΔT = temperature differential (K)

As an example of convection as a method of heat transfer, consider a small waste paper bin fire producing a flow of hot gas at 400^0C over a surface at 20^0C: with (h) taken as 5 $W/m^2.K$ in air (Quintiere, 1997b), the rate of heat transfer to the surface is:-

$$q'' = 5 \text{ W/m}^2\text{.K} \times (400^0\text{C} - 20^0\text{C}) = 1{,}900 \text{ W/m}^2 \text{ or } 1.9 \text{ kW/m}^2$$

1.1.3.3 Radiation

Thermal radiation concerns the transfer of heat by electromagnetic waves of a narrow range in the electromagnetic spectrum (i.e. visible region to the far infra-red). Stefan and Boltzmann showed that that the total energy emitted by a body is proportional to T^4 (T = temperature in Kelvin). The total emissive power is $\varepsilon\sigma T^4$

where: σ = 5.67×10^{-8} Watts/m^2 (K^4), the Stefan-Boltzmann constant

ε = Emissivity, the efficiency with which a surface emits radiant energy

To calculate the rate of heat transfer by radiation from a hot surface (or a flame) to another surface, it is necessary to use a configuration factor. There are two types of configuration factor:

(i) for calculating the total radiation exchange between two bodies or surfaces. This requires a relatively complex geometrical calculation and incorporates the areas and shapes of receiver and emitter as well as the distance between them.

(ii) for calculating the radiation intensity at a point some distance from the emitter – this is given by

$$q'' = \phi\varepsilon\sigma T^4$$

In this equation ϕ is a simple configuration factor that allows the calculation of radiation intensity at a point at a specified distance from the heat source (e.g. a large fire).

1.1.4 Ignition of materials

'*All fires start with ignition'* (Babrauskas, 2003a) and 'ignition' is defined as the process for initiating self-sustained combustion and 'ignition energy' as being the quantity of heat energy that should be absorbed by a substance for it to ignite and burn (NFPA, 2011b).

DeHaan (2007e) and NicDǽid (2004) stated that a fuel must attain a characteristic temperature by means of conducted, convected or radiated heat until it can sustain combustion. The primary source of ignition for all fires is therefore heat.

Most material will burn if the ignition source has enough heat energy to transfer into that material and start the combustion process. By conducting tests involving known materials with potential ignition sources, the investigator can continue to develop, test and prove or disprove their hypotheses. Icove and De Haan (2004a) reflected on a statement from Sir Arthur Conan Doyle's famous detective stories of Sherlock Holmes:

'I have devised seven separate explanations, each of which would cover the facts as far as we know them. But which of these is correct can only be determined by the fresh information which we shall no doubt find waiting for us.'

In other words, conducting tests and/or testing developed hypotheses can be fundamental in identifying and proving the correct ignition source and how that source could have interacted with a combustible material. It has been identified during this research that fire investigators have determined the wrong causes of fires when it was possible to have conducted some very basic tests to determine 'fresh information' which would have either validated or dismissed their hypotheses.

The development of fire depends on the orientation of the fuel. This can be illustrated by using the example in [1.1.2.1] and considering the difference in the speed of burning of a lighted match held horizontally or vertically. Materials (e.g. wood) stacked in close vertical piles in a warehouse will encourage fire spread. Fire needs to be supported by the ignition source until it is self-sustaining.

Lentini (2006a) opens his discussion on fire dynamics with a quotation from Hottel: '*A case can be made for fire being, next to the life process, the most complex of phenomena to understand*'. This quote has been used to emphasise that the understanding of this phenomenon is of great importance to the fire investigator. Both deliberate and accidental fires may have a significant financial impact on an individual or organisation (or both) if the accurately identified ignition source was, for example, the application of a naked flame or due to a design fault within a component part. It may result in a custodial sentence in the former situation or have a high cost implication relating to a product recall in the latter. This section is not intended to replace or expand upon some of the extensive literature that already exists relating to types of ignition sources, e.g. the ‘Ignition Hand Book’ (Babrauskas, 2003a), ‘An Introduction to Fire Dynamics’ (Drysdale, 1998b) and Kirk’s Fire Investigation’ (DeHaan and Icove, 2011b), but to highlight the importance of the fire investigator being able to accurately identify the ignition source of a fire.

Lentini continues to define the ignition of solids occurring when the heat generated in a given volume of material exceeds its dissipation rate with the temperature rising within the material, decomposing it into volatile substances until the combustion process commences through either piloted (250 to 450^0C) or auto (500^0C+) ignition (Lentini, 2006a). He also outlines the potential for chemical ignitions involving substances that ignite when they come into contact with air or water, known as either pyrophoric metals or exotic organic peroxides.

Ignition sources, for example in vehicle fires, can be complex and are often not explored fully. The most important consideration when conducting a vehicle fire investigation, is identifying the point of origin (Cole, 2001). Although predominantly based on vehicles from the USA, the principles Cole identified are the same throughout the world. Accurately determining the origin and cause of a vehicle fire may invoke a recall notification, law suit or another action that could cost an organisation a lot of money. Inaccurately determining the cause may cost the investigator a lot of money!

The fire investigator needs to have a good understanding of ignition sources as well as the flammability of materials and how its physical state at the time of the fire would have had an impact on its ability to combust, including its density and physical form, heat capacity (how much heat must be added to the material to increase its temperature) and thermal conductivity (ability to absorb heat). These three characteristics are referred to as the material’s ‘thermal inertia’. The higher the thermal inertia, the harder it is to ignite. In other words, a material with high thermal inertia is dense and requires a lot of heat to raise its temperature.

Either ad hoc field tests or planned fire testing should be carried out by fire investigators at every opportunity. Field tests can comprise of a sample piece of material from the fire scene and a lighter or match applied by the investigator to see if the material is capable of igniting and sustaining combustion, or how easily it was ignited. This can escalate to fully instrumented test burns in a controlled environment like a laboratory or test burn facility. In each case, the results of the tests should be fully documented.

1.1.5 Materials first ignited

Generally, the identification of the material (item) first ignited is the first step in analysing the cause of the fire. The area of origin of a fire may vary from only being able to identify the compartment of origin, due to the compartment experiencing flash-over conditions (see [1.1.7.1(a)] below) to being able to identify the actual point at which combustion commenced. The first material ignited is that which sustains combustion beyond the ignition source (NFPA, 2004h). The physical form of the material must be carefully considered when ascertaining the first material ignited. For example, a solid piece of timber has a low surface to mass ratio and is difficult to ignite compared to sawdust from that same piece of timber, which has a very high surface to mass ratio and is more easily ignited. That is why dusts that become suspended in air such as flour for example, which have an extremely high surface to mass ratio, require comparatively short duration energy ignition sources such as a spark to start their rapid combustion process.

If a vapour or gas was the initial fuel to be ignited, the investigator must analyse the burn patterns carefully so as to identify that possibility. Difficulties could arise when additional materials some distance from the fire's origin are ignited by the vapour or gas.

1.1.5.1 Fire spread to other materials

This research does not address the already extensively researched subject of fire spread, which can be the most complex and sometimes controversial part of a fire investigation. It is extremely important that the fire investigator has a comprehensive understanding of the combustibility and heat release rates of different materials involved in fires, especially when considering the various mechanisms of heat transfer (see [1.1.3] above) and the effects that ventilation has on those materials involved. To completely understand how a fire has spread, other specialists may need to be consulted, for example computer fire modellers using computational fluid dynamics, material testing laboratories and test burn facilities, such as the Burn Hall at BRE Global, where partial and/or full-scale fire reconstructions can be conducted with full instrumentation to assist in further computer fire modelling.

1.1.5.2 Types of materials involved

Statistics are gathered by the UK Fire Services (see [2.1]) as to the types of materials that are predominantly responsible for the development of fires. Table 1.1 below details the categorisation of those materials in dwellings and other buildings. It is an illustrative example and covers the year 2005. The materials are divided into the following groups:

- gases
- liquids
- agricultural and forestry products
- textiles, upholstery and furnishings
- structure and fittings
- food
- paper, cardboard
- other materials

These are then subdivided again to more closely define the materials and substances involved.

Table 20: Fires and casualties from fires in dwellings[1] and other buildings by material mainly responsible for the development of the fire, 2005

United Kingdom — Number

Material first ignited	Dwellings[1]			Other buildings		
	Fires[2]	Casualties		Fires[2]	Casualties	
		Fatal	Non-fatal		Fatal	Non-fatal
Total	**57,753**	**376**	**11,565**	**35,250**	**27**	**1,401**
Gases	**495**	**6**	**136**	**250**	**1**	**36**
Mains gas	320	5	57	81	-	8
Liquid petroleum gas	128	-	62	99	1	21
Acetylene gas	-	-	-	43	-	1
Other	47	1	17	27	-	6
Liquids	**882**	**18**	**219**	**1,296**	**8**	**111**
Petroleum	341	11	110	377	6	45
Paraffin	32	2	3	41	-	1
Diesel oil, fuel oil	105	-	4	128	-	3
Paint, varnish	85	1	14	200	-	11
Other oils	55	-	5	304	-	9
Spirits	60	1	27	60	-	10
Other	204	3	56	186	2	32
Agricultural and forestry produce	**827**	**3**	**93**	**946**	**2**	**24**
Animal products	660	3	77	103	-	9
Standing vegetation	13	-	-	17	-	-
Cut but unprocessed vegetation	107	-	11	764	2	14
Other agricultural produce	47	-	5	62	-	1
Textiles, upholstery and furnishings	**9,811**	**198**	**3,162**	**3,534**	**13**	**363**
Clothing, on person (not nightwear)	75	12	51	54	4	29
Clothing, nightwear on person	23	4	17	6	-	3
Other textiles and clothing	2,799	23	701	1,111	2	122
Bedding (on bed or mattress)	1,169	35	495	360	3	81
Bed or mattress used as bed	897	16	391	193	1	53
Bed or mattress not used as bed	177	1	62	140	1	6
Furniture, not upholstered	459	12	165	283	-	15
Combustion-modified foam upholstery	71	2	39	20	-	-
Other foam upholstery	535	26	212	245	-	17
Other upholstery, covers	1,331	44	514	537	2	18
Curtains, blinds	899	1	245	151	-	8
Floor coverings	957	6	179	243	-	8
Furniture and furnishings - other	419	16	91	191	-	3
Structure and fittings	**6,099**	**26**	**939**	**7,509**	**-**	**176**
Floors, stairs	573	3	45	260	-	13
Wall, partition, wall tiles	253	-	16	1,187	-	19
Ceiling, ceiling lining	82	2	16	89	-	3
Cavity contents (wall, ceiling, floor)	121	-	4	107	-	3
Roof, roof members	634	-	72	841	-	17
Chimney or hearth	64	-	5	4	-	-
Internal fittings	1,140	10	293	769	-	48
External fittings	485	-	18	733	-	2
Other structure, fitting etc	2,747	11	470	3,519	-	71
Food	**19,851**	**18**	**3,940**	**3,856**	**-**	**153**
Fat	12,160	18	2,985	1,997	-	123
Other	7,691	-	955	1,859	-	30
Paper,cardboard	**3,059**	**7**	**416**	**3,538**	**1**	**90**
Paper and cardboard (not recycling or waste)	1,480	3	226	2,010	1	55
Waste paper, cardboard	1,579	4	190	1,528	-	35
Other materials	**14,604**	**42**	**2,238**	**12,905**	**-**	**392**
Materials for recycling	46	-	5	127	-	6
Unspecified waste	1,775	1	160	1,659	-	40
Packaging and wrapping	577	-	91	569	-	29
Lagging, non-electrical insulation	407	1	53	338	-	23
Electrical insulation	4,646	-	354	4,744	-	73
Electrical insulation in bedding3	23	-	7	1	-	-
Dust, powder, flour	126	-	4	414	-	10
Fireworks	72	-	10	33	-	3
Ammunition, explosives	67	-	20	24	-	7
Other	6,865	40	1,534	4,996	-	201
Unspecified	**2,125**	**58**	**422**	**1,416**	**2**	**56**

[1] Includes caravans, houseboats and other non-building structures used solely as a permanent dwelling (see explanatory note 19).
[2] Including fires started by electric blankets where the material first ignited was reported as electrical insulation.

Table 1.1 Materials involved in the development of fires

Example of Fire Statistics UK 2005 (Communities and Local Government, 2007)

1.1.6 Oxygen sources

Air is the most common provider of oxygen (21%), which is enough to enable most fires to burn efficiently. It is when this percentage begins to fall due to the oxygen being used in the combustion process within a compartment and it cannot be replaced quickly enough, that the fire may start to burn itself out. Rapidly burning large fires, for example large warehouse and forest fires, will consume vast quantities of oxygen from the air, rapidly entraining air to feed the fires, creating localised low-level winds and oxygen deficient zones.

Increased levels of oxygen, such as from medicinal oxygen concentration machines for emphysema sufferers, which increase the oxygen supply to approximately 52%, will enable the combustion process of any localised fire, including smouldering fires, to grow and develop extremely quickly. Many fires have been caused by these people smoking whilst using the attached cannula from these machines.

1.1.7 Fire spread phenomena

The behaviour of material in a fire depends on its inherent physical and chemical properties and the degree of confinement, i.e. the development of every fire is dependent upon the fuel(s) involved, the configuration of such fuels, the available oxygen and surrounding environment and whether the fire is confined or unconfined. In the unconfined fire, such as a forest fire, the availability of air and fuel will enable continuing combustion of any combustible materials present. The hot gases and products of combustion, which will be less dense than the surrounding atmosphere, will rise due to buoyancy until they are cooled by the ambient atmosphere, therefore becoming denser. Those products of combustion will start to either fall or spread laterally at the level where the buoyancy force has become too weak to overcome the viscous drag of the surrounding ambient atmosphere (Drysdale, 1998a).

In a confined compartment fire, the hot gases and products of combustion will rise in a plume due to buoyancy effects and the entrainment of air and continue to grow as heat is radiated back onto remaining unburned fuel. As the plume increases in temperature and volume, the hot gases and products of combustion will rise continuously until it is either (a) cooled to an ambient temperature by entrainment or (b) eventually become obstructed by a ceiling or other horizontal surface, as occurred for example by the roof covering in the stand at the Bradford City Football Club fire in the UK in 1985 (Firth, 2005). In the later, the plume will spread out horizontally underneath the obstructing surface developing into a ceiling jet and start to radiate heat downwards onto any surfaces below it (see [1.1.3.3] above).

1.1.7.1 Fire growth profile

The combustion products within a fire plume will be forced to spread laterally along the underside of a horizontal surface, e.g. the ceiling in a compartment. They will continue to rise from the burning fuel package up to the horizontal surface and keep spreading outwards in an even direction. These products will be stopped from travelling outwards if they come against a vertical surface, such as walls or bulkheads. They will decrease in temperature the further they move away from the fire plume however, once contained by surrounding vertical surfaces the heat will start to increase within the layer of combustion products which is now forming under the horizontal surface and start to radiate heat downwards and onto any surfaces below. Air will be drawn into the compartment through any aperture that exists, such as doors, windows, chimneys and gaps in the building structure or fabric.

Two points of specific significance can be described:

(a)Flash-over

For the phenomenon of flash-over to occur, there has to be enough fuel and air to sustain combustion and also a horizontal surface above the fire to trap a smoke layer, which will radiate heat to combustible surfaces below. Flash-over is the transition between a developing fire within a compartment becoming a compartment on fire, so that all the combustible materials within that compartment have ignited. Indicators of an impending flash-over are when the materials that were not affected by the original fire are starting to pyrolyse, or ‘gas-off’, due to the radiated heat from the hot gas layer above them. These combustible gases are being driven off by the radiated heat and will soon ignite, virtually simultaneously; these are flash-over conditions. Full room involvement will immediately follow flash-over conditions, unless the fire selfextinguishes due to the depletion of fuel, lack of oxygen or is extinguished by fire-fighting media (see figure 1.3 below).

Hot gases will be escaping from the same openings that are allowing oxygen to come in to feed the fire and, due to the fuel rich products of combustion, these gases may ignite outside of the compartment. Decay will then follow as the available fuel is consumed.

(b) Back-draught (smoke explosion)

A back-draught can be defined as a deflagration due to the sudden in-rush of air (NFPA, 2004a) into a confined space containing hot products of incomplete combustion due to lack of available air. For a back-draught to take place, fire growth occurs as in [1.1.7.1(a)] above but sufficient air may not be available for sustained combustion. There may be fuel, in the form of gases, and heat but the compartment could become oxygen deficient and the fire may extinguish itself due to lack of air. The opening or failure of a door, window or any other aperture may allow air to rush into the confined space and combined with the hot gases within the compartment, cause the combustion process to develop fast enough to produce a 'back-draught'.

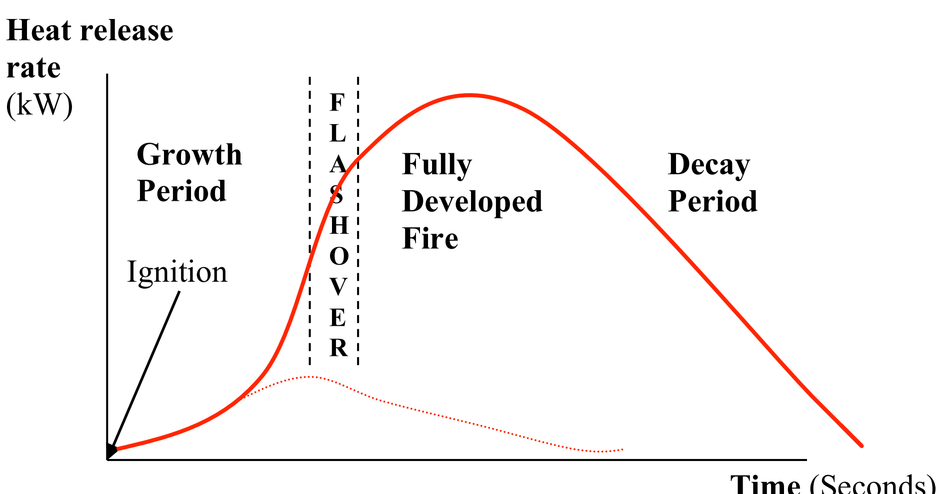

Fig 1.3 Fire growth and decay profile (Drysdale, 1998c)
The Course of a well ventilated compartment fire expressed as the rate of heat release as a function of time. The broken line represents depletion of fuel before flashover has occurred

1.1.8 Auto-ignition Temperature (AIT)

This is the temperature at which any flammable gas or vapour will ignite without the introduction of an ignition source. It must be remembered that it is the vapour from a liquid or the small particles in the gas phase of a decomposed solid that ignites (NFPA, 2004c).

Extensive tests have been conducted to ascertain the AIT is for certain gases and vapours. Two tests used by the United States Bureau of Mines are ASTM D 2155 and ASTM E 659 (Babrauskas, 2003a).

1.1.9 Upper and Lower Flammability Limits

These are well-defined upper and lower concentration limits of the flammable vapours of an ignitable liquid or gas in air at a specified temperature, normally 298K (25^0C) and pressure, usually 1 atmosphere, and expressed as a percentage of fuel by volume that can be ignited (Drysdale, 1998d). Below the lower limit, a fuel/air mixture is said to be too 'lean' to sustain combustion. Above the upper limit and the fuel/air mixture is said to be too 'rich' to sustain combustion. The most reliable data that is available regarding the flammability of gases and vapours is provided by Zabetakis (1965), obtained from tests carried out at the US Bureau of Mines.

Flammability limits depend upon the ambient temperature; the higher the temperature the wider the flammable range. In a 'closed' system, the flammability and explosive range of a gas or vapour are considered to be the same. In an 'open' system however, other factors such as turbulence may allow a rich gas or vapour to mix with air to bring it within its flammable range and therefore start a fire (DeHaan and Icove, 2011a).

1.1.10 Flash Point

This is the lowest temperature of a liquid at which the vapour above the surface will ignite momentarily by the application of a small flame. The lowest temperature that a property of a liquid fuel at which this will occur, for each product, can only be determined by specific laboratory tests where the liquid gives off enough vapour to support a momentary flame across its surface. (NFPA, 2004f) Values may change depending upon which test was used, for instance whether the test used the open cup apparatus, such as the Tagliabue (Tag) tester or closed cup apparatus, such as the Pensky-Martens tester.

The vapour pressure of a liquid fuel is described as a percentage of 760mmHg. At its flash point temperature, the vapour pressure is equal to its lower limit of flammability. A liquid fuel must, therefore be able to produce enough vapour to reach that lower limit in air before it will ignite (DeHaan and Icove, 2011a).

1.1.11 Fire Point

This is the minimum temperature at which a combustible liquid will sustain a flame upon the application of a pilot flame as opposed to momentarily igniting and is also known as the 'flame point'. As with gases, there are upper and lower flammable limits associated with the vapours of flammable liquids. These limits define the flammable range. This range is determined at a specific temperature and pressure of a flammable vapour from a liquid and air, expressed as a percentage of fuel by volume that can be ignited (NFPA, 2004e). The flash point associated with volatile liquid products such as methanol can often be considered as the same temperature as the fire point (DeHaan and Icove, 2011a). The difference between the flash point and the fire point usually becomes greater with greater viscosity and vapour pressure.

The temperature relationships associated with liquid ignitions are as follows:

$$T_{flashpoint} \leq T_{firepoint} < T_{s.s.\ surface} < T_b$$

Where: $T_{flashpoint}$ = Flashpoint of liquid (K)

$T_{firepoint}$ = Firepoint of liquid (K)

$T_{s.s.surface}$ = Steady State Surface Temperature of liquid (K)

T_b = Boiling Point of the liquid (K)

1.2 Accident or crime?

As the purpose of a fire investigation is to try to prevent future fires, the correct identification of the mechanism that brought the ignition source together with the fuel needs to be clearly identified and determined if that mechanism was accidental or undertaken with criminal intent.

1.2.1 Fire-setting and Arson

Different categories of motives for fire setting behaviour have been published over the years by various professionals (psychiatrists and psychologists), such as Freud (1932), Lewis & Yarnell (1959), Canter (2003) (1995b) and Williams (2005d). In addition law enforcement agencies such as the US Federal Bureau of Investigations (FBI) and the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) have also published research and guides to categorising behaviour and motives. The categorisations of fire setting motives used for this research are described below:

1.2.1.1 Profit

An individual may profit from an arson fire in several ways.

(a) *Personal gain, 'hero-syndrome', relocation*

Examples of personal gain:

i. Time off from work following a fire, which temporarily closes the business.
ii. Diversionary from the fire setter, if the fire takes precedent over another negative activity of which the fire setter may be the focus.
iii. Improvement of image or the 'hero syndrome' (Williams, 2005c). By 'discovering' a fire and extinguishing it, they believe that they will be looked upon with respect by their colleagues or society in general. Far too often these fire-setters progress to start fires that they cannot control.
iv. Relocation by housing authority; many fire setters have been identified as starting fires within their own property in order to be relocated by their housing authority, e.g. the Moss Side Estate in Greater Manchester during the 1980's/1990's.

(b) ***Insurance Fraud - Financial gain***

i. This type of fire setter will benefit from financial gain by making a claim against his or her insurance company following a fire that they have either set themselves, or engaged a third party to set.

ii. Criminals running protection rackets may use fire setting against the property of individuals, in order to extort money from them.

1.2.1.2 Vandalism

This category of fire setter will get as much pleasure (bordering on excitement) from starting a fire and damaging property as they would from smashing a window or writing graffiti on a wall. Vandalism fire setters often stop fire setting when they become adults (Williams, 2005a).

1.2.1.3 Excitement

This is a complicated category, which encompasses a wide range of individuals. Classified as one of the most dangerous types of fire setter (Williams, 2005b), they can start at a young age and progress to become serial murderers, generally founded on the excitement they receive from watching fires develop and the power that the individual may feel in association with the damage the fire produces.

1.2.1.4 Revenge

Fire has been used as a weapon throughout history (Rossmo, 1999), (Prins, 1994) and is still a powerful and destructive force . Some examples are:

(a) the setting of a car fire due to a minor altercation between neighbours;

(b) the murder of a family by pouring petrol through a letter box due to some long-held grudge against a family member;

(c) the actions of a jealous or spurned person against an ex-girlfriend or boyfriend;

(d) the setting of a wild land fire because an applicant was rejected from joining his local fire department (Shears, 2009).

1.2.1.5 Crime concealment

Many criminals are aware that fire may destroy evidence, such as DNA and finger prints. Deoxyribo Nucleic Acid (DNA) analysis has advanced over recent years to the extent that ‘cold cases’ are being reviewed and some criminals have subsequently been successfully convicted of crimes dating back over ten years due to DNA matching and finger prints have also been recovered from soot covered fire scenes. Others have been wrongly convicted and subsequently exonerated following these cold case reviews.

An example is the theft of cars in Mid and West Wales where most of the cars, stolen by joy-riders, were then set on fire once they had become aware that it was the policy of the police to check for finger-prints and DNA in every car that was recovered following its theft (Fitzjohn, 2001). Much research is being carried out regarding finger print recovery (Deans, 2006) and DNA retrieval (NicDæid, 2006) at fire scenes and there have been many documented successes. Finger prints have been found below the smoke staining (soot and carbon layers) on smooth surfaces and DNA has been retrieved from blood spatter that has been protected from the heat of a fire by an object or other materials.

1.2.1.6 Extremism

Extremists use fire to make a political statement for a cause where they feel there has been an injustice. Terrorism can be included within this category, as there are many examples throughout the world where fire has been used to terrorise populations in order to attack a national government, e.g. the ‘9/11 attacks’ on the Twin Towers in New York on September 11th 2001. The Animal Liberation Front within the UK has also used fire as a weapon against individuals associated with, in their view, the cruelty of animals (Bucks FRS Arson Task Force).

1.2.2 Criminal Damage Act 1971

The Criminal Damage Act 1971 comprises twelve Sections. As this is the Primary Legislation relating to arson in the United Kingdom, those Sections relevant to the crime of 'arson' will be explained here.

Section 1

Subsection (1) concerns the destroying or damaging of property where the emphasis here is on 'intent'. It has to be demonstrated beyond reasonable doubt that the accused intended to destroy or damage, or was reckless, which resulted in destruction or damage to any property belonging to another person. This action would be classified as 'criminal damage' if there was no lawful reason as to why that property was damaged or destroyed.

Subsection (2) defines guilt of an offence. The addition to Section 1(1) is that the property may belong to another or the accused AND that those actions may endanger the life of another.

Sub-section (3) defines the charge of arson. Damage by fire means exactly that, however in the case of an explosion there has to have been evidence of flame propagation, even momentarily, to be considered arson. Criminal damage by fire is deemed 'arson'.

Section 2

This covers threats to destroy or damage property. If someone threatens to destroy or damage someone else's property, whether by fire or not, or threatens to destroy or damage their own property which could endanger someone else's life, then they will be guilty of an offence.

Section 3

This section considers any possessions that could be used to destroy or damage property. In relation to fire setting, if any person is carrying an ignition source, fuel source or liquid accelerant with the intent to use it, or give it to someone else to use, to destroy or damage a third person's property, or do the same to his own or a third person's property when he knows that in doing so will endanger someone else's life, he will be guilty of an offence.

Section 4

This section covers the punishment of offences, including arson.

Sub-section (1) states that if a person is found guilty of criminal damage by fire or found guilty of destroying or damaging any property, which could endanger the life of another person, he could receive a life sentence.

1.2.3 The Crime of Arson

It is well recognised that fire scenes should be treated as potential crime scenes. Gardner (2004) dealt with this by identifying law enforcement officers' goals and objectives, explaining the nature of physical evidence and the actions of the initial responding officer at any generic crime scene. He also explained, in detail, good processing methodology and scene assessment, including crime scene photography, scene sketching and mapping; all relevant to fire scenes.

1.2.3.1 Arson Prevention Bureau

The Arson Prevention Bureau (APB) was established by the Home Office and the Association of British Insurers in 1992. Kelly (1992) of the 'Fraudulent Arson Working Group' wrote an article discussing the potential for the insurance industry to fund fire investigations by the fire service, recognising the fire officers' unique role at a fire scene relevant to subsequent investigations. Fire service investigators also determine un-insured losses, which could be used for evaluating future insurable risks. The APB (1992) addressed the large number of insurance fraud fires, which were due to the insured:

- obtaining funds to resolve liquidity problems;
- profiting from over-valued or non-existent assets;

This was managed by establishing a connection between the insured and the arson by:

- issuing a reservation of rights letter;
- liaising with other interested parties;
- commissioning a forensic investigation to establish arson and complicity of the insured;
- testing defences other than fraud.

In 2003, the Arson Prevention Bureau's Chief Executive accused the UK Government of 'brushing aside' the arson problems and highlighted that school arsons, for example, were costing the UK approximately £100m per year (Pyke, 2003).

1.2.3.2 Vehicle fires

Vehicle fires represented a 'niche' market in fire investigation, which fluctuates depending on the economy (credit and loan insurance scams to release negative equity); scrap metal prices (low metal prices manifest themselves in more abandoned vehicles) and local criminal activities (pool cars, cloned cars, etc.). However, in the UK and due to the volume of such fires, particularly in the late 1990's and early 2000's, most car fires are investigated by either the first responder, with almost no fire investigation training, or a specialist forensic insurance investigator, subject to the amount of the insurance claim. In London, approximately 12,000 vehicle fires occurred in 2001 with approximately 10,000 of those being classified as deliberate.

1.2.3.3 Laboratory Analysis

Whilst most fire investigation literature, as opposed to fire science literature, focused on the scene examination and analysis of data, Nic Daéid (2004) highlighted the need for laboratory analysis of samples recovered from the scene, particularly when arson is suspected. Gas chromatography, a technique now widely used in the identification of ignitable liquids, was not used for fire debris analysis until 1960 (Stauffer, 2004); it was some 18 years later when fire investigators were warned about the need to collect 'control samples' when submitting debris to a laboratory for analysis (Thomas, 1978). Almirall and Furton (2004) made the point that the presence of an ignitable liquid is not proof in itself of arson, but an unexplained presence of an ignitable liquid at a fire scene may assist in the subsequent arson investigation.

1.3 People involved in fire

People are involved with fires in various ways, which include:

(1.3.1) becoming a victim of fire, suffering injury or death

(1.3.2) causing the fire by accident or design

(1.3.3) being the rescuer/fire-fighter

(1.3.4) acting as a witness

(1.3.5) undertaking the subsequent investigation.

1.3.1 Victims

In 1996, the London Fire Brigade introduced a database for recording accurate details of fire investigations. Before then, little data were available to identify factors that were instrumental in fire victims' injuries and deaths. Use of legal, e.g. alcohol, and illegal, e.g. cannabis, substances that could affect a person's movements and responses, any disabilities or other restricting factors that could prevent effective escape from a fire, pre-existing medical conditions, whether the victim(s) was asleep when the fire started or any other activity prior to the fire were not accurately recorded. The national statistical recording form 'Fire Data Report' (FDR1) introduced in 1987 (amended in 1994) has only ever recorded the age of any victims.

1.3.1.1 Injuries

Statistics taken from the London Fire Brigade database and detailed in Table 1.2 below show the proportion of injuries due to accidental and non-accidental fires. There has been a significant reduction of fires and therefore fire related injuries since 1996.

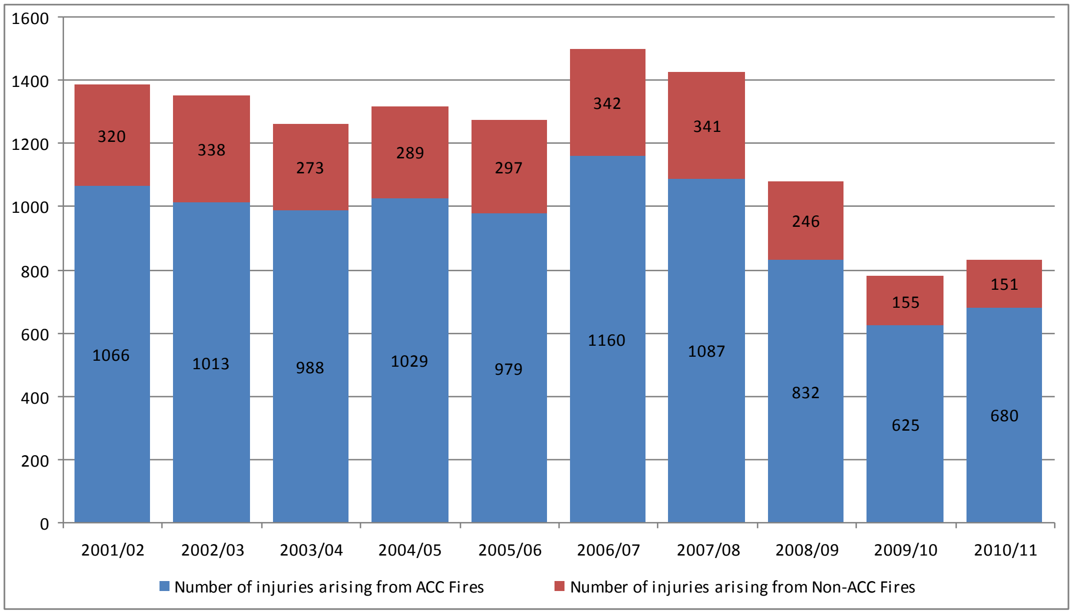

Table 1.2 – Injuries in London due to Accidental and Non-Accidental Fires (McMillan, 2006b)

Note: Accidental fires are those recorded with the causes 'accidental' and 'not known'. Since 1st April 2005 'not known' fires have been grouped with accidental fires in accordance to the guidelines produced by the former Office of the Deputy Prime Minister and now the Department of Communities and Local Government. This categorisation has been applied to the historical data in this table.

1.3.1.2 Deaths

Statistics taken from the London Fire Brigade database are detailed in Table 1.3 below and show the correlation between fire deaths, injuries and all primary fires.

London Fire Brigade Statistics	YEAR									
	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
Total number of deaths	76	82	84	39	67	47	56	39	62	62
Incidents resulting in deaths	68	73	78	37	61	41	52	37	52	58
Total number of injuries	1386	1351	1261	1318	1276	1502	1428	1078	780	831
Incidents resulting in injuries	956	896	871	913	849	1010	930	739	596	602
Number of all primary fires	22,486	19,702	19,967	17,372	15,861	15,086	13,880	13,564	14,076	13,345
Number of primary fires per 1 death	296	240	238	445	237	321	248	348	227	215
Number of primary fires per 1 injury	16	15	16	13	12	10	10	13	18	16

Table 1.3 - Ten-year trend in deaths, injuries and incidents in London (McMillan, 2006b)

The table indicates a downwards trend over the past 10 years in fire deaths, injuries and primary fires. 2004/05 had less than half the fire deaths of 2003/04 but was an out of proportion reduction in comparison to the number of injuries, incidents giving rise to injuries and number of primary fires. Based on the ten year trend the fire deaths for 04/05 and 08/09 were likely to be anomalies (McMillan, 2006b).

1.3.2 Fire-setters

Fire-setting must have taken place as soon as the art of making fire was discovered. Early humans would have become familiar with devastating forms of natural fires caused by inter alia lightning strikes, volcanoes and the accidental intensification of the sun’s rays. From fearing fire and its consequences they would have rapidly appreciated the potential benefits of initiating and controlling fire. Early humans would have discovered the advantages of knowing the characteristics of various fuels and their optimum means of ignition, e.g. impact, friction or sparks.

Fire setting today can be divided into three categories:

a) 'Designed Use' whereby the initiation of a fire is designed, controlled and may be extinguished by the user as and when required.
b) 'Accidental' whereby the initiation of a fire, either by an ignition source or a self-heating process, was not intended.
c) 'Non-accidental' or deliberate whereby the fire was not started for designed use but for financial or psychological gain by damaging or destroying property or to injure or threaten an individual or individuals.

1.3.2.1 Juveniles

Juveniles that are involved in fire setting may have a myriad of motives and intentions, e.g. curiosity, excitement, vandalism and revenge or may be the result of abuse or bullying.

1.3.2.2 Persons with Criminal intentions

As discussed in [1.2.1.1] to [1.2.1.6], fire setting may be an additional function to facilitate other criminal acts or intentions, e.g. to destroy DNA.

1.3.2.3 Mental health patients

Adults, who set fires that are not solely associated with criminal activity or anti-social behaviour, often suffer from mental health issues. The setting of fires can often be a release from associated anxieties that they might be experiencing.

1.3.3 Fire and Rescue Services

The legal requirement for local authorities' to establish fire brigades came about with the passing of the Fire Brigades Act 1938. There were approximately 1600 brigades throughout the UK at that time. During the Second World War local authority fire brigades had been merged to form a single National Fire Service. Following the war and under the Fire Services Act 1947, 'fire' was restored back to local authorities in 1948. The UK Fire Service has undergone major changes in recent years, due to devolution of central government's powers, new legislation and a change to operational procedures in the light of terrorism attacks and threats.

A Fire and Rescue Service (FRS) is the operational fire fighting body, as distinct from the Fire and Rescue Authority which is the legislative, public and administrative body made up of non-operational personnel and councillors that run the FRS.

The Fire and Rescue Services Act 2004 is the first significant change in the law on the operation of the Fire and Rescue Services in over 50 years. The 1947 Fire Services Act expected fire services to focus on fighting fires, and the law constrained what they could do. The role of the UK Fire Service has dramatically changed. Under the new Act, Fire and Rescue Authorities now have a range of statutory duties to:-

- Promote Fire Safety; and
- To prepare for:
    - fighting fires and protecting people and property from fires;
    - rescuing people from Road Traffic Collisions; and
    - deal with other specific emergencies, such as flooding or terrorist attack which are set out by Statute;
    - particular needs of their communities and the risks they face.

The Act also gives powers to prepare properly for other risks to life and the environment – this includes the power to investigate fires.

1.3.4 Witness Accounts

Witness testimony may differ from reality due to reasons ranging from a traumatic event that a person may have witnessed, which may distort their perception of time, to the memory recall capabilities of an individual. A hypothetical but familiar example is a witness who called the fire or ambulance service and claim to have waited almost half an hour for the appliance to arrive, when telephone records and mobilising data prove the time to be less than ten minutes. The accounts from anyone who are claiming to have witnessed an event should not be ignored but put into context with all available data and within a time line.

1.3.5 Forensic identification and analysis

Most fire services and their local police forces now have a Memorandum of Understanding for Fire Investigations, which details the responsibilities and working practices of the two organisations and their representatives during a fire investigation. It is normally the responsibility of the police to remove, package and store evidence if the fire is thought to have been deliberately set.

Although fire services now have the power to investigate fires, including the seizing and testing of evidence, the involvement of other interested parties such as forensic insurance investigators, should be considered before evidence is examined so that it is not spoiled for their, and possibly others', investigations.

1.4 The fire scene – Components

No fire is said to be the same as another fire and certainly no fire scene is the same as another fire scene. There are many components that create the fire scene, apart from the actual fire, and these are outlined below.

1.4.1 The scene

The aftermath of a fire is often a complex and hostile environment. The scene itself may be confined to a relatively small area, such as a vehicle fire, or may cover a wide geographical area, for example a large factory complex, shopping centre or vast area of wild land. The resultant damage will depend on the behaviour of the structure(s) affected by the fire and the actions of fixed installations and/or actions of human agency involvement such as fire suppression methods.

1.4.2 Health and Safety

The Incident Commander conducts dynamic Risk Assessments during fire fighting operations (National Incident Command System 2008). A Risk Assessment and continuing Dynamic Risk Assessments should always be conducted by the fire investigator upon arrival at a fire scene and during the entire excavation and processing stages. Munday (1994) detailed measures to be taken to protect the investigator and anyone else on the scene from injury. All investigators must relay safety information to other parties, whether present or not and in the most appropriate manner, and also seek such information from others to safe-guard themselves from injury; health and safety is everyone's responsibility.

1.4.3 Fire fighting

Fire fighting may destroy some evidence (data) that the investigator would have used to establish the origin, cause and development of the fire. It is more important, however, to extinguish the fire to protect life and property than to risk a fire redeveloping due to fire-fighters trying to preserve the scene and mitigate water and other destructive damage. A thorough understanding of suppression, ventilation and other related tactical techniques (Department for Communities and Local Governments, 2007) used by fire-fighters during an incident will assist with any subsequent fire investigation.

1.4.4 Scene preservation

Over the last decade throughout the United Kingdom, operational fire fighters and incident commanders have become more 'forensically aware' and try to balance the need to extinguish the fire with the need to understand the origin and cause of the fire in order to try to prevent it happening again. Operational Fire Investigation Officers have also been conducting scene preservation training for fire crews whilst they are still at a post-fire scene to enhance that awareness. In a fire investigation in 2003 of a triple murder-arson incident, the crews had protected the entrance hall to a large house converted into bed-sits by placing sections of a short extension ladder over the threshold. Fire fighting crews then traversed the ladder sections to tackle the fire, thereby preserving crucial evidence for the subsequent murder convictions. However, the need to extinguish a fire to save life and protect property will always take precedence over scene preservation.

1.4.5 Turning over

What may appear to be an extinguished fire could still be burning below debris or within other materials. Therefore it is important that fire crews ‘turn over’ or ‘overhaul’ anything that they consider may be concealing a deep seated fire to prevent re-kindling occurring. Whilst this activity is being carried out, it is good practice to apply water to any areas that still appear hot. The turning over and application of water may destroy certain potential evidence and part of the training of fire crews should be to make them aware of their actions and to mentally record anything that may assist a future investigation or liaise with any on-site fire investigation personnel, where practicable. Wallace and De Haan (2000) described the fine balance between effective ‘overhauling’ and scene preservation. They discussed issues that are still as topical now, regarding the rekindling of fires due to too much care being demonstrated to preserve the scene and the loss of evidence due to first responder fire fighters wanting to ensure the fire has been completely extinguished.

It is also important that the fire investigator makes provisions for extinguishing any deep-seated fires whilst they are excavating a scene that may have recently been extinguished.

1.4.6 Processing the scene

All fire scenes are ‘processed’ to various levels when an investigation is being conducted. This may range from simply documenting and recording the scene by using sketches and various forms of photography with little disruption to that scene, to a complete excavation and removal of all remaining contents and fire debris. If the latter is conducted, then all stages must be documented and recorded as the scene is processed.

1.4.6.1 Fuels available/supplied and suitable ignition sources

As already discussed in [1.1.5] above the amount of heat needed to cause ignition of a material or substance depends on the physical characteristics of that material or substance. Therefore the investigator must be able to identify appropriate available ignition sources for the appropriate fuel that was available or supplied at the time of, or shortly before, the fire. For example, a gas/vapour may be ignited by a small spark or flame, whilst a solid will require a more intense or longer duration heat source.

The investigator must consider the physical form of the material when ascertaining the first material ignited. If a vapour or gas was the initial fuel to be ignited, the investigator must analyse any burn patterns (see [1.1.2.2]) and other indicators carefully so as to identify that possibility. Difficulties could arise when additional materials some distance from the fire origin are ignited by the vapour or gas.

1.4.6.2 Fire dynamics

The fire investigator must have an understanding of fire dynamics. Available literature (Drysdale, 1998b, DeHaan, 2007d, NFPA, 2008a, Babrauskas, 2003a) needs to be studied by new fire investigators, reviewed by experienced fire investigators and incorporated into training courses so that underpinning knowledge and understanding can be maintained and remain current.

1.4.7 Human factors

Some of the most important components of a fire scene are the human factors that either initiated the cause, contributed to the development or became a victim of the fire. Human behaviour is thought to be very unpredictable during traumatic situations such as a fire, which may be described as 'panic'. Many studies have been conducted (Canter, 1990) (BRE, 1993) (Sime, 1992a) (Sime, 1992b) addressing this complex subject and it has been identified that depending on the role of the person involved and the environment that they are in, a response to the situation may be predicted (Townsend, 1998). For example, the parent of a teenager in a shopping complex would most probably try to find their son or daughter in an emergency situation, unless prior planning had been agreed between them. A parent who has gone to the shopping centre alone would most probably leave by the nearest exit to a place of safety. Panic has historically been attributed to negative outcomes following a fire in relationship to the behaviour of those that have become casualties of that fire. These factors must be considered by the investigator when assessing the fire scene in its entirety.

1.5 Roles of Fire Investigation in court procedures

Evidence at fire scenes must be treated as forensic evidence and be scientifically analysed. The accurate interpretation of data found at fire scenes will result in, at least, the correct identification of the ignition source, the first fuel package and the mechanism that brought them together.

1.5.1 Coroner's Court

All fatal fire investigations will be reviewed by a Coroner as they fall within the 'sudden death' category. It is the responsibility of the police to report to the Coroner. However, in London, most of the Coroners request the attendance of the lead London Fire Brigade Fire Investigation Officer. The Fire Investigation Officer will report on the factual evidence relating to the origin, cause and development of the fire and may be asked questions by the Coroner, family or friends of the deceased. The investigating police officer may also be called, as may any forensic scientists involved in the investigation.

1.5.2 Crown Court (Criminal Courts Review, 2000)

Police have primacy in all criminal investigations, including non-accidental fires. The police investigating officer will often call on the expertise of a forensic scientist. In many cases, the forensic scientist as well as the police officer will also be called to give evidence.

1.5.3 Civil Court

Fires that involve civil litigation are becoming more prevalent. Today's 'blame culture' has grown to such an extent that television and radio advertisements are being broadcast to the public to sue a third party, at no expense to them if they believe that they were not to blame for their accident; this includes fires.

1.6 Fire Statistics

It can be seen in [1.3.1] above that fire statistics are gathered in a variety of ways and classified by descriptors, which periodically change. This can often make patterns and trends difficult to follow.

Tables 1.1 and 1.3 are examples of the vast array of data that can be obtained from fire statistics that are gathered by Fire and Rescue Services from around the UK.

1.6.1 Analysing UK Fire Statistics

Patterns and trends that are identified with particular accidental fire issues, for example the misuse or lack of maintenance of electric blankets, may allow resources to be allocated to help prevent those fires happening again.

Many fire officers in the UK Fire and Rescue Services state that approximately 60% of all fires that they attend are recorded as non-accidental (deliberately) started fires (Mansi, 2006). It is the non-accidental fires that can cause difficulties, particularly in the large metropolitan brigades where most fires occur, when attempting to identify patterns and trends.

There is a need for constant interpretation and analysis of the statistics gathered relating to all fires. In a recent project in London (London Fire Brigade and Metropolitan Police Service, 2007), the Metropolitan Police Service's Intelligence Bureau and the London Fire Brigade's Fire Investigation Group and Arson Task Force were collating fire data from both organisations' databases and also using information being gathered from organisations such as Crimestoppers, Victim

Support, the Susie Lamplugh Trust and the Jill Dando Institute. Patterns, trends and hotspots across London's 33 boroughs were monitored and interrogated.

Property types, demographics, socio-economic make-up, times of the day, week, month or year and weather conditions were all being analysed in relation to non-accidental fire setting. Unless pan-regional statistical monitoring is continuously maintained by a dedicated team and in a systematic manner, it will be difficult to quantify the extent of the problems.

1.6.2 The Ten Stage System for Serial Arson Investigations

Between January 2007 and April 2008 it was identified in this study that 'serial arson' patterns and trends pan-London were not being addressed in a structured, methodical or measurable way by any agency. It was evident that as arson fires were not being clearly identified, almost no proactive work was being carried out to apprehend the arsonists responsible. Investigating arson fires is as much about analysing fire statistics as investigating the causes of fires. A new 'Arson Case Log Book' was developed and the 'Ten-Stage System', which had been viewed, assessed and approved in principle by intelligence officers within the Metropolitan Police Service, was then implemented.

The success of the Ten Stage System completely relied on the close working relationships between the case Arson Task Force Practitioner, Fire Investigation Officer (or the Incident Commander), who had identified that the ignition was a deliberate act and the Metropolitan Police Service Officer. Fires that were recorded as arson by either of the attending agencies, London Fire Brigade or the Metropolitan Police Service, were differentiated from those where both agencies attended to get an accurate profile of all arson fires in London and minimise duplication of statistics. The methodology was posted onto the Arson Control Forum's website as 'good practice'. The Ten Stage System is outlined below:

Stage	Action
1	Identify the geographical area involved and time frame to be covered
2	Obtain and select appropriate LFB data
3	Obtain and select Crime Reporting Intelligence System (CRIS) and other Met Intelligence Bureau data
4	Plot all data onto map (LFB attendance – red dots, MPS attendance – blue dots, LFB *and* MPS attendances – green dots)
5	Visit incident locations, make sketches, take photographs & obtain any local intelligence (preferably at the same time of day that the incidents occurred)
6	Identify telephone numbers (especially first callers)
7	Case Conference(s) – Internal/External
8	Develop or Adjust Action Plan – Set Time Frame – Set 'Mile Stones'
9	Assess Action Plan at 'Mile Stone' dates
10	Close Case or Revert back to Stage Eight to reassess action plan

Table 1.4 Ten Stage System for Serial Arson Investigations

1.7 The Problem – The Need for this Research

A logical comprehensive framework for the investigation of fires does not exist. As De Haan (2007c) stated *'Because of the difficulty and complexity of a complete and accurate fire investigation, and the potential of mental preoccupations, there is a special need for every investigator to develop a comprehensive analytical approach to the task*.' The problem is that human nature, as well as competencies, dictate the success or failure of an investigation; any investigation. The difficulty with investigations is that human nature can often lead the investigator to allow the facts to fit their hypothesis.

In August 2009, a report was published for the Texas Forensic Science Commission (Beyler, 2009) which analysed the fire investigation methodology used in two criminal arson cases where one convicted arsonist was subsequently released and the other executed. Ernest Ray Willis was accused and convicted of deliberately setting a fire at his home in Iraan, Texas on the 11th June 1986, which killed two female occupants; he was released from prison on 6th October 2004. Cameron Todd Willingham was accused and convicted of deliberately setting a fire at his home on 23rd December 1991, which killed his three children; he was executed by lethal injection on the 17th February 2004. The report clearly shows a need for this research, highlighting the irregularities between the methodologies applied to each investigation and the lack of consistency and reiterating that a logical comprehensive framework for the investigation of fires still does not exist.

The author's conclusions stated:

> '*Their methodologies did not comport with the scientific method or the process of elimination.*'

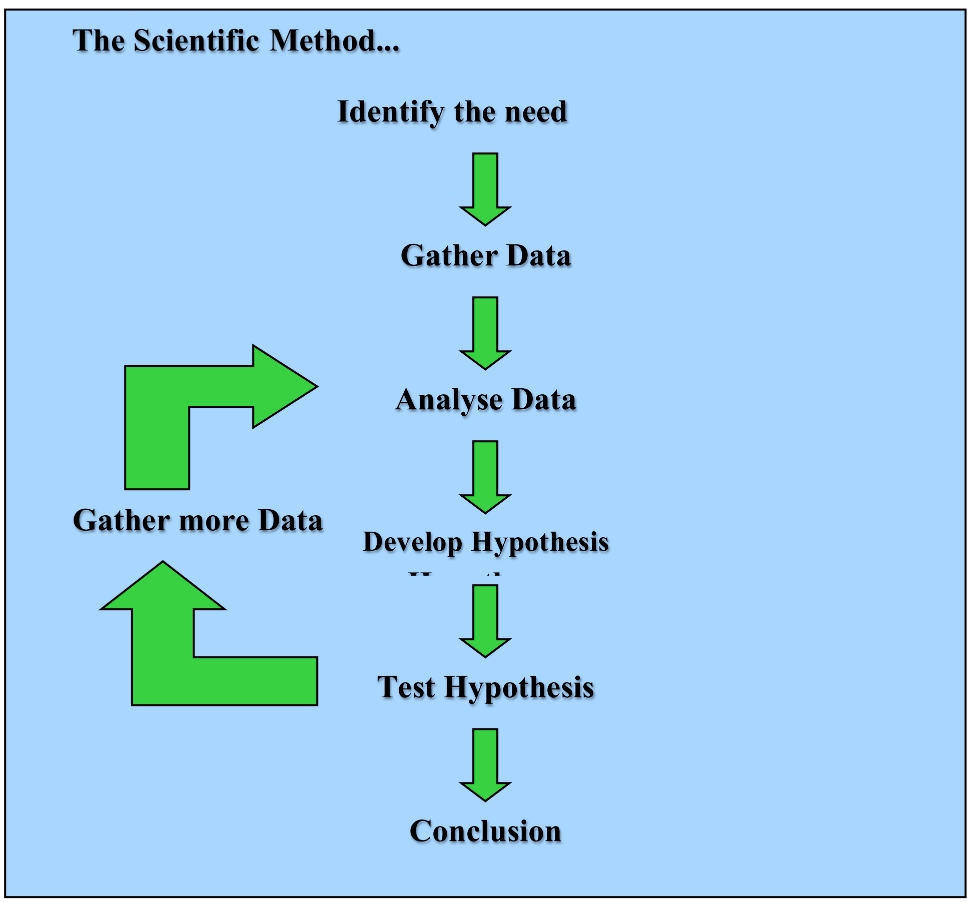

Figure 1.4 The Scientific Method (NFPA, 2011a)

Figure 1.4 shows the Scientific Method as published in NFPA 921. To teach investigators to only develop a hypothesis (singular) is possibly allowing them to miss other potential hypotheses that could have also been the cause of the fire. An investigator should not simply accept the first hypothesis that is proved. The underpinning science remains that hypotheses are based on available data and not that data is collected to support hypotheses. Currently there are a number of shortcomings, which may need to be addressed. These include:

(i) Lack of consistency in approach at the scenes

Although investigators have their own individual styles in carrying out their work, the end result should be the same for each investigator if they have collected all the relevant data relating to the incident under investigation. Much like a jig-saw puzzle, the pieces may be collected and analysed in differing sequences but the final result will be the one true conclusion. To ensure that none of the pieces are missing, a structured, holistic methodology should be adopted by the investigator.

(ii) Lack of a code of "Best Practice"

To enable fire investigation practitioners to be consistent and sustain consistency, a code of "Best Practice" with regard to investigation methodology needs to be established and reviewed regularly. The 'Scientific Approach' should be applied to every investigation no matter how small or large. NFPA 921, widely recognised as one of the world's leading guides to fire and explosion investigations covered 'Basic Methodology' in Chapter 4 (NFPA, 2004b), which consisted of less than one and a half pages in the 2004 edition and two and a half pages in the 2011 edition, where new paragraphs were added to cover presumption, expectation bias and confirmation bias. This thesis will address the need for thorough guidance in investigation methodology for the investigator at any fire or explosion scene.

(iii) Lack of rigour in analytical procedures

Analysing data obtained by the investigator should be rigorous and objective. The investigator should have the knowledge and training to know when and how to analyse data. The use of laboratory analysis must be exploited where necessary to offer sound scientific credence to the investigation's evidence.

(iv) Lack of clear distinctions between accidents and criminal activities

Investigators have varying responsibilities at a scene. Criminal investigators may be seeking to establish, at an early stage of the investigation, whether a prosecution is possible, which may prevent the crime being repeated. Insurance investigators are seeking liability. Fire service investigators should be determining how the fire can be prevented in the future and where best to direct their resources to achieve that goal.

All parties need to share their expertise and information to ascertain as soon as possible whether a fire was accidental or non-accidental. All fires should be treated as non-accidental until an accidental cause has been clearly identified; this cannot be done until all the data have been collected and analysed. To this end it is imperative that nothing is touched, moved or altered prior to recording and photographing any item(s). As with any other part of the investigation, all interested parties must be considered as the destruction of any evidence being examined can be seriously detrimental to a third party's investigation.

(v) Lack of confidence in the judicial system

The judicial system has been criticised over recent decades due to prosecutions and convictions being based on unreliable evidence. Some examples in the UK are the 'Bridgewater Four', convicted for murder in 1979 with the case overturned securing their release in 1997; Winston Silcott convicted for murdering PC Keith Blakelock in 1985 but cleared in 1991; Sally Clark convicted of murdering her two small sons in 1996 based on evidence by expert Sir Roy Meadows and released on appeal in 2003. These high profile cases have resulted in much negative publicity for various forensic disciplines. In an attempt to rectify this loss of confidence the Council for the Registration of Forensic Practitioners (CRFP) and the sub-group of 'Fire Scene Examiners' were introduced. The CRFP peer reviewed practitioners from various disciplines; upon demonstrating a high standard of competency, by providing evidence of their case work, they could become 'Registered Forensic Practitioners'. Various Judges within the United Kingdom were asking their 'expert witnesses' if they are CRFP registered, and if not, why not (Council for the

Registration of Forensic Practitioners, 2006). The CRFP terminated on 1st April 2009 by the newly appointed Forensic Regulator due to its high running costs and now 'Skills for Justice' are currently addressing fire investigators' competency issues.

(vi) Problem Definition

It is evident that there is a need for the fire and explosion investigator to have received an extensive range of training and education to be competent at carrying out an investigation. Whilst there are many opportunities to receive training and to study for certifications, registrations, accreditations, diplomas, degree courses of varying types and levels and now the opportunity to demonstrate competence against the National Occupational Standards, there is still a need to develop a full systematic approach to the investigation of these incidents.

1.8 The Objectives of this Research

a. To devise a methodology that would assist a fire investigator in accurately identifying the cause of a fire and recognise their limits of expertise; this would also assist in increasing the prosecution rate for arson.

b. To review the current methodologies of investigating fires and non-terrorist explosions by the London Fire Brigade and the Metropolitan Police Service, other United Kingdom Fire and Rescue Services and Police Forces and also commercial forensic fire investigation companies and services.

c. To devise a series of fire investigation 'road maps' (FIRMs) and associated decision trees with supporting guidance that detail a uniform and logical methodology of investigating the causes of real fires and non-terrorist explosions, also addressing human agency involvement. All possible alternative routes should be identified to provide a scientifically-rigorous appreciation and analysis of events and the interpretation of interactions, which resulted in intermediate outcomes and consequences.

d. To inter-link the individual FIRMs to define the roles of the victims, witnesses, emergency personnel and fire setters regarding the human agency involvement at the incident.

e. To analyse and interpret the stages of each incident in relation to the existing application of fire science and theories relating to the causes of fires and non-terrorist explosions.

f. To examine the human agency involvement and roles of all individuals at the incident addressing human motivations, intentions, performances and locations.

g. To combine the scientific understanding of the fire/explosion causation with that of the roles of people involved. It is envisaged that such a combination will arise from the inter-linking of FIRMs across the entire scenario of fire/explosion incidents.

h. To apply the FIRMs and their associated guidance documents to analyse a number of real incidents and cold case reviews.

i. To evaluate the success or otherwise of the above devised FIRMs by considering the findings in relation to investigations of known causations involving fires and explosions.

Chapter 2

Literature Survey

It has been shown in Chapter 1 that accurate identification of the mechanism, which brings an ignition source and a combustible material together is fundamental in determining whether a fire was accidental or deliberate. It has also been discussed that the presence of an ignition source and a combustible material is insufficient to determine the cause of a fire.

This chapter discusses the history and development of fire investigation and gives an overview of existing published materials that may act as guidance for fire and explosion investigators. It also considers studies carried out on fire setters and arsonists, including a serial arson investigation methodology. It explores how fires and explosions are currently investigated in the UK and how one non-fire related court case in the USA has had a major impact on how fires are now investigated there. Few books actually discuss the fire scene components, but do emphasise how to document and record such scenes (Cole, 2001, Leitch, 1993, Icove and DeHaan, 2004a, DeHaan, 2007d, NFPA, 2008a)

This chapter also identifies why a new approach by fire investigators is needed to identify the cause of a fire and outlines the various global organisations that are continually trying to improve fire investigation standards.

2.1 Historical development of fire investigations

Fire has been a destructive force throughout history, however, it is through the development of towns, cities and transportation and the fires within them that fire investigation has evolved in order to make locations safer places to work and live. Emphasis had been placed on the fire protection of buildings for almost three hundred years until it was realised that by investigating 'real' fires, as opposed to 'test' fires, fire protection failures could be remedied.

2.1.1 Early recorded fires and the resulting reactivity (1666-1792)

The Great Fire of London started in the premises of Thomas Farynor (Alagna, 2004), a baker for King Charles II, at 25, Pudding Lane after midnight on the 2nd September 1666. It was investigated by a team that included the architect Sir Christopher Wren. The multi-disciplinary team reached a number of conclusions, which led to reactive laws and guidance. The first recorded building regulation was introduced the following year (1667) relating to the separation of buildings and construction of party walls to prevent fire spread from one building to another. King Charles II issued a decree saying that all buildings were to be built out of brick or stone and that roads were to be widened i.e. increasing the separation distances between buildings.

On Friday night, 9th May 1679 (Corporation of London, 1679) a fire occurred within a prison in Clerkenwell, London. The fire investigation recorded by the Keeper himself, determined the fire to have been set by a prisoner or his guard (turn key) according to the Keeper of the Prison, Mr. Green. The prisoner, Mr. Woodgar, was a notorious Papist who would prophesise about 'Incendiaries of Kingdoms', which made him a suspect for the alleged arson. Mr. Green stated that he returned back to the prison at about eleven o'clock that evening, smoked his pipe 'very diligently, as he always used to', and went to bed at about mid-night. This 'witness testimony' may have been biased in favour of the Keeper. Within half an hour the turn-key raised the alarm of a fire. Mr. Green instructed him to get the 'Watch' to quench the fire and secure the prisoners. Mr. Woodgar and the turn-key were either consumed by the fire or escaped from the premises. All the remaining prisoners were physically seen by Mr. Green as they were released to save their lives. The prison burnt down. The Corporation of London started documenting the causes of these fires since the Great Fire of London, albeit relying solely on what may be considered biased witness testimony of the occupier in most cases, as this case study demonstrates.

Further legislation introduced laws aimed specifically at fire prevention, e.g. the London Cooking Fire Byelaw (1705).

The Fire Prevention (Metropolis) Act (1774), placed buildings into seven classes with laid down thicknesses of external and party walls, including provisions for the maximum floor area of stores. It introduced the first piece of legislation that dealt with human life and means of escape as well as building safety.

In 1790, (Philanthropos, 1790) a study was conducted into fires which had occurred across London. The study included the Law of Arson and was addressed to The Right Honorable Lord Kenyon, Lord Chief Justice of England. The conclusions were not just relevant to the insurance companies but also of great public interest in terms of arson. It was apparent that deliberate fire setting was being used to cover other crimes such as forgery, fraud and counterfeiting. At this time, arson carried the death penalty upon conviction. Even then, accurate identification of fire causation was recognised as important in identifying patterns, trends and serial arson.

In 1792, the Association of Architects were the first organisation to conduct research into the problems caused by fires by appointing a committee to focus on the relevant issues. This association would later become the Royal Institution of British Architects (RIBA). The committee considered:

- causes of frequent fires
- best methods of preventing such fires
- means to bring prevention methods into general use.

This research involved carrying out fire tests within a house in central London to assess the best method of containing a fire within a compartment and culminated in a report, whose contents were requested to be made public (Read, 1994). It was a century later before any other recorded fire research was conducted within the UK.

2.1.2 Recorded fires from the Victorian period to the end of the Second World War

In 1840, a Royal Commission was established to investigate working conditions in the mining industry. Their findings were published in 1842 and highlighted that the accidents, brutality, lung diseases, long hours and dangerous environments, including fires and explosions, seemed to be the norm. The reaction from public pressure was to establish the Mines Act 1842, which sought to improve working conditions in coal mines.

Although the Fire Officers' Committee (FOC), which was formed in 1868, had been conducting tests on fire detection and extinguishment equipment since 1889, Europe's first fire testing station was opened in London by the British Fire Prevention Committee (BFPC) in 1899, which was formed in 1897 following several disastrous fires in London. The First International Fire Prevention Congress (1903) adopted the Universal Standards of fire resistance that had been proposed by the BFPC addressing temporary, partial and full protection of structures. It was at this congress that the terminology 'fire-resisting' was adopted and the term 'fire-proof' condemned and advocated the establishment of testing stations in its members' countries. The BFPC published the results of their tests in 'Publications', which then became known as 'Red Books' and was disbanded in 1924 with its remit to be taken up by the National Fire Brigades' Association.

In 1911, a Government funded initiative aimed at the investigation of fires and explosions in coal mines allowed the formation of an experimental station at Eskmeals in Cumberland. Ten years later, during 1921, The 'Safety in Mines Research Board' was established with facilities in Buxton and in Sheffield to investigate fires and explosions within the coal mining industry. The Buxton site became the 'Explosion and Flame Laboratory' (EFL) whilst the Sheffield site focussed on safety engineering and became the Safety Engineering Laboratory (SEL) (see Section 2.1.3).

In 1917, the Department of Scientific and Industrial Research (DSIR) proposed the creation of an organisation to assess building methods and materials to build new houses after the First World War. The Building Research Board eventually came together in June 1920 culminating in the Building Research Station (BRS) being established to carry out research work for the Board in 1921 as a central, Government-funded laboratory. BRS moved from Acton in west London to a large Victorian house called Bucknalls just outside Watford.

In 1927, the Forest Products Research Laboratory (FPRL) under the Forest Products Research Board (FPRB) opened at Princes Risborough in Buckinghamshire covering all aspects of timber utilisation, such as strength testing and insect attack.

In May 1929, the Science Standing Committee of the RIBA decided to move the FOC from Manchester to Borehamwood, which took place in 1935. In 1946 and just after the Second World War, DSIR and the FOC established the Joint Fire Research Organisation, which then became the Fire Research Board. This facility later became known as the Fire Research Station in 1949.

The National Fire Service (NFS) produced short census reports starting in 1942 on every incident attended, entitled 'Reports of Outbreaks'. 'The Study of Outbreaks of Fire' was a chapter within a 1947 report (National Fire Service, 1949) by the NFS and led to discussions with the Fire Service Department of the Home Office resulting in a revised short census report to not only include data for the Home Office annual statistics, but also for fire research purposes. The new form was introduced on the 1 January 1944 and can be considered the first formal fire investigation reports from real fires. These reports went to the Fire Research Division and from December 1946 to the Joint Fire Research Organisation.

This revolutionised the way data was recorded about real fires. A newly designed punched-card system documented data on approximately 75,000 fires each year recording the type of fuel involved, active source of energy and material first ignited. Due to a shortage of resources to conduct a full analysis only one-in-four random samples were used.

2.1.3 After the Second World War (UK activity as an example system i.e. other countries followed similar routes)

In 1947, the Safety in Mines Research Establishment (SMRE) was formed as part of the Ministry of Fuel and Power, bringing together the work of the two teams of the Safety in Mines Research Board in Buxton and Sheffield. It was not until 1995 that these two facilities, the Explosion and Flame Laboratory (EFL) in Buxton and the Safety Engineering Laboratory (SEL) in Sheffield, merged with the Occupational Medicine and Hygiene Laboratory (OMHL), which was based at Cricklewood, North London. They became the integrated 'Health and Safety Laboratory' (HSL) culminating in all being located at Buxton in November 2004 and serve the experimental needs of the Health and Safety Executive (HSE).

It was realised in 1949 that monetary loss was the most practical measure to assess damage caused by fire and from 1950 regular analyses were made of large-loss fires. Monetary information on fire losses was first included in the Home Office Annual Report in 1967.

Responses resulting in a fire or explosion investigation have always occurred where there has been a major incident, such as the collapse of Ronan Point, a 22 storey high rise block of flats in East London, following a gas explosion on 16 May 1968, causing four deaths and 17 injuries. The incident occurred when the occupier of flat number 90 on the 18th floor went to light her gas cooker and, due to a leak from a defective pipe joint, caused an explosion resulting in the collapse of the south-east corner of the building. The Minister for Housing and Local Government requested a Public Enquiry under Section 318 of the Public Health Act 1936 and section 290 of the Local Government Act 1933. The investigation involved 108 witnesses and required a team of experts, appointed by the Home Secretary James Callaghan, from several organisations to complete the investigation. This would now be considered a 'Level 3' investigation (see section [2.9.1.1]). The remit of the team was, as with all such investigations, to determine the cause, implications and recommendations. The enquiry lasted two months. It was the public interest, media coverage and scale of damage that invoked this rapid response of inquiry.

The Fire Research Station (FRS) and the Forest Products Research Laboratories (FPRL) merged with the Building Research Station (BRS) and all became part of the Building Research Establishment (BRE) in 1972 with the FRS maintaining its identity at Borehamwood in Hertfordshire up until privatisation in 1997, when it became the Fire and Risk Division of BRE. The FPRL moved from the Princes Risborough site to BRE's site in 1988. In 1994 the FRS moved from Borehamwood to Garston, Watford and a new fire testing Burn Hall with a cone calorimeter for small to medium scale tests was built on the BRE site at the same time. A disused airship hanger in Cardington, Bedfordshire was still being used in a number of large fire reconstructions and explosions but has since been sold and a replacement has been established at Middlesbrough in the north-east of England. The Foundation for the Built Environment (FBE) was founded in 1997 and renamed the BRE Trust in 2005. All profits made by the BRE Groups are gift-aided to the BRE Trust to be spent on furthering fire science by supporting research, PhD studentships, etc.

It was not until 1973 that the formation of a 'Field Investigation Section' was established within BRE putting fire investigation onto a formal basis, although its remit was still to study compartmentation, fire spread and combustibility of materials (Read, 1994). The FRS and subsequently BRE have been involved in the investigation of nearly every high profile and complex fire or explosion within the UK over many decades.

At about 7.40pm on the 2nd August in 1973, 51 people died and 80 people seriously injured when a fire engulfed a leisure complex called 'Summerland', situated on the Douglas promenade on the Isle of Man with approximately 3,000 people within the premises at the time. This was the worst peace-time fire disaster since 11 July 1929 when a local fire brigade demonstration at a park fete in Gillingham, Kent involving a

40 foot structure made out of wood and canvas, caught fire, trapping and killing all 15 men and boys who were part of the demonstration within it.

The subsequent major investigation that was carried out by the 'Summerland Fire Commission' (SFC) consisted of three men appointed by the Lieutenant Governor of the Isle of Man. The Chairman of the SFC was a presiding judge; one was the second in command of the UK Home Office Fire Inspectorate and the other a professor who was the Head of the Department of Building at the University of Manchester's Institute of Science and Technology (UMIST). The hearing ran from the 19th November 1973 to 13th February 1974, involved 91 witnesses and cost approximately £400,000.

The Summerland building was a steel-framed structure with the roof and parts of the walls built of 'Oroglas' polymethylmethacrylate (PMMA), a rigid transparent material allowing natural light through into the enclosures below and considered a state-of-the-art building at the time. Parts of the external walls, including the east end where the fire started, was built from Colour Galbestos, sheets of zinc coated steel with asbestos felt that was saturated with bitumen and faced with a polyester resin coating on both surfaces, which was cheaper to use than other materials such as concrete but did not possess two-hours fire resistance. The internal linings fixed to timber studs were made from a product called 'Decalin', a combustible fibre board, which was selected as a substitute for plaster board as it was considered to have better sound absorbing qualities. Oroglas was initially considered the cause of the rapid spread of the fire and subsequent deaths and injuries.

The fire investigation highlighted several aspects of the building construction that led to the rapid spread of the fire and products of combustion. These included (Cooke, 2000):

- over-use of Oroglas on the walls and roof than was necessary for transparency
- Vertical unstopped voids in the external combustible walls
- Haphazard arrangements and use of stairs and exits

- Lack of simple scientific knowledge demonstrated by designers, e.g. BRE were not consulted on the use of Oroglas or Galbestos.
- BS476 fire tests were potentially misleading as small scale tests did not indicate fire behaviour of the same material in full scale conditions.

The fire started at about 7.40pm by three school boys smoking in a disused kiosk adjacent to a crazy golf terrace outside of Summerland. The boys told the police that it was a discarded cigarette that started the fire, but their Counsel admitted to it being a lighted match. As staff fought the external fire, with the kiosk collapsing against Summerland's external walls made from Galbestos panels, they were unaware of the fire developing within the void behind the panel due to conduction through the steel sheeting igniting the combustible surfaces on the inside of the panel. Rasbash (1991) estimated that the heat transfer from the burning kiosk to the Galbestos wall was around $60kW/m^2$, which greatly exceeded the $10kW/m^2$ threshold that the material had passed in a test. Due to high thermal conductivity of the steel and zinc coated core of the panels, fumes would have been developing on the inner side of the wall after just over two minutes and within a minute later, strong flames would have developed. Rasbash also considered that the fire within the void would have been fuel rich as there was little air available for combustion.

The conclusions drew heavily on the Fire Research Station's investigation. The FRS team was convinced that Oroglas was a secondary factor in the fire's spread due to the massive internal fire at the east end of the building. The use of Decalin, which was also combustible, to line the internal walls may have been the biggest structural contribution to the disaster because it created a 12 inch wide concealed gap or void (Rasbash, 1991) with combustible surfaces either side; Galbestos on the outside and Decalin on the inside. Over a ten minute period from the fire transferring into the void, the fire gained in intensity until it broke through the Decalin ventilating the fire to the open plan internal compartment of the building at about 8pm. As the flames developed within the voids, they spread upwards to the roof structure igniting the Oroglas.

The public enquiry that was commissioned concluded that the death toll was so high due to the rapid development of the fire and the delayed, unorganised and difficult evacuation of the building. Emergency doors were found to be padlocked and other exits that were fitted with turnstiles, could not cope with the volume of people trying to exit the building. It also concluded that Oroglas was not the main cause of the disaster based on the evidence provided. Most victims died on upper level terraces before they had the chance to reach any exits, locked or unlocked. New fire safety legislation came into effect on the Isle of Man in 1975.

It would normally be after such a large incident as the Summerland fire with a significant loss of life that fire testing would be reviewed. In 1979 another large fire occurred in a Woolworth store in Manchester and claimed the lives of ten people with 47 people being taken to hospital. Various fire tests were conducted to see why the fire spread so quickly, which highlighted the concern of fire brigades throughout the UK at this time that the foam interior of furnishings were causing rapid spread of fires and rate of heat generation with large amounts of smoke.

Before the Woolworth fire, due to concern about the ‘flammability’ of new polyurethane filled mattresses, various tests were conducted at BRE and subsequently published in the journal, ‘Fires and Materials’ addressing the problem of mattress fires and the importance of correct mattress covers or protective interlinings (Woolley et al., 1976).

In 1979 a significant study was conducted into the burning characteristics of fabric covered foams being ignited with the smallest of ignition sources (Woolley et al., 1979). The article stated that flexible foams produce relatively intense fires of short duration with rapid rate of heat generation, accompanied by copious amounts of smoke, with latex rubber producing the most.

In the early hours of the 14th February 1981 a fire occurred at a nightclub in Dublin, called the ‘Stardust’. 840 people were at a disco but 48 young people died with a further 128 seriously injured. This incident was the subject of a major fire investigation involving BRE. BRE’s investigation focused on how a small fire confined to a few seats when discovered could develop into a large and deadly fire. Again the investigation centred on the speed of development of the fire and found that no single factor was responsible for what was a very rapid fire growth (Malhotra et al., 1981). BRE’s study included small-scale flame spread, fire spread, heat release and fire propagation tests to try to determine the cause of ignition to the seats. A fire test involving a full scale reconstruction of part of the nightclub was then carried out and included specially made carpet tiles to match the original tiles that lined the walls of the club at the time of the fire; the original tiles were no longer manufactured at the time of the test. The full-scale test demonstrated how the fire in a seat against a wall could ignite and spread rapidly through the carpet tiles so quickly that within two minutes the whole building could have been involved. The original carpet tiles were designed for the floor and not to line walls. The cause of the fire is still undetermined.

The Fire Research Journal was a publication that aimed to promote an integrated approach to fire and flammability research. It consisted of one volume, with the first issue being published on 1 March 1977 and after its final issue on the 6 June 1979, Volume 2 was renamed the ‘Fire Safety Journal’. The Fire Safety Journal published a special edition in 1984 devoted to the Stardust Fire and edited by Rasbash who also wrote an article focusing on potential ignition sources and the difficulties in identifying an ignition source in such a severe fire (Rasbash, 1984). The special edition journal included papers discussing all aspects of the complexities of the fire’s development and spread. One of the articles discussed the test methods used to assess materials involved in the fire (Rogowski, 1984) whilst another addresses the importance about understanding the downward radiated heat from flame extensions under a non-combustible ceiling (Hinkley and Wraight, 1984), the latter giving the investigator a better understanding about the mechanism that leads to a flashover within a compartment.

These fire tests on various materials eventually supported the introduction of the Furniture and Furnishings (Fire) (Safety) Regulations 1988 (as amended in 1989 and 1993) which set levels of fire resistance for domestic upholstered furniture, furnishings and other products containing upholstery.

One industry in particular that has developed fire investigation from within is the Air Accidents Investigation Branch (AAIB). When there has been an aircraft incident involving a fire, the accident investigators have developed a team approach that deals holistically with electrical and mechanical engineering, aerodynamics and fire science. An example of this is the study of the Manchester International Airport accident on 22 August 1985 (Cooper, 1988). The report into the accident by the AAIB identified that wing access panels needed to be of the same impact strengths as the fuel tank floors to prevent flammable fuel escaping from punctured wings. It identified two distinct fire damage patterns that occurred during two phases of the fire; one in motion and one static. 55 passengers lost their lives due to an uncontrolled fire in the left engine and when the aircraft came to a stop, the wind was in a direction that assisted smoke to be blown into the fuselage, with most of the victims dying due to smoke inhalation. Unlike other fires, actions to prevent the causes of aircraft fires are taken immediately following their discovery.

Many other significant fires and explosions have been subjected to fire investigations by particular lead bodies, for example in the UK, the Incident Investigation Team at the Health and Safety Laboratory (as part of the Health and Safety Executive) have investigated inter alia:

- Abbeystead Pumping Station (1984) – 16 fatalities and 28 injuries involving a methane/air explosion
- Kings Cross Underground (1987) – 31 fatalities involving an underground railway station fire
- Piper Alpha disaster (1988) – 167 fatalities involving a large fire on a North Sea oil rig

- Maryhill, Glasgow (2004) – nine fatalities involving a structural collapse flowing a LPG (Liquid Petroleum Gas) leak
- Buncefield explosion (2005) – involving an explosion and fire at a large fuel storage depot

It is clear that fire research, testing and investigation should be conducted in harmony and not isolation.

2.2 Why investigate fires?

Fires are investigated to clearly identify their origin, cause, route of development and to assess the effectiveness of any fire prevention or protection systems. Ideally, the lessons learnt would minimise any repetition. Society benefits from knowing the causes of fires and can call for changes in practice and legislation as discussed in the previous section in relation to furniture regulations. An investigation can distinguish between accidental and deliberate fires. In relation to accidental fires, any faults within the design or operation of equipment or choice of materials can be identified, such as the Manchester Airport fire outlined above or the investigation of a series of fires involving Beko auto-defrost fridge/freezers in 2010, which led to a product recall throughout the UK. In relation to deliberate fires, an investigation may identify the extent of criminal activity and through identifying the modus operandi, the perpetrators. An example would be the investigation and analysis of serial arson, which has occurred within a defined geographical location and timeframe. That data could then be utilised by various agencies to apply passive (CCTV) and active (teams of observers) surveillance activities to help apprehend the arsonist(s).

Fire can destroy evidence of other crimes and has often been used as a means of revenge. Correct identification of fire causation is necessary if any individual involved in fire setting is to be apprehended. Historical events involving fire have recently been investigated to establish additional information about that event. Murley (2003) reported on how the physical and chemical effects of fire can give an indication of scale and duration of the fire, even when the fire happened 2000 years ago, using Boudicca's revolt and the burning of London, St Albans and Colchester as examples. Fire can therefore preserve evidence as well as destroy it.

2.2.1 General early approaches to fire investigation

An investigation of a fire involves the accurate identification of the area of origin, the ignition source, the first materials to be ignited and the mechanism which brought them together; it should also include a detailed analysis of the fire spread mechanism and the roles of any people involved. These are the topics of direct interest to fire brigades and consequently form the basis of the work described in this thesis.

Significant fires throughout history have been 'investigated' by various groups of people from differing disciplines; architects, jailers, surveyors, engineers, etc. Most of those investigations resulted in methods preventing them happening again, as opposed to identifying the true origin and cause of the fires. The infamous Coconut Grove Night Club fire in the USA on the 28th November 1942 (Icove and DeHaan, 2004b), which claimed the lives of 489 people and injured a further 131, is still recorded as a fire with an 'undetermined origin and cause', but the club was identified as having inadequate fire exits. The National Fire Protection Association issued a report on January 11th 1943, only six weeks after the tragedy, whereas today, less serious fires can easily take over a year to analyse due to the thoroughness of the investigations.

Due to its practical, technical and scientific complexities, a fire investigation needs to be structured in a logical framework of planning, managing and reporting. With a lack of formal fire investigation training programmes, the International Association of Arson Investigators was formed in Kentucky in 1949 with the aims of providing training, knowledge and the sharing of experiences amongst fire and arson investigators.

It is only during the last several decades that fire investigation has become recognised as a stand-alone discipline with new, up-to-date scientific training and guidance. Indeed, there are many examples of publications relevant to fire investigations that have been newly published or revised since the late 1960’s to date (Kirk, 1969; Brannigan, 1971; Brannigan, 1980; Kirk & De Haan, 1983; Cooke and Ide, 1985; Drysdale, 1985; Leitch, 1993; Noon, 1995; Redsicker and O'Connor, 1997; NFPA 921, 1998; Karlsson and Quintiere, 2000; Babrauskas, 2003; NicDǽid, 2004; Williams, 2005; Lentini, 2006; Quintiere, 2006; and De Haan and Icove, 2011)

2.2.2 History of fire investigation within the London Fire Brigade

History demonstrates how people learn from past experiences. As discussed in [2.1] fires that caused significant destruction would influence the future building methods of similar properties and legislation in the form of building regulations that dealt with specific fire risks, began to appear in the 12th century. As buildings became taller, more complex and with a greater variety of uses, (Steiner, 1998) the ‘finding out’ of why fires were happening became a formal ‘fire investigation’. The findings of these investigations help prevent future fires in similar properties. Some infamous fires, however, have never been thoroughly investigated, or had any investigations published, due to their political nature, such as the burning of Cork City in 1920 (The Irish Labour Party and Trade Union Congress, 1921).

Insurance companies originally formed fire brigades in order to mitigate their financial losses. In 1833, 10 independent insurance companies joined together to form the London Fire Engine Establishment (LFEE) consisting of only 19 fire stations and 80 men and was led by James Braidwood. Braidwood (1800-1861) founded the world’s first municipal fire service in Edinburgh in 1824. At this time, the insurance companies were reactive rather than preventative.
However, in 1862 insurance companies told the government that they were unwilling to be responsible for London’s fire protection as the cost of compensation was becoming too high. The government decided that the Metropolitan Board of Works would take control. The Metropolitan Fire Brigade Act came into existence in 1865.

The Metropolitan Fire Brigade (MFB) was formed on 1st January 1866 and was controlled by the Metropolitan Board of Works, which was responsible for protecting all life and property from fire throughout London. Originally the Metropolitan Police were chosen to take control of the Fire Brigade, but it was felt this would be too complicated. The MFB was renamed in 1904 as the 'London Fire Brigade'.

The Fire Data Report (FDR1) was introduced by the Home Office in 1978 (amended 1994) to assess annual fire statistics within the UK. In 1980 (Home Office, 2007) the London Fire Brigade returned the cause of approximately 2,000 fires out of a total of approximately 14,000 as 'unknown'; this figure of over 14% was not acceptable. In spite of managerial action to improve these figures, by 1983 the figure was still in the region of 7%. It was not until 1983 that the London Fire Brigade introduced dedicated Fire Investigation Officers into a Fire Investigation Team (FIT) due to these significant numbers of fires being recorded as 'unknown' in their origin and cause. The focus of the new team was on the 'causes' of fire. The on-site collection of fire damaged evidence and samples, for example damaged electrical equipment that may have been the cause of a fire required appropriate scientific analysis, often within a laboratory, before final conclusions to the investigation could be made, therefore scientific support was made available to assist the new FIT.

In London, the Metropolitan Forensic Science Laboratory (Met Lab) used to be an integral department within the Metropolitan Police Service. It was called The Forensic Science Service® (FSS) until March 2012 and was a UK Government owned company (GovCo) (Home Office, 2007) and competed with other forensic service providers for contracts from police forces within the UK. 2011 has seen most of the FSS closed down.

2.3 Benefits to the community

The successful investigation of fires leads to the correct cause being identified. This allows the police and fire service to utilise their resources in the most efficient and effective ways. Trends in anti-social behaviour and serious criminal activity can also be identified. Death, injury and environmental damage by fire and its products can be reduced and in some instances completely eliminated.

2.3.1 Benefits to the fire service

Fire investigation is at the forefront of 'Community Fire Safety'. Accurate data from fire investigations can be utilised by many fire service departments; fire engineering, fire safety, community fire safety, health and safety, planning departments, juvenile fire setter intervention schemes, operational planning and strategic resource allocations. It not only enables efficient and effective ways to prevent fire and protect both the public and property, but also to protect fire-fighters from injury.

2.4 Fire investigation methods

Fire investigation has previously been considered by some investigators as an 'art' form rather than a science. It is only in recent decades that it has developed considerably to become a mixture of both science and engineering.

2.4.1 Prescriptive routes using published literature (1949 to 1970)

In order to encourage a more systematic approach to the complex discipline of fire investigations, organisations such as the International Association of Arson Investigators have published periodical magazines for over 60 years with case studies and technical articles. An example is the study of a complex fatal fire involving a young female sleeping in a camper van with her boyfriend being charged with her murder (DeHaan, 2003). In order to educate the practicing fire investigator in the need for a full and thorough forensic fire investigation the study explored the fire science and the burning characteristics of the materials involved, questioning some of the original fire investigation findings.

Two police officers (Fitch and Porter, 1968) from Baltimore, USA published advice and guidance to fire investigators based on their own knowledge and experiences as law enforcement officers with the responsibility to investigate fires. They both had other relevant experience to fire investigation before joining the police department; Fitch as an electronics graduate with ten years in the automotive industry and also four years in the US Navy and Porter as a volunteer fire fighter. This allowed them to share their joint knowledge about vehicle fires, marine fires, vacant buildings and also arson investigations. As non-academics, their discussions around the psychological aspects of fire setters may have been ambitious but the intention appears to have been to give the operational fire investigator an outline understanding of some of the issues relating to the subject.

‘Kirk’s Fire Investigation’ series have added a wide range of topics to the fire investigators’ knowledge base with the first edition (255 pages) (Kirk, 1969) including subjects such as fire related phenomena, arson, explosion, asphyxiation, pyrolysis and carboxy-haemoglobin. Proving a popular publication, the second edition (Kirk and DeHaan, 1983) consisted of 352 pages with the additional subject matter consisting of new fire investigation methodologies and techniques, e.g. photography, case studies and developments in scientific applications for fire scenes, collection of evidence and its laboratory analysis. The seventh edition consisted of 763 pages, demonstrating the need to increase the subject matter further by expanding chapters on fire statistics, building construction, hydrocarbon fuels, detailing new fuels such as bio-fuels, marine fires and included many colour photographs to illustrate burn patterns and discoloration of materials due to the effects of heat and fire (DeHaan and Icove, 2011b).

2.4.2 Prescriptive routes using published literature (1971 to 1990)

Brannigan (1971) had the safety of fire fighters in mind and detailed ‘tactical considerations’ that the reader was to pay particular attention to as it involved potential collapse or failure of a structure. His motto was ‘know your buildings’ and he focussed on the principles of construction, fire resistance, fire growth, smoke and fire containment and movement, high rise construction, rack storage and sprinklers. All of these subjects are also of great importance to the fire investigator as well as the operational fire fighter as ‘to know your buildings’ will enable a better understanding of their performance during fires. The fourth edition brought up-to-date many of the newer construction techniques being used for buildings e.g. brick-clad timber-framed buildings (Brannigan, 2008).

The first ‘Anarchist Cookbook’ was published by Ozark Press (Anonymous, 1971) with the latest edition published in 1989. Many arsonists have used techniques contained within the book and it would be prudent for the fire investigator to become aware of such publications and methods of fire starting that are published within them.

Describing arson as America’s fastest growing crime in 1978, Battle and Weston (1978) emphasised the need of the investigator to recognise that arson is a crime of violence and should be investigated as such, discussing for example, interviews and interrogation, the law and the importance of evidence. Unfortunately they only dedicate two and a half pages to the point of origin and just half a page on the ignition device.

Carroll (1979) correctly stated that the main objective of any fire investigation was to determine the cause of the fire and eliminate all other possible causes. He then suggested that the next objective may be to develop a case for litigation. His publication is specifically aimed at arson and insurance investigators as opposed to fire investigation for the safety of the public and does not offer much advancement for the fire investigator.

Yallop and Kind (1980) detailed forensic methodologies to be employed and topics to consider when carrying out an investigation specifically relating to an explosion and was published by the Forensic Science Society. This may have been considered beyond the competencies of many fire investigator practitioners due to its scientific and technical content.

Brannigan, Bright and Jason (1980), three very respected and experienced fire researchers at the National Bureau of Standards (now National Institute of Standards and Technology) wrote the Fire Investigation Handbook (Brannigan, 1980), which was an authorative guide to fire investigation methodology and techniques to determine the causes of fires at that time. However, some myths, such as crazed glass as an indication that the glass was rapidly heated and potential evidence of arson, was allowed into this respected publication referred to by most fire investigators in the field.

2.4.3 Prescriptive routes using published literature (1991 to 2000)

In 1992 the National Fire Protection Association (NFPA) issued NFPA 921 ‘A Guide for Fire and Explosion Investigations’, which has been described as authoritative and given the general status of a ‘standard’. Although Chapter 1 states: "*The purpose of this document is to establish guidelines and recommendations for safe and systematic investigation or analysis of fire and explosion incidents*" the Michigan Circuit Court decision rejected the testimony of a veteran fire investigator who could not explain the scientific method as defined by NFPA 921. The court also held that the NFPA 921 is a "standard" in the fire investigation community. NFPA 921 is revised based on a three-year cycle and is managed by a Technical Committee of subject matter experts. Anyone can contribute to suggestions for updates or additions for the Committee to consider and all approved changes are highlighted using a vertical line adjacent to the new or amended paragraphs.

Shanley (1994c) wrote a series of journal articles discussing the new and rapid developments within the fire investigation discipline and the need to raise the standards of investigators globally. In his first article he discussed an overview of the fire investigation discipline at the time (Shanley, 1994c). The second article addressed the need for science to be used whilst conducting a fire investigation and the importance of all fire investigators understanding the science of fire (Shanley, 1994a). In his final series he outlined some of the myths that had been passed down in time and some of the new tools to be used relating to fire investigations (Shanley, 1994b), for example the myth that spalling concrete can only occur if a flammable liquid has been used.

Munday (1994) a former member of the Metropolitan Police Forensic Science Laboratory, wrote a paper for the Fire Protection Association to help promote fire scene safety education for all fire investigation practitioners; following his observations of dangerous practices at fire scene investigations.

The 1995 edition of NFPA 921 revised the chapter dealing with the collection and handling of physical evidence and integrated NFPA 907M 'Manual for Determination of Electrical Fire Causes'. New chapters were added to this edition and included the fire investigation of motor vehicles, incendiary (arson) fires and appliances. Another new chapter dealt with the management of major investigations.

The main syllabus reading for the Membership Examination of the Institution of Fire Engineers (see 2.7.4 below) were 'The Principles of Fire Investigation' (Cooke and Ide, 1995) and 'A Guide To Fatal Fire Investigations' (Leitch, 1993).
Advice in these publications was given on:

- assessing the resources needed for an investigation, once the fire is under control;
- maintaining scene preservation;
- thoroughly examining the fire scene and obtaining witness testimony;
- determining the possible cause.

Whilst this was a good outline management structure for a fire investigation, it was not explicit in how to determine the origin, cause and development of a fire and consisted of what was already being practiced by many local authority fire investigators. The syllabus appeared to simply support the Membership exam in fire investigation.

Noon (1995b) wrote 'Engineering Analysis of Fires and Explosions' advocating the 'reverse design' of a building following a fire or explosion to determine the origin and cause of the event. The book is aimed at professional forensic engineers but is as important to the local authority fire investigator. It highlights the need for fire and rescue service fire investigators to have a good understanding of the discipline of fire engineering. Noon also demonstrates within his text that fire investigation brings other important disciplines such as chemistry, metallurgy, civil engineering and even interviewing skills.

Redsicker and O'Connor (1997) recognised that although the knowledge and training of fire investigators had increased due to more publications relating to fire investigations being available to the practitioner, the detection, arrest and prosecution rate for arson fires remained low. Due to several organisations in the USA supporting minimum standards for fire investigators, Redsicker declared that '*training has reached the level of certification in many states (USA)…*' which implies that it had not in other US states, although he does not declare what that certification consisted of.

The UK Fire Protection Association during the late 1990's (Fire Protection Association, Undated) surprisingly recommended the acquisition of the following data from a fire, whilst maintaining scene preservation for any subsequent investigation by others:

- how it was discovered
- how it was extinguished
- what was involved and how did it develop
- were there any previous fires at that premises.

It is not clear why this recommendation was made as it would appear to be an obvious course of action following any fire, however it may have started to focus not only the UK fire brigades but also the UK Government as to the importance of data that could be obtained from fire investigations.

In the USA, the Bureau of Alcohol, Tobacco and Firearms (ATF), as it was called up until 2005 when 'and Explosives' was added to its name, developed and published a field booklet called the 'Arson Investigative Guide' (Bureau of Alcohol Tobacco and Firearms, 1997). The booklet was designed to guide the arson investigator in the field and consisted of 180 pages divided into seven sections:

- ATF Investigative Support

- Fire Scene
- Insurance
- Financial
- Real Estate (Property)
- Sources of Information
- Glossary

The guide predominantly focused on arson fires and how the 'local investigator' can be supported by the ATF; only Section Two relates to the fire scene and does not offer new subject material that has not already been published. The Bureau is a law enforcement agency, hence the guidance was 'crime centred', i.e. included topics such as insurance fraud.

Quintiere (1997c) discussed fire science subjects such as heat transfer, ignition, flame spread, fire plumes and burning rates, which greatly assisted the fire investigator to understand the fundamental physics and chemistry associated with fires. Like much of the fire related scientific and engineering literature published, it did not address the methodology of investigating fires or explosions but did emphasise the need for all fire investigators to address the science within their discipline.

The 1998 edition of NFPA 921 introduced a new chapter dealing with fuel gas systems in buildings and its impact on fire and explosion investigations. The re-organisation of the chapter dealing with 'electricity and fire' including clarification of related terminology and the inclusion of additional references was also completed. As the constant study of fire patterns, including field and laboratory tests are conducted, several sections within the chapter dealing with fire patterns were revised to assist the investigator in such pattern recognition. As well as new text regarding what was the increasing use of hydrocarbon detector canines and their handlers, the chapter addressing physical evidence and preservation of the fire scene were also amended to include US rules of evidence, burden of proof and spoliation of evidence.

In 2000 Karlsson and Quintiere (2000) again addressed the important subjects of fire plumes, heat transfer, combustion products and energy release rates, all of importance to the fire investigator. The development on Quintiere's previous publication was that this focussed on compartment fires, which are the majority of fire investigations undertaken across the world, allowing the investigator to consider how ventilation within compartments impacts on fire growth and burn patterns.

2.4.4 Prescriptive routes using published literature (2001 to 2011)

The 2001 edition of NFPA 921 introduced new chapters addressing building systems, fire related human behaviour, failure analysis and analytical tools, fire and explosion deaths and injuries and wildfire investigations. For instance, the new chapter entitled 'Failure Analysis and Analytical Tools' discussed the value of time lines and outlined the difference between 'hard' and 'soft' times. It also explained how the development of 'fault tree' diagrams could assist in the logical analysis of a fire or explosion event.

Cole (2001) first published a guide to investigating motor vehicle fires in 1980, updating it to its fourth edition in 2001 to reflect design and system advancements in motor vehicles. Early model vehicles were fairly simple in design and the investigation of the cause of a vehicle fire was not too difficult, compared to modern day vehicles fitted with complex systems, additional hoses, cables and other materials to add to the fuel load.

The 'Ignition Handbook' (Babrauskas, 2003a) attempted to cover the entire subject of the ignition of unwanted fires. Consisting of 1116 pages, 627 black and white figures, 447 tables, 140 colour photographs and 5,005 references, it is the largest reference book relating to fire causation. This publication is predominantly to be used as a reference book addressing almost every type of ignition source and fuel load that may have been the cause of a fire. No author had yet dealt solely with ignition sources and ignition energy and this has become an important book for the fire investigators' library. It does not, however, address any type of systematic fire investigation methodology.

Whilst NFPA 921 can be regarded as a technical reference manual, the International Association of Arson Investigators saw the need for a more practical users' manual for fire investigators; the first users' manual was written in 2003 and revised in 2011 (NFPA and International Association of Arson Investigators, 2003). The aim of the manual had been to expand upon and support NFPA 921. Each chapter sets aims and objectives for the fire investigator to attain and reflects the latest NFPA 921 editions.

Custer (2003) also recognised the need to provide the investigator with something more practical than having to carry NFPA 921 to scenes with them, so he developed and published a note-book style document called 'Field Guide for Fire Investigators'. Having chaired the NFPA921 Technical Committee for its first three editions, he was well placed to produce an informative and usable field book which was the first of its kind.

'Forensic Fire Scene Reconstruction' (Icove and DeHaan, 2004a) aimed to aid fire investigators during their scene excavations. This covered:

- principles of reconstruction
- basic fire dynamics
- fire pattern analysis
- fire scene documentation
- arson crime scene analysis

Although the book dealt with previously published subjects, it was an advancement for the discipline as it provided direction specifically for the field investigator for example, emphasising the need for scene reconstruction whilst at the scene, wherever practicable as well as the complex and sometimes debatable subject of fire pattern analysis.

'Fire Investigation' (NicDǽid, 2004) outlined the practical uses of how to and the reasons for conducting laboratory reconstructions, analysing debris samples and their subsequent interpretations. NicDǽid promotes the importance of the scene investigation, including scene reconstruction, collecting samples correctly and why a fire investigator needs to get them analysed in a laboratory.

Also in 2004, The Royal Society of Chemistry published ‘The Essentials of Forensic Science’ dealing with issues relating to the crime scene, progressing through to the Court of Enquiry with Chapter 8 specifically relating to ‘Fire Investigation’ (White, 2004). The chapter addresses not only the nature of fire and flame propagation but also the investigation and excavation of the scene. This highlighted the need for all fire investigators to understand the chemistry, physics and biology involved with the complexity of a fire investigation and has brought the subject matter relevant to both fire investigation field work and forensic laboratory work together.

NFPA 921 completed its 2004 publication with one new chapter entitled ‘Analysing the Incident for Cause and Responsibility’; a chapter rewrite on ‘Legal Considerations’ to reflect up-to-date changes in law and a revised chapter addressing the recording of the fire scene.

Quintiere’s (2006) ‘Fundamentals of Fire Phenomena’ again addressed in great depth the broad range of fire science subjects but for the first time discussed the importance and value of scale modelling when conducting fire tests. His guidance allowed what are normally very expensive full-scale fire tests to be conducted at a fraction of the costs when scaled down using the correct proportional maths relating to fire science of the scale of the model. Quintiere demonstrated the importance of these tests when testing hypotheses concerning very large structural fires that may be too expensive to otherwise conduct and therefore being able to add great value to the fire investigation. However, these scaled tests address fire development and not the origin and cause of fires.

‘Scientific Protocols for Fire Investigation’ (Lentini, 2006b) was an important publication to emphasise and reinforce the importance of using the Scientific Method and the need to collect all existing data and thoroughly analyse it. He detailed 30 fire case histories to support the text. One of the fundamental differences with Lentini's publication is that he explains many of the myths that have developed within the discipline over the decades and some of the errors emanating from them. Not accurately identifying the cause of a fire will not only stop future prevention measures being effective but will also hinder the successful prosecution of arsonists, or the unjust successful prosecution of innocent people. Lentini uses his case histories effectively as many fire investigators have learnt more from practical examples of the application of fire science than by simply learning the theory.

The sixth edition of NFPA 921 (2008) included the rewriting of many chapters including 'Basic Fire Science', 'Fire Patterns', 'Origin Determination', 'Motor Vehicle Fires', 'Management of Complex Fires' and the introduction of a new chapter addressing 'Marine Fire Investigations'. All of these subjects reflecting new identified methodologies and good practice for fire investigators to adopt or consider. For example, the development of 'new' chapters such as the investigation of 'Marine Fires' (12 pages) dealt with factors relating to recreational boats, generally less than 65ft or 19m in length, and outlined maritime terminology, common parts of boats, propulsion, gas, cooling and hydraulic systems. This new chapter reflected the complexities involved in investigating such fires and was important knowledge that would be required if conducting a marine fire investigation.

Chandler was a fire chief in the USA; became a fire marshal and then moved onto the private sector as a fire investigator. Sharing his life experiences with other fire investigators, as did Fitch and Porter (1968) he produced a publication simply called 'Fire Investigation' (Chandler, 2009). Although he referred to US Standards relating to fire investigation, e.g. NFPA 921 and to fire investigators e.g. NFPA 1033, he emphasised the importance of scene safety, case studies, incident photographs, interviewing witnesses and testifying in court. The clear difference in content between Chandler and others, such as Quintiere, Drysdale and Babrauskas, is that Chandler's approach is from an operational fire officer and field fire investigator, addressing the practical investigation process rather than the fire science. Whilst experience is of considerable value, the fire science and engineering needs to be addressed to provide further interpretations of events to aid current and future fire investigators.

The seventh and latest edition of NFPA 921 (2011) included new sections and major revisions to several chapters including addressing ‘Report Review Procedures’ in Chapter 4 and the need for independent peer reviewing of fire investigation reports; Chapter 12 addressed safety issues such as chemical hazards and contamination exposure to the fire investigator, e.g. airborne carcinogenic materials and the need for respiratory protection and Chapter 18, which dealt with ‘Fire Cause Determination’ was one of the major rewrites and is in the same style as Chapter 17, following the scientific method. Negative Corpus, that is basing a hypothesis on the absence of supporting evidence was considered improper by the NFPA Technical Committee and has caused much debate amongst the fire investigation community around the world. The chapters dealing with investigating explosions and fire deaths and injuries were completely revised to include carbon monoxide, cyanide and other toxic gas poisonings and various types of injuries, such as shrapnel, thermal and blast pressure injuries, as examples. The chapter on motor vehicle fire investigations expanded to include recreational vehicles (RVs or motor homes) and agricultural equipment. NFPA 921 is in its eighth cycle for the 2013 edition.

2.4.5 Anecdotal routes

The Fire Research Station since 1946, now BRE, ran symposia discussing an array of fire engineering and fire investigation studies and their outcomes. A fire investigation course leading towards the Institution of Fire Engineers exam at Membership level is still been delivered at Edinburgh University. When the London Fire Brigade established a dedicated Fire Investigation Team in 1983, there was only ‘best practice’ provided to the local authority fire investigators from which the investigator could learn and develop. This ‘word of mouth’ approach concentrated on the cause of the fire and was of great use to the police, insurers and Coroners but these causes were based on individual cases (Steiner, 1998). Repeat causes of fires were often only recognised due to the experience of individual investigators attending similar fire scenes. The insurance industry had the most accurate records of fire causation based on claims made until Local Authority fire services started collecting their own data based on all fires attended.

Training in the public sector during the early 1980's in the UK was carried out by Fire Investigation Officers within their own fire brigades, who were enthusiastic and willing to share their knowledge with colleagues. Even on developing training courses, such as those offered by the Fire Service College and fire brigades' in-house courses, inaccurate word-of-mouth teaching involving 'old wives tales' such as 'spalling concrete indicates that a liquid accelerant has been used' was aired on occasions. In the late 1990's Gardiner & Associates started to develop structured theory and practical courses promoting the team approach to fire investigations involving fire, police and insurance personnel. Training is now tailored to meet the National Occupational Standards for fire investigators at all training locations in the UK, as detailed in (2.9.1) below.

2.5 Fire setters and arsonists

Relatively few scientific studies have been conducted on arsonists compared to other criminal activities and behaviour. Studies by agencies such as the FBI in the USA are limited and clinically driven. The studies which have been undertaken in the UK usually categorise the person involved into four broad groups (Home Office, 1999):

- youth disorder and nuisance: acts of vandalism; fires brought on by boredom and thrill seeking;
- malicious: arson attacks driven by revenge, racism and clashes of beliefs or rivalries;
- psychological: fires started by persons suffering from mental illness. It also includes fires started by suicidal persons;
- criminal: fires started to conceal another crime such as theft, murder, etc. and those where the perpetrator stands to gain financially, as in an insurance fraudulent claim.

2.5.1 Group studies

The Northumbria Arson Task Force, January 1998 – May 1999 (Home Office, 2003a) identified 103 primary property arson fires from 267 fires in the Tyne and Wear area and the evidence suggested that 80% of these fires were due to vandalism. The UK Home Office ran an arson scoping study on similar lines to those used in Northumbria. Wright criticised the Home Office study on the basis that the fires were only investigated to the level where a decision on whether they were accidental or deliberate could be made and not identify patterns or trends to prevent them happening again.

In 2002, University of Auckland staff investigated fire setting behaviour in children and adolescents (Lambie et al., 2002). Three stages were identified:

- fire interest: curiosity
- fire play: experimentation
- fire setting: deliberate intent.

It was found that fire setting formed part of a more complex set of behavioural problems.

Williams (2005d) examined 310 cases of arson. She categorised fire setters under the following headings:

- the experimental or curiosity fire setter
- the delinquent fire setter
- the thought-disordered fire setter
- the revenge fire setter
- the thrill-seeker fire setter
- the disordered coping fire setter (these are individuals who set fires in order to return to a state of emotional equilibrium after experiencing intense anxiety, rage or both)

These categorisations gave the fire investigators and other agencies effective interviewing and case handling strategies when dealing with fire setters, as each had their own idiosyncrasies.

2.5.2 Studies involving single persons

Many of these studies related to persons with psychological problems. Barker (1992) highlighted the need for the prosecution of such people, so that proper treatment would be given. Roberts (1996) described the Henderson Project, a refuge which was a therapeutic centre for arsonists. Prins (1994) suggested that arsonists suffering from mental disorders have 'unfinished business' to complete when they are released. This was re-iterated by Williams (2005d). Fritzon et al (2001) wrote a paper on the relationship between distance travelled by an arsonist to set a fire and the motivational aspects of fire setting behaviour. Arsonists, whose behaviour contained a strong emotional component, tended to travel much shorter distances than arsonists who sought direct instrumental benefits from setting fires.

2.6 Lessons from major and minor fires

Currently, three levels of fire investigation are referred to by fire investigators from both the public and private sectors:

- Level One: where the fire service's Incident Commander or other investigator with no formal fire investigation training determines the origin and cause of the fire.
- Level Two: where a competent fire service investigator and/or a competent police officer, forensic scientist, crime scene investigator or insurance investigator determines the origin and cause of the fire.
- Level Three: where a multi-agency investigation is conducted involving competent fire investigators from various organisations and other disciplines, e.g. electrical engineers.

Further discussion about these three levels is in [2.9.1.1] below.

2.6.1 Major incidents

Major incidents will always be a Level Three investigation, involving agencies such as the police, Health and Safety Executive (HSE), fire service, forensic service providers, forensic insurance investigators and consultancies, building surveyors, the

Fire and Risk Sciences Division of BRE (formally the Building Research Establishment's Fire Research Station), etc. The investigations will normally sit within a Court of Enquiry chaired by a senior judge with witnesses questioned by an experienced Queens Councillor and senior scientist resulting in a high profile or protracted court case, often years after the event. Catchpole (1996) outlined a seminar at the Building Research Establishment in Watford, England, which discussed the need for better dissemination of data derived from such fire investigations and laboratory tests within the discipline. Courts of Enquiry normally result in a report and many research papers on topics relevant to the case.

Recent major investigations that have been or yet to be held in a Coroners, Crown or County Court, such as those into the clothing wholesale/retail shop basement fire in Bethnal Green Road in 2004, which claimed the lives of two fire-fighters; the fire in a high-rise block of flats in Stevenage in 2005, claiming the lives of two fire-fighters and a member of the public; the fruit and vegetable distribution warehouse fire in Atherstone-on-Stour, Warwickshire, which claimed the lives of four fire-fighters; the Lakanal fire, a high rise block of flats in south London which claimed the lives of six members of the public and the fire in the high rise block of flats in Southampton, which killed another two fire-fighters. All of these incidents have assisted in the development of protocols on how large and complex investigations should be managed, resulting in working parties from various agencies meeting to discuss positive and negative issues relating to the management of these investigations.

Historically the report findings from major incidents, where loss of life has occurred, have brought about changes to legislation and codes of practice. Two examples on a national level:

- the Kings Cross fire (Fennell, 1988)
- the Bradford City Football Stadium fire (Firth, 2005) and

a local example following a two-week inquest is:

- the Bethnal Green Road fire investigation (Mansi, 2004).

The lessons from these fires have been outlined below.

2.6.1.1 Lessons learnt from major incidents (Nationally)

Following the inquiry into the Kings Cross fire (Fennell, 1988), the multi-disciplined team of fire investigators concluded that the accumulation of debris and dust below the escalator combined with the grease used to lubricate the escalator mechanisms allowed a discarded cigarette to ignite the grease and debris under the wooden escalators. Another outcome from recommendations by the fire investigation team was that smoking was banned on the entire Underground network with all wooden escalators being replaced. An emphasis was placed on staff training, cleaning and maintenance regimes were improved. It was also during this fire investigation that the 'trench effect' was discovered following large scale tests (something that the forestry industry had been aware of for many years). The lessons from this fire investigation, particularly the trench effect, have subsequently been included into fire investigation training courses around the world.

Lessons learnt at the Bradford fire following an extensive fire investigation, studying TV footage and examining records of the local enforcing authorities brought about a change in legislation for the fire safety of all sports stadia and involved many large sports stands to be demolished and rebuilt in non-combustible materials. Smoking was also blamed for igniting the accumulated rubbish below the stand and banned from all sports stadia. At the incident, the fire exits were also locked during the match to prevent people letting others into the stadium without paying, which highlights a continual conflict between safety and security.

2.6.1.2 Lessons learnt from major incidents (Locally)

Following the Coroners Inquest relating to the Bethnal Green Road fire where two fire-fighters died (Mansi, 2004), basement fire-fighting procedures were updated, communications were improved and newly developed operational training packages were distributed to all operational fire fighters within the London Fire Brigade. The need for basic water management at all fire scenes and that the use of hose reels in basement fires was inappropriate were important lessons

2.6.2 Minor incidents

It is at minor incidents that the fire investigator can identify many failings that cause fires in order to prevent them happening again. Minor incidents would involve investigations at Level 1 or Level 2 and would require a robust recording and reporting system so that their findings can be shared with the appropriate interested parties.

Fatalities at domestic residences would normally fall into these categories. It is through the improvement of fire investigation techniques that fire deaths have reduced over the last decade, as the correct identification of 'failures' that cause fires, whether human agency or not, allow resources to be targeted to where those true causes of fires exist. An example of this is the misuse or failure of electric blankets and their component parts. Electric blankets have been known to cause serious fires, some leading to fatalities or serious injuries, or just cause localised burning to bedding materials. Fire and rescue services have had Community Fire Safety campaigns, often just before the winter months, to check the electrical integrity of these types of blankets, free of charge to the occupier, in order to both educate the public and remove any damaged and/or dangerous equipment. These investigations also identify changes in societal needs and requirements.

2.6.2.1 Lessons learnt from minor incidents

The increasing use of 'social lighting' in the form of candles during the late 1990s was identified as an emerging fire causation problem and in particular the use of tea-light candles. These candles are extremely cheap and can be bought in packs or bags of more than 50. A London Fire Brigade Fire Investigation Officer (Townsend, 2002) conducted some research into tea-light candle fires and their growing social use of lighting following several minor fires. Many home 'make-over' programmes show these candles to give a more relaxed atmosphere to a room. The Fire Investigation Officer identified that if some debris, such as the end of a match, fell into the wax within the foil container, there is a potential for a 'double wick' effect to ignite the entire surface of the melted wax and substantially increase the temperature of the foil container. This was validated following scientific research that demonstrated a rapid temperature rise of the aluminium casings of over 200^0C during double wick situations. This was due to the wax decomposing at a higher rate and causing more fuel to produce larger flames and a higher heat generation rate (NicDǽid and Thain, 2002).

Following several extractor fan fires in toilets and bathrooms (Carey, 1996) a study was carried out identifying that a build up of dust can cause small extractor fans to stall and overheat over many hours until they ignite and fire spreads to their plastic casings and any surrounding flammable materials. This can also occur when fans are removed from storage during hot summers and any accumulated dust is not removed. The cleaning of these fans is now considered during fire risk assessments.

The author was managing an on-going case involving an auto-defrost Beko fridge/freezer which had a design fault identified by a London Fire Brigade Fire Investigation Officer and subsequently led to a National Safety Campaign and police enquiry (Mansi, 2010). Beko were informed about the identified problem in June 2010, which the manufacturers disputed. In November 2010, the author wrote to Beko to inform them that there had been a fatal fire involving one of their appliances and that the Coroner would be informed. A Corporate Manslaughter charge was raised against Beko but the Crown Prosecution Service decided in May 2012 that there were to be no charges made. The London Fire Brigade issued a warning on its web site and the BBC ran a series on national news programmes to address the concerns of the public.

2.7 Reporting of fires

Department of Communities and Local Government (DCLG) fire statistics provide a general purpose description of all fires and false alarms attended by UK fire brigades based on information collected from fire reports. Data collected about serious, reportable fires includes:

- Time and date of call
- Brigade or other geographical area
- Type of building or vehicle
- Most likely motive (accidental or malicious)
- Cause of fire (e.g. oil pan fires, electrical, etc.)
- Source of ignition (e.g. cigarettes, cookers, etc.)
- Materials (e.g. furniture, etc.)
- The spread of fire (beyond room of origin, etc.)
- The nature of fire casualties
- Rescue information and method of extinction
- A report into the effectiveness of automatic smoke detectors (Fire Safety Advice Centre, 2007)

The DCLG[††] and local fire brigades use these fire statistics when making operational decisions, policy development and promoting public awareness about the dangers of fire. These statistics are also used to measure the effectiveness of fire

brigade activities and some Fire and Rescue Authorities have recognised the importance of accurate fire investigations in order to capture this data.

Data regarding property fire and/or fire involving casualties attended by UK fire brigades were collected on detailed reports (FDR1) (see [2.7.1] below). There are approximately 200,000 serious fires each year, on which data are collected.

([††] *The Home Office had ministerial responsibility for the UK Fire Services until 2001 when that responsibility was transferred to the Department for Transport, Local Government and Regions (DTLR), then the Office of the Deputy Prime Minister (ODPM) became responsible in 2003 up to 27th June 2006 when the Department of Communities and Local Government (DCLG) was designated as a new Government department with those responsibilities*.)

2.7.1 Fire Data Report (FDR1)

In 1994, form FDR1 was revised involving many changes in the structure of the fire data collected by brigades, opening up the potential for electronic data interchange between fire and rescue services and the DCLG which would make possible more detailed analyses of the causes and effects of fires.

The division of fire types by local government agencies into ‘Primary’ and ‘Secondary’ causes some confusion, not only amongst fire service personnel, but also other agencies, including the police. This is due to former Home Office guidance that although prescriptive in many ways, is out-dated and illogical.

For example, a primary fire is supposed to be a fire that has caused a financial loss and a secondary fire is classified as rubbish, or abandoned vehicles. However, according to FDR1/94 Home Office guidance on completing the FDR1, a secondary fire includes garden fencing and overhead gantries; the former could have a value in the region of hundreds of pounds and the latter into many thousands of pounds. Other agencies, especially the police, understand a secondary fire to be a fire that

has been started by a primary fire, i.e. a fire is started and spreads to another fuel package and this then becomes the secondary fire. Many fire investigators have been instrumental in trying to change this recording method to eliminate the misunderstanding described but have so far not been successful.

Since 1994, FDR1 forms have been manually inputted on the basis of a systematic sample, with the following approximate sampling fractions: 1994 – 10%; 1995 – 40%; 1996 – 20%; 1997 – 20%. These variations appear to be due to the scale of work involved and availability of staff to enter the data. Each fire record is weighted to agreed totals, according to the fire and rescue service area and the time of year in which the fire occurs. However, all fires involving fatal and non-fatal casualties are input, making a 100% record of casualty fires (Fire Safety Advice Centre, 2007). This is therefore not a true and accurate account of fire statistics for the UK.

2.7.2 Incident Recording Information System (IRIS) and the Incident Information Management System (IMS) - London Fire Brigade

The London Fire Brigade used a computer database programme called the Incident Recording Information System (IRIS) between 1999 and November 2008; this has now been replaced with the Incident Information Management System (IMS). These databases record every incident that an appliance attends, whether it is a fire, road traffic collision, flooding or one of the many other special services, which the fire authority provides. Upon return from an incident, the Incident Commander will enter the relevant details into IMS so that a range of information can be analysed and used for statistical purposes or preventative initiatives. IMS auto-populates fields on the database to minimise time and prevent data entry mistakes by the in-putter. The Incident Commander decides whether the fire was either a 'primary' or 'secondary' fire, whether it was started accidentally or non-accidentally and then enters this information into IMS. They will also enter other information into the IMS database, including the post code and property type, for example dwelling, vehicle, educational establishment, etc. The IRIS and IMS statistics are, therefore, the most accurate statistics available for the recording of fires in London, due to every fire attended by the London Fire Brigade being given a unique Incident Number. However, the determination of the fire's causation is often only deemed 'the most probable' cause.

2.7.3 Real Fire Library

In 1983 the London Fire Brigade selected operational personnel to start a dedicated fire investigation team due to the growing concerns of the Home Office regarding the increasing amount of 'unknown' causes of fires being reported by fire services across the United Kingdom. The London Fire Brigade attends approximately 10% of all the UK fires (Office of the Deputy Prime Minister, 2004) and in 2005 this represented approximately 49,882 fires (London Fire Brigade, 2005) where the cause of the fire would need to be determined by the incident commander. Operational fire officers trained in fire investigation techniques would be available to assist the incident commander in the determination of the origin and cause of any fires that they were not able to determine. This dramatically reduced the amount of ‘unknown’ fires being returned on the Home Office Fire Damage Reports (FDR1).

During the mid-eighties, it was recognised that Fire Investigation Officers were collecting, or in a position to collect, a vast array of data that was, or could be of use to many other departments and organisations that are involved in the fire industry. The Real Fire Library database was designed and became the main functional database within the Fire Investigation Group. Since 3rd November 2008 it has become an integral part of the Incident Information Management System.

2.9 The ‘Daubert Challenge’

A son of a Mr & Mrs William Daubert had been born with serious birth defects. He and his parents sued Merrell Dow Pharmaceuticals Inc., a subsidiary of Dow Chemical Company, in a California state court in June 1993, claiming that the drug ‘Bendectin’ had caused the birth defects. The court did not accept the methodology used to challenge Merrell Dow as relevant or scientific. The court case is now used to challenge so called ‘expert witness evidence’ and is referred to as the ‘Daubert Challenge’. It has had a direct impact on fire investigators in the USA. Transcript from the case states:

"*Scientific methodology today is based on generating hypotheses and testing them to see if they can be falsified; indeed, this methodology is what distinguishes science from other fields of human inquiry*."

"General acceptance" is not a necessary precondition to the admissibility of scientific evidence under the Federal Rules of Evidence, but the Rules of Evidence--especially Rule 702--do assign to the trial judge the task of ensuring that an expert's testimony both rests on a reliable foundation and is relevant to the task at hand. Pertinent evidence based on scientifically valid principles will satisfy those demands”.

From the Daubert case arose three ‘tests’ that expert testimony had to pass before it can be deemed admissible:

2.8.1 First test: Scientific knowledge

The testimony must be scientific in nature and the testimony must be grounded in "knowledge" and that "scientific knowledge" had to be arrived at by the scientific method.

2.8.2 Second test: Trier of Fact

The first test must assist the Trier of Fact in understanding the evidence or determining a fact at issue in the case and there must be a "valid scientific connection to the pertinent inquiry as a prerequisite to admissibility."

2.8.3 Third test: Judge's Determination

The judge would make the threshold determination regarding whether certain scientific knowledge would indeed assist the trier of fact in the manner contemplated by Rule 702, entailing a preliminary assessment of whether the reasoning or methodology underlying the testimony is scientifically valid and of whether that reasoning or methodology properly can be applied to the facts at issue. This preliminary assessment can turn on whether something has been tested, whether an idea has been subjected to scientific peer review or published in scientific journals, the rate of error involved in the technique, and even general acceptance, among other things. It focuses on methodology and principles, not the ultimate conclusions generated.

2.9 New approach

As can be determined from the 'Daubert' case and the general position of the fire investigation discipline detailed above, a more structured and robust system for the investigation of fires needs to be established. Fire and explosion scenes are often referred to as being 'processed' when their examination is being conducted. Road maps, or fault trees, are used in the chemical and allied industries to identify hazards and quantify the risks in process plants, such as the excess generation of hydrogen during the retrieval of nuclear waste from old silos. By applying this approach to the investigation of fires and explosions it should be possible to demonstrate, in a Court if necessary, a methodology that will stand the rigorous test of detailed cross examination and not simply state that *some* hypotheses were considered, tested and eliminated at the scene as a matter of course.

When major fire or explosion incidents have been thoroughly investigated, science has been used to explain how the incident happened, detailing the ignition source which ignited a combustible material and how, if relevant, it escalated and was subsequently extinguished. Human factors may have also been included within the scope of those investigations; how people reacted to warnings and instructions; how they may have tried to deal with the situation themselves; how they escaped and how they were rescued.

There is a need for a robust socio-technological* approach to fully investigate all fires and their consequences.

2.10 Competencies and qualifications of fire investigators

Most fire investigators within the commercial sector have academic qualifications, although not all relating to fire investigation. Increasingly, public sector fire investigators are undertaking various types of formal academic qualifications, ranging from foundation degrees to PhDs, in subjects such as psychology, criminology, photography, fire safety engineering, electrical phenomena and fire investigation.

2.10.1 UK National Occupational Standards for fire investigators

No common standards had been set for fire investigators from any organisations within the United Kingdom, until the introduction of the National Occupational Standards in July 2005 by the Employers Agency. Fire investigators would base their

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**Holistic consideration of human agency involvement including behaviours and influences, combined with all available physical evidence* expertise on various factors; the public services, such as the fire service, would base it predominantly on the experience gained over a period of time investigating a number of scenes. It was taken for granted by this sector that the more experience an investigator had and the more scenes attended, the better they were at investigating fires. Prior to 2005, there were no structured assessment processes that were set against any recognised standards.

Forensic insurance fire investigators and forensic service personnel are often academics or practicing engineers that have obtained scientific diplomas or degrees at various levels in subjects such as mechanical or electrical engineering, geology, physics, chemistry, biology and forensic science. However, the same issue applied whereby the assessment process to deem the new fire investigator as 'competent' remained solely with the employer.

The National Occupational Standards for Fire Investigators (revised by Skills for Justice in 2009) enables a trained fire investigator from any organisation to demonstrate competence against the standards in a structured and measurable format. The standards therefore apply to all practitioners in the discipline of fire investigation.

2.10.1.1 Mis-understandings regarding the 3 Levels of Fire Investigations

Level 1, 2 and 3 investigations, and not, as is often misinterpreted, investigators, were introduced with the National Occupational Standards (Employers Organisation, 2005) and these are, at the time of writing, being misunderstood by many fire investigation practitioners and their organisations. Originally, some academics attempted to determine levels of each fire investigator, but due to much discussion within the National Occupational Standards working party in 2004 and the National Occupational Standards revision working party in 2008/2009, it was agreed that it was the investigation and not the investigator which would be categorised to indicate the appropriate level of resources being used.

- A Level 1 fire investigation occurs when the fire service Incident Commander can easily determine the cause of the fire with no additional resources and some very basic fire investigation awareness training, normally as the first responder.

- A Level 2 fire investigation requires the attendance of a competent fire investigator. The competent fire investigator is one who has demonstrated competencies aligned to the National Occupational Standards, irrespective of previous experience or academic qualifications and is maintaining those competencies.

- A Level 3 investigation is a multi-agency fire investigation, which would involve the fire service's investigator and possibly other fire service departments such as fire engineering, accident investigation and fire safety and may include the police, forensic services, HSE, engineers, borough surveyors, forensic insurance investigators, etc. for example, the Kings Cross fire (1987) and the Buncefield explosion (2005). It does not mean that a Level 3 investigation has to have all of the latter as, for example, it may become evident that it is not a crime scene or fatal fire incident, therefore the police and by default, forensic services would not be required. However the involvement of the fire service, local authority departments, insurance investigators, engineers and so on would dictate the investigation to be at Level 3.

2.10.2 International Association of Arson Investigators (IAAI)

The IAAI facilitate two programmes that test a fire investigator's knowledge, training and experience.

2.10.2.1 IAAI-Certified Fire Investigator Programme

In 1986, the IAAI resolved a national concern by developing the Certified Fire Investigator (CFI) Program. The CFI Program is an established procedure for identifying and recognizing a fire investigator's expertise. Certification is based on:

a) Being a full time fire investigator for 4 years or part time for 5 years.

b) Attaining at least 150 points from a specified pre-defined assessment scheme based on education, training, and experience
c) Passing a comprehensive examination

Before a person is allowed to take the examination, review committees must approve the application. It must be possible to document every point claimed on the application. Certificates, diplomas, testament letters, and transcripts are examples of acceptable documentation. Once the application is approved, details will be sent of the examination date and location.

The Certified Fire Investigator (IAAI-CFI) Program is administered by the International Association of Arson Investigators (IAAI) in conjunction with Participating Chapter CFI (PC-CFI) Committees. Re-certification is every five years. The IAAI-CFI qualification is reviewed and approved by the Pro-Board in the USA and recognised by the Qualifications and Curriculum Authority in the UK.

The post-nominal of IAAI-CFI demonstrates that the fire investigator has experience, training and education but cannot demonstrate or confirm the competencies of that fire investigator.

2.10.2.2 IAAI-Fire Investigation Technician Programme

In 2009, the Fire Investigation Technician Programme was launched and designed to be an intermediate stage towards a fire investigator attaining their IAAI-CFI certification. The post-nominal of IAAI-FIT demonstrates a level of experience, training and education in the field of fire investigation. The training and experience required for the IAAI-FIT would be considerably less than that required for the IAAI-CFI.

2.10.3 Council for the Registration of Forensic Practitioners (CRFP) - Fire Scene Examination

The Auld Report by Lord Justice Wolf in September 2000 (Criminal Courts Review, 2000) addressed many miscarriages of justice brought about by ‘expert witnesses’ not having passed a formal validation process to hold the status of an expert and their evidence subsequently being proved to be flawed. The CRFP was established in 1999 to address this serious problem but was terminated on 1st April 2009 partly due to its high administration costs. There were 25 specialities within the CRFP that have registers of practitioners who have undergone peer review and a structured process for recording, documenting and reporting their investigations. Upon successful completion of the process, the practitioner would be able to display ‘RFP’ (Registered Forensic Practitioner) after their name for a period of four years, when they would have to be revalidated for registration.

Registration consisted of the practitioner completing an application document relevant to their discipline. If successful at this stage, the applicant’s details were passed to an assessor who would then, using standard forms, request a list of casework for the previous six to 12 months. The assessor would select three to six of these cases and ask the applicant to send copies of the entire case files, anonymised, so that they can be assessed; this would include all contemporaneous notes. Set against well established marking criteria, the assessor would then evaluate the evidence and make a decision as to whether the applicant was suitable to be entered onto the appropriate register. This decision was then sent to a lead assessor to approve the original assessor’s decision. If the decision was negative, then the lead assessor would pass all the case files onto a second assessor who would make an independent evaluation of the same case files. A robust appeal procedure existed for any disputes that may have arisen.

The CRFP process was not able to evaluate the practitioner’s performance whilst carrying out their duties, simply the way they recorded and documented their findings.

2.10.4 Institution of Fire Engineers (IFE) – Member’s Paper for Fire Investigation

The IFE examinations are for individuals working in various fire related disciplines such as operational fire services, fire engineers and fire safety specialists. Four levels of examinations exist; Preliminary, Intermediate, Graduate and Members. The Member level is the highest level. One of the optional papers is ‘Fire Investigation’ and the syllabus is predominantly based on the IFE publication ‘The Principles of Fire Investigation’ (Cooke and Ide, 1995). It is possible to pass this paper having had no practical experience of fire investigations (Mansi, 1997).

The IFE Members exam can only demonstrate a candidate’s retentive memory and application of that knowledge during examination conditions.

2.10.5 The Forensic Science Society (FSSoc) Fire Investigation Diploma

Examinations for Forensic Science Society Diplomas are conducted each year. At the time of writing, the exams are:

(a) Crime Scene Investigation
(b) Document Examination
(c) Fire Investigation
(d) Firearms Examination
(e) Forensic Imaging.

For a candidate to be eligible to take the fire investigation diploma examination they must be a practicing fire investigator for a minimum of five years and meet other specified criteria, such as provision of three case studies. If the candidate is successful in the written examination, an interview will be held on the case studies submitted.

2.11 Conclusions

Large, complex and high profile fires, or fires involving fatalities or serious injuries, call for a Court of Enquiry. Although these incidents occur rarely, any new data analysed during these enquiries provide a means of seeing what can or should also be done for the investigation of smaller incidents to prevent further similar incidents occurring. With the removal of Best Value Performance Indicators (BVPI) on the 1st April 2008 from Fire and Rescue Authorities within the UK and the introduction of only two National Indicators relevant to fire to replace the BVPI’s, NI33 relates to ‘arson’ and NI46 relating to primary fires and injuries (both have since been rescinded in April 2010), there is a need to develop standards to aid the investigation of all sizes of fires and explosions. Without required standards fire investigators may not be given the training and support required to attain competence and maintain continual professional development.

There is clearly a need for all fires to be investigated at various levels by trained, qualified and competent fire investigators and to continue to conduct thorough investigations at the more complex scenes. It has been established in Chapter 1 and Chapter 2 that all fires need to be thoroughly and rigorously investigated to identify whether the cause of the fire was accidently or deliberately started. The competencies of a fire investigator and the application of a robust fire investigation methodology are factors that are continually being challenged in courts around the world.

A ‘Road Map’ technique has been identified as a potential methodology that any trained and competent fire investigator could use, irrespective of their experience, to conduct a thorough investigation using a structured and logical approach. The Fire Investigation Road Maps would help prevent important data being missed by the investigator due to the complexity of such investigations.

Chapter 3

An Approach based on the Scientific Method

A more structured and robust system for the investigation of fires needs to be established. Road maps, or fault trees, are used in the chemical and allied industries to identify hazards and quantify the risks in process plant, for example identifying the production of excess hydrogen and how to prevent it happening. By applying this approach to the investigation of fire and explosions it should be possible to demonstrate, in a Court if necessary, a methodology that will stand the rigorous test of detailed cross examination and not simply state that *some* hypotheses were considered, tested and eliminated at the scene as a matter of course.

The development and publication of Fire Investigation Road Maps (FIRMs) should allow the fire investigator to carry them in their 'tool kit' and use them as aide-memoirs (See Chapter 4), just as commercial pilots use aide-memoirs to carry out their aircraft safety checks before take-off.

In Chapter One, Section 1.10, the 'Scientific Method' was the term utilised to indicate how a systematic fire investigation could be carried out. The problem of 'lack of consistency in approach at the scenes' (Chapter One, S 1.7(i)) was also discussed and to this end, this thesis offers an appropriate method for conducting fire investigations. The FIRMs provide a vehicle to identify the required:

- fire science
- methodology to conduct a thorough investigation
- depth of inquiry

3.1 Fire Investigation Road Maps relating to fire and explosion investigations with no human involvement

(a) A series of FIRMs have been designed with supporting text so that investigators may refer to them at the incident and/or at their offices whilst they are continuing their investigation and compiling the fire incident report. The aim of the FIRMs is to guide the investigator throughout the investigation so that all available data relating to the cause of the fire is collected and analysed holistically. Decisions about which route to follow within each road map (i.e. similar to a road atlas) are based on training, knowledge and experience and are presented in the supporting text associated with each of the road maps. The objectives are that the conclusions of the investigation are accurate, correct and based on a scientific and methodological approach in the development and testing of hypotheses. Appendix Two gives detailed instructions outlining existing knowledge and acceptable scientific debate on the necessary decisions needed to progress along chosen routes and how to use each one of them.

(b) The FIRMs, which consist of road maps and decision points supported with guidance text, have been divided into seven sections that encompass accidental and deliberate causes of fires and explosions and are detailed below. The FIRMs are not to be used in isolation and all should be considered using the designed systematic and scientific methodology during an investigation. Figure 3.1 specifically addresses human agency involvement or inter-action in these incidents. It is envisaged that considerable cross-referencing between the FIRMs will occur in relation to decision making.

(c) The requirements of the FIRMs are to:

- identify the main components in an investigation
- define the categories involved using the FIRMs one to seven, e.g. Fire Investigation Road Map #3: Fuel/Energy Source
- identify the subjects within those categories, e.g. Fire Investigation Road Map #3.18: Petrol/Diesel
- evaluate the events leading up to the fire or explosion; and that event being the interaction of the main components across all categories
- ensure that a socio-technological approach to the investigation is maintained.

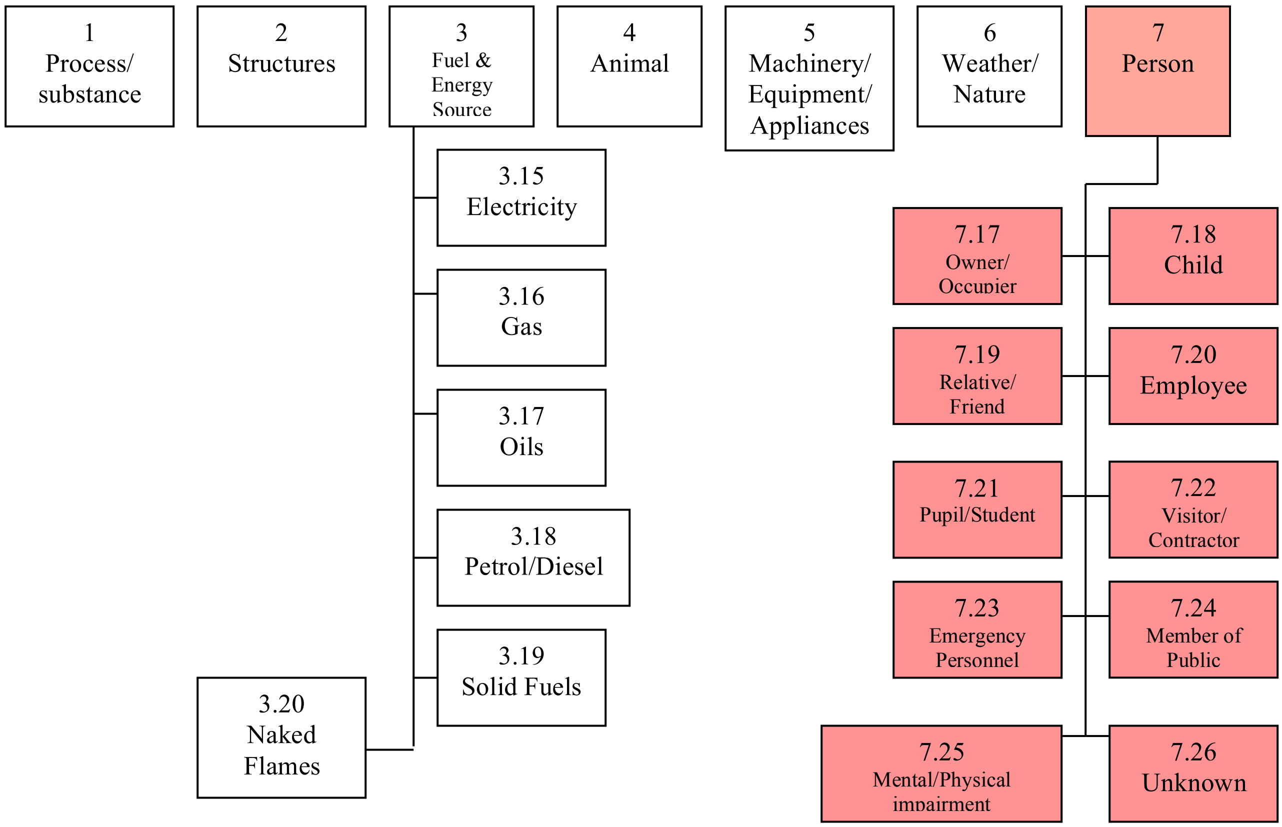


Figure 3.1 Titles of Fire Investigation Road Maps (FIRMs)

(d) The examination of fire scenes and the investigation of fires and explosions can be a very complex, analytical and scientific process. The most information intensive time for an investigator is when they arrive at the scene and start to collect data. There are several methods in which these incidents can be investigated; by first creating a time line which includes 'hard' (verified recorded times) and 'soft' (estimated unrecorded times); by collecting and analysing witness testimony; by examining the scene and interpreting the fire and smoke damage; by collecting and examining physical evidence from the scene. All of these processes need to be completed before any hypotheses can be developed and tested, but their order of completion depends upon the personal style or system of the investigator.

- The investigator has to be flexible in his or her approach as the data will be very wide ranging. Scene safety, for example air-borne contaminants, dangerous structures, unsafe floors, etc will be paramount and a post-fire or post-explosion scene may be very dynamic with regard to risk assessments.

- Ensure that any process or substance delivery system, electrical, gas or other energy supply has been isolated and 'locked off', preferably with a lock and key, and labelled, so that re-activation of the system will not occur.

- Some investigators may arrive when the emergency operations are still active; for the fire service investigator, it allows an opportunity to gather data from the Incident Commander, first crews to respond to the scene and have access to the scene that would not be given, in most cases, to other agency investigators.

- Photographing, videoing, sketching, recording witness details such as names, addresses and contact information, securing data logging devices, such as CCTV, etc. will totally preoccupy the investigator to an extent that referring to the road maps may not be practical.

- It is important for the investigator to briefly refer to the road map flow charts at the earliest and most practicable opportunity as questions that may need to be asked of witnesses (that could leave the scene) could be generated by referring to the road maps. Questioning witnesses, including emergency service personnel, with relevant questions as soon as is reasonable practicable, is paramount to getting the most accurate information from them.

- If the investigator is working as part of a team, it would be beneficial to schedule a time when the team refer to the road maps and then decide who will deal with any issues that transpire.

- Whether the road maps are referred to early or later in the investigation, the key point is that they are referred to before the investigator leaves the scene.

(e) Forensic fire investigation should identify the origin and cause of an incident by providing physical evidence and/or witness testimony and demonstrating that all other possible causes have been eliminated. In any court, a fire investigator can be thoroughly tested in the witness stand, often until he or she has fully explained their investigation methodology. Many cases have collapsed (The Florida Bar Journal, 1999) through the lack of testing of soundly formulated hypotheses.

Other guides have been written to assist with the investigation 'process' (NFPA, 2004j) (NFPA, 2011c) (U.S. Department of Justice, 2001), which are all practical guides as 'actions' that need to be considered at any investigation. They do not comprehensively address the 'thought' processes of the investigation allowing for the development of multiple hypotheses. FIRMs will provide a means to achieve this.

(f) The FIRMs should to be used to ensure that the investigator(s) encompasses all possible causes of fires within pre-determined categories. Causes of fires have been categorised into individual FIRMs and are numbered. For instance, 'Fuel/Energy Source' will be FIRM #3. It must be recognised that the road maps can become 'three dimensional' as one will invariably interact with another in the hypotheses developing and testing process. For example, a 'Process' (FIRM #1) may involve the use of acids and oils in a complicated metal plating production line. Decision point [1.5] may identify a problem with the continuity of a process and the way in which the oil is applied to the metal. Once the oil has been identified as being a drying oil, it may be necessary to refer to Fuel and Energy Sources (FIRM #3) to follow the route of decision point [3.17] (Oil) ***as well as*** continuing with [1.5].

Basic principles and techniques of fire investigation must be learnt from reputable training programmes, books and other sources. The importance of thoroughly recording data by writing comprehensive notes and by the use of photography cannot be emphasised enough. Data also refers to any items or information that comes within the scope of the investigation as well as the fire scene itself.

3.2 Overview of the properties of non-human agency Fire Investigation Road Maps (FIRMs)

An overview of all the FIRMs (to date) is outlined below.

(a) The road map approach provides:

- a means of identifying and defining all potential ignition sources in the vicinity of the area of origin
- a way of identifying all flammable materials
- a method of identifying any interaction between the latter and the ignition sources
- a means of considering any influential involvement of animals, weather and/or nature upon the origin, cause and/or development of the fire or explosion.

3.2.1 Processes and substances (FIRM #1)

The term ‘process’ is taken to mean a series of actions which produce a chemical change or development in physical matter or a method in doing or producing something. This FIRM #1 deals with any process(es) which may require the need for strict control measures with regard to the way substances are used or handled and the order with which they are applied. It will include any substance, whether solid, liquid, and gaseous or particulates that may be affected by the way it is produced, stored, separated or handled. The term ‘substance’ is taken to mean chemical substances (also sometimes referred to as pure substances) and may be defined as *any material with a definite chemical composition* in most introductory general chemistry textbooks.

3.2.2 Structure (FIRM #2)

This Fire Investigation Road Map has categorised ‘Structures’ to cover buildings, frameworks, gantries, chassis, foundations, superstructures and any other relationship or inter-relationship of parts in a construction. Structures also provide passages for all building services which can result in gaps being left around, for example, service pipes passing through compartmentation walls and floors, allowing smoke and other products of combustion to penetrate through them. It also addresses issues of compliance with building, design and operational codes. The main consideration when using this FIRM is whether the structure has been influential in creating an ignition source by either bad design or inadequate workmanship.

3.2.3 Fuel and Energy Sources (FIRM #3)

'Without some source of energy, there will be no fire' (DeHaan, 2007c). All of the other Fire Investigation Road Maps #1, #2, #4, #5, #6 and #7 are cross-linked to this Fire Investigation Road Map #3, as they will all require an energy source to initiate a fire. It is therefore most probable that when using the other Fire Investigation Road Maps, the investigator will be referring to this section at some point during the investigation. This road map does not include mechanical or frictional sparks as these are included in FIRM #5, 'Machinery, Equipment and Appliances' nor lightning or solar radiation, as these are covered in FIRM #6, 'Weather & Nature'.

This Fire Investigation Road Map is subdivided into six categories of fuel/energy:

- [3.15] Electricity (to include microwave)
- [3.16] Gas
- [3.17] Oils (not petroleum based)
- [3.18] Petroleum based products
- [3.19] Solid fuels
- [3.20] Naked flames

It encompasses any intended or 'designed' source of energy that may become an ignition or a fuel source, accidentally or non-accidentally (deliberately).

IMPORTANT NOTE:

In the absence of any other possible fuel/energy source and by exploring FIRM [3.20] – Naked Flames, the investigator must be aware that this does not encompass the *deliberate* application of a naked flame by the use of a match, lighter, pyrotechnic or any other device that produces or sustains a naked flame, and is intentionally introduced to a fuel package. This will be covered in depth within FIRM #7: 'Person'.

3.2.3.1 Electricity (FIRM #3.15)

This road map is to be used if the area of origin has an electrical energy supply within or close to it. It must always be used to satisfactorily eliminate any electrical activity as being the possible cause of the fire. As with any investigation, it is imperative that nothing is touched, moved or altered prior to recording and photographing any item(s). Careful evaluation of any evidence of electrical involvement must be conducted in conjunction with any other potential ignition sources present. If the electrical knowledge of the investigator is limited then somebody with electrical expertise should be consulted before the road map is followed.

Electrical examinations can be extremely time consuming and must be done carefully, methodically and all stages recorded and photographed where necessary. The investigator must remember that fuses and circuit breakers are safety devices designed to protect against electrical short circuits, over-current and overloads. They will not protect against resistive heating, unless the heating subsequently causes a short circuit. A large over-current that persists is considered an over-load and may cause the conductor to become hot enough to ignite adjacent fuel loads.

3.2.3.2 Gas (FIRM #3.16)

The term gas is used here to describe any fuel that is in the gaseous phase at room temperature and atmospheric pressure. If mixed with air, it will form a flammable mixture within well-defined upper and lower flammability limits. The equipment used to store and deliver gas consists of storage tanks, cylinders, 'bottles' containing liquefied petroleum gas (LPG), pipe-work of varying materials, joints, connections, including flexible connections, pressure valves, regulators and control valves to isolate or operate equipment.

When gas escapes and mixes with the atmosphere, it is initially too lean to be ignited by an energy source. As the fuel increases, an ignition at lean or at the stoichiometric mixture would be very forceful but would unlikely sustain a flame following the deflagration. If the mixture ignites when it is rich, but still below its upper flammability limits, the deflagration may be less forceful and more likely to sustain a flame. (DeHaan, 2007b)

3.2.3.3 Oil (FIRM #3.17)

Oil is a flammable substance, which is usually insoluble in water and composed mainly of carbon and hydrogen. Oils may be solids, such as fats and waxes, or in liquid form. The three main types are 'Essential Oils' which are obtained from plants, 'Drying Oils' which are obtainable from animals and plants and 'Mineral Oils', which are obtained from refined petroleum or crude oil. Drying oils are susceptible to self-heating, some more than others, as they react with oxygen to generate heat. Oil based products (OBP), as used in this road map, are any materials that contain oils, which may be susceptible to self-heating.

It is important that the investigator is able to identify the oil, its determined flash point and the upper and lower flammability range of the product. This may require a laboratory analysis of a sample.

This Fire Investigation Road Map #3.17 – Oil, has been separated from Fire Investigation Road Map #3.18 – Petrol/ Diesel, as the characteristics of petrol and diesel differentiate considerably from most oils in their natural state. For example, petrol has a flash point of approximately 235K (–38^{0}C) (NFPA, 2004h), diesel has a flash point of 325-369K (52-96^{0}C) (NFPA, 2004h), and mineral ‘engine’ oil has a flash point of approximately 483-530K (210-257^{0}C) (NFPA, 2004h),.

Petrol and diesel are also not prone to self-heating.

3.2.3.4 Petrol and Diesel (FIRM #3.18)

Crude Oil is a dark-coloured, viscous flammable liquid occurring in sedimentary rocks, consisting mainly of hydrocarbons. Fractional distillation heats and separates the crude oil into gas, petrol, paraffin, diesel oil, lubricating oil and other derivatives.

Petrol: various volatile flammable liquid mixtures of hydrocarbons obtained from petroleum and used as a solvent and a fuel for internal combustion engines (US name: *gasoline*)

Diesel Oil: a fuel obtained from petroleum distillation that is used in diesel engines (also known as *derv – Diesel Engine Road Vehicle* (Hutchinson, 1994)).

Properties of Petroleum Products			
Petroleum Distillate	***Boiling Point Range***	***Flash Point***	***Auto-ignition Temperature***
Gasoline (low octane)	32 – 190^{0}C (90 – 375^{0}F)	– 43^{0}C (– 45^{0}F)	257^{0}C (495^{0}F)
Medium Petroleum Distillate	125 - 215^{0}C (250 - 400^{0}F)	13^{0}C (55^{0}F)	220^{0}C (428^{0}F)
Mineral Spirits		40^{0}C (104^{0}F)	245^{0}C (473^{0}F)
VM&P Naptha (regular)		-2^{0}C (28^{0}F)	232^{0}C (450^{0}F)
Kerosene (C10 – C16)	175 - 300^{0}C (350 - 500^{0}F)	>38^{0}C (100^{0}F)	210^{0}C (410^{0}F)
Fuel Oil #1:		175 - 260^{0}C (350 - 500^{0}F)	260^{0}C (500^{0}F)
Diesel Fuel (Fuel Oil #2)	200 - 350^{0}C (400 - 675^{0}F)	52^{0}C (125^{0}F)	260^{0}C (500^{0}F)

Table 3.1 Properties of Petroleum Products (DeHaan, 2007a)

It is important that the fire and explosion investigator has a fundamental understanding regarding the processes of the ignition of petroleum liquid products. The mechanism employed for a petroleum ignition may be critical in the investigation and prosecution of arson fires.

3.2.3.5 Solid Fuels (FIRM #3.19)

Throughout this FIRM, solid fuels will be taken to mean wood, wood products, paper, plastics, dried paints, metals, coals, fabrics, structural polymers, synthetic fuels, vegetation, waxes and fire-lighters. Solids can ignite in two ways; external heat application (by convection, conduction and/or radiation), or self-heating. There can sometimes be a combination of both, however, for *most* solids, ignition due to external heating occurs in the gas phase as volatiles are driven off from the solid and burn freely in the surrounding atmosphere. As will be detailed in [3.19.9] self-heating occurs in the solid phase. Arc tracking through solids is covered in FIRM #3.15: 'Electricity'.

Where ignition temperature of a material is known, it may allow the fire investigator to deduce that if an available heat (ignition) source was not able to meet the ignition temperature of that material, then that material could not have ignited from that source. For example, rigid polyurethane foam requires a temperature of approximately 378^{o}C to ignite from a piloted ignition source and 502^{o}C for auto ignition of the material (Babrauskas, 2003b).

The following summary is quoted from the Ignition Handbook and relates to some general features of the problem of the flaming ignition of solids. (Babrauskas, 2003c)

'First of all, since flames are a gas-phase phenomenon, for a solid to be capable of flaming ignition it must respond to heat by breaking down and releasing combustible vapours. This is known as the 'pyrolysis process', which is a 2-step process. Upon initial exposure to heat, large molecules break apart and release some small fragments which emerge as gas molecules. These now have the potential to ignite in the air above the solid's surface under the right conditions.

For a pyrolysing solid to ignite in a flaming mode, the same three conditions must be satisfied, as for liquid fires:

[1]. The solid must be sufficiently heated so that an adequate concentration of pyrolysate (the pyrolysed vapour) exists at some location away from the surface (of the solid).

[2]. An adequate concentration of an oxidiser (typically, air) must be mixed in with the fuel vapours so that a flammable fuel/oxidiser gas mixture exists somewhere above the surface.

[3]. Either the temperature of the pyrolysate/air mixture must become high enough (for auto-ignition to occur) or else a sufficient external energy source such as a pilot flame or a spark must be introduced (for piloted ignition to occur).'

It is therefore important that a fire investigator understands the relationship between the energy involved in the preheating of a solid and the premixing of the pyrolysed vapour and air to enable piloted or auto-ignition to occur.

3.2.3.6 Naked Flame (FIRM #3.20)

This FIRM deals with all forms of naked flame, irrespective of the ignited fuels and the rate that they are burning. It encompasses matches, lighters, smoking materials, bonfires, domestic fires such as gas-flames, logs, synthetic logs or coal fires, fireworks and flares, heaters, cooking equipment, burnt food items including cooking oils, fats and alcohol, camping equipment, hot-works equipment such as blow lamps and welding torches, and candles.

Although smoking materials constitute a smouldering fire, they are included within this FIRM as they produce a combustion zone within the material due to their burning characteristics and propensity to start fires in upholstery and paper products, although there will be some cross-reference to Fire Investigation Road Map #3.19: 'Solid Fuels'.

3.2.4 Animals (FIRM #4)

The ‘Animal’ road map includes any living organism; mammal, bird, fish, insect or reptile, characterised by voluntary movement, the possession of specialised sensory organs enabling rapid response to stimuli, and the biting and/or ingestion of complex organic substances (Hanks, 1989a).

3.2.5 Machinery, equipment and appliances (FIRM #5)

Mechanically or electrically operated devices that either have a specific function, automatically performs tasks, or assists in performing tasks (Hanks, 1989b) for either industrial, commercial or domestic purposes. It also includes any means of transportation. The road map addresses any use, misuse, reliability and/or failure of these devices.

If the item is either within the area of origin, or it is recognised that it could have started a fire in the area of origin, even if the item is remote from it, then it must be examined so as to confirm or eliminate it as a cause of the fire. An example of an item appearing to be remote from the area of origin is one where a fire has spread from a defective overhead heater due to burning materials dropping from the heater onto a fuel package below.

3.2.6 Weather and Nature (FIRM #6)

In modern times, building materials and component parts can influence the effects of weather and nature to create a situation for combustion to start, whereby it may not have if those materials or component parts were not present; an example is when lightning strikes a television aerial fixed to a brick chimney stack, which passes high voltage electrical current through the co-axial cable, igniting the television at the end of that cable.

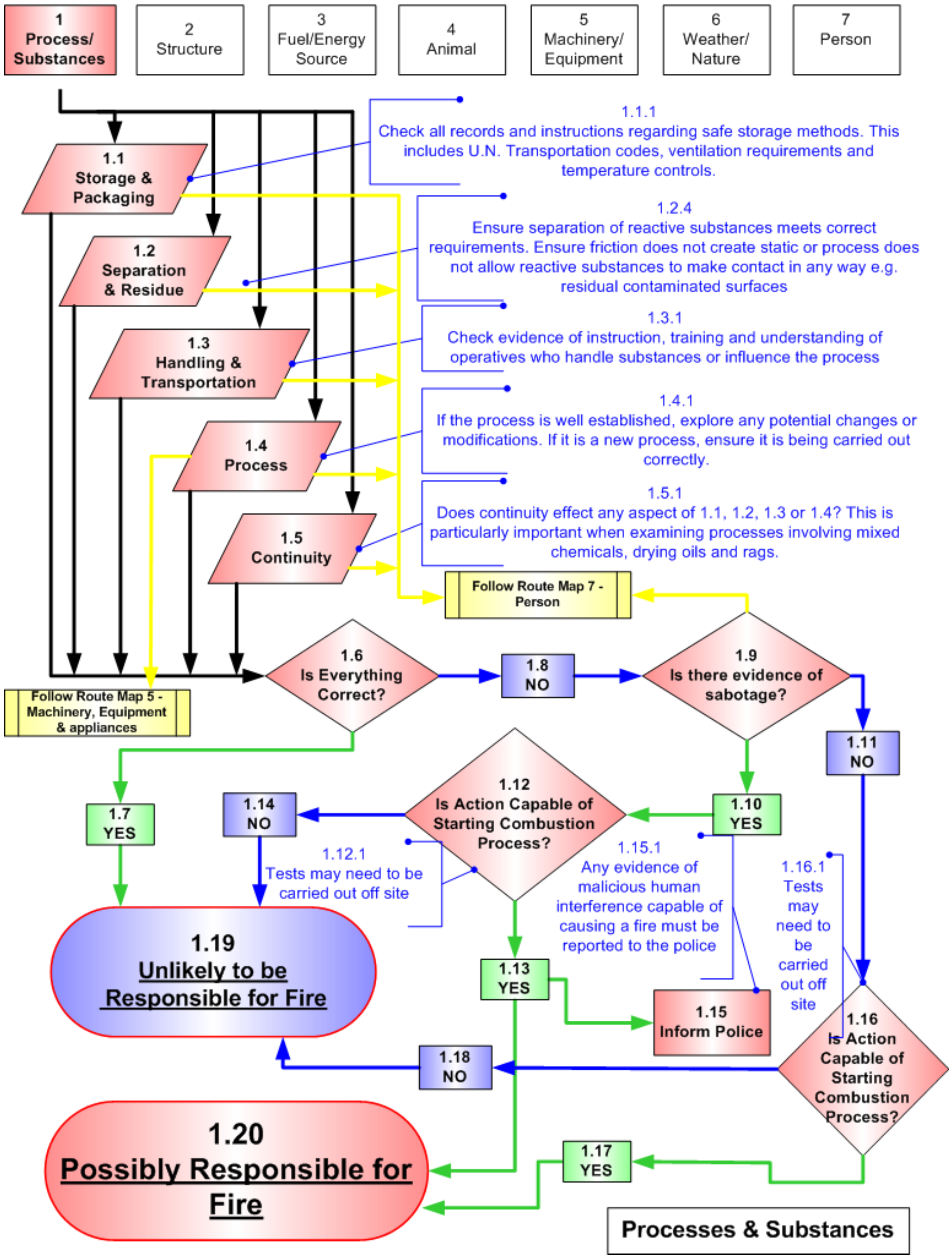
Chapter 4

Fire Investigation Road Maps (FIRMs) Non-human agency

The Fire Investigation Road Maps (FIRMs) within this chapter address the non-human agency element of fires as outlined in Chapter Three. The layout of the FIRMs is given here, but the necessary material to aid decision making, with the detailed instructions on how to use the FIRMs, can be found in Volume 2.

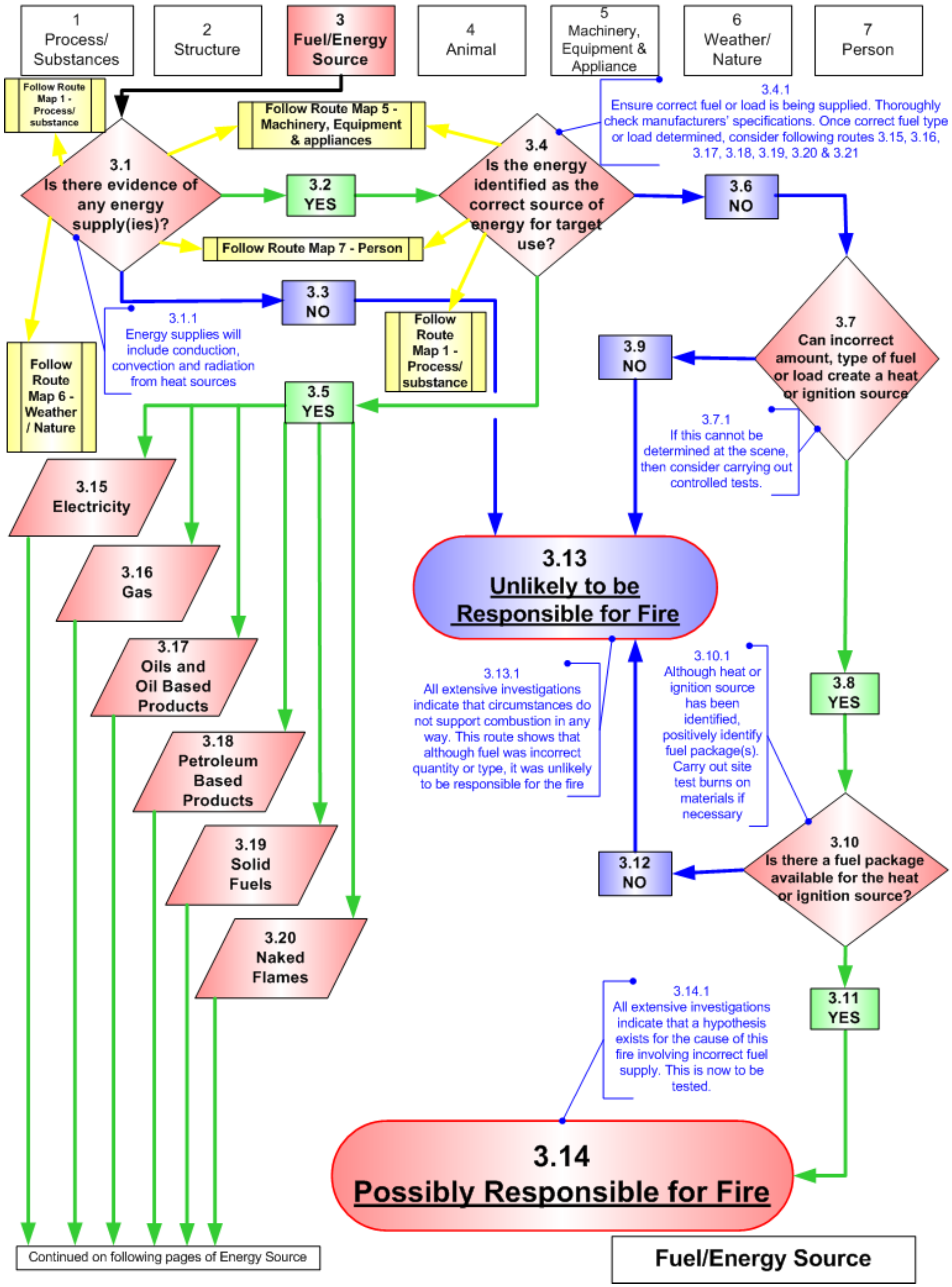
FIRM #1 **Process/Substances**	Fire Investigation Road Map - Page 87 Supporting Guidance – Volume Two
FIRM #2 **Structures**	Fire Investigation Road Map - Page 88 Supporting Guidance – Volume Two
FIRM #3 **Fuel/Energy Source**	Fire Investigation Road Map - Page 89 Supporting Guidance – Volume Two
FIRM #3.15 **Electricity**	Fire Investigation Road Map - Page 90 Supporting Guidance – Volume Two
FIRM #3.16 **Gas**	Fire Investigation Road Map - Page 91 Supporting Guidance – Volume Two
FIRM #3.17 **Oil**	Fire Investigation Road Map - Page 92 Supporting Guidance – Volume Two
FIRM #3.18 **Petrol/Diesel**	Fire Investigation Road Map - Page 93 Supporting Guidance – Volume Two
FIRM #3.19 **Solid Fuels**	Fire Investigation Road Map - Page 94 Supporting Guidance – Volume Two
FIRM #3.20 **Naked Flame**	Fire Investigation Road Map - Page 95 Supporting Guidance – Volume Two
FIRM #4 **Animal**	Fire Investigation Road Map - Page 96 Supporting Guidance – Volume Two
FIRM #5 **Machinery/Equipment /Appliances**	Fire Investigation Road Map - Page 97 Supporting Guidance – Volume Two
FIRM #6 **Weather/Nature**	Fire Investigation Road Map - Page 98 Supporting Guidance – Volume Two

Table 4.1 Fire Investigation Road Map (FIRM) Index

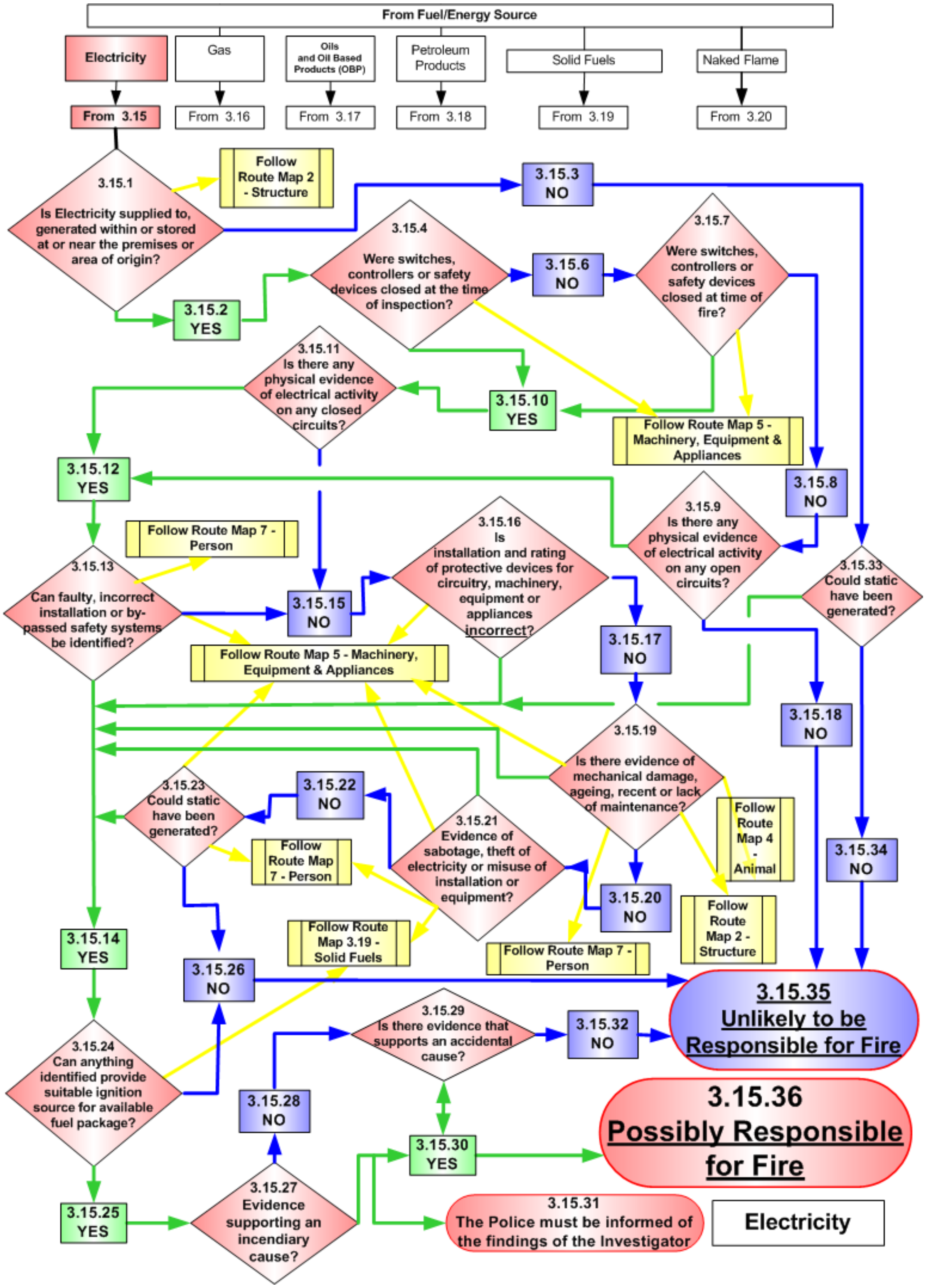


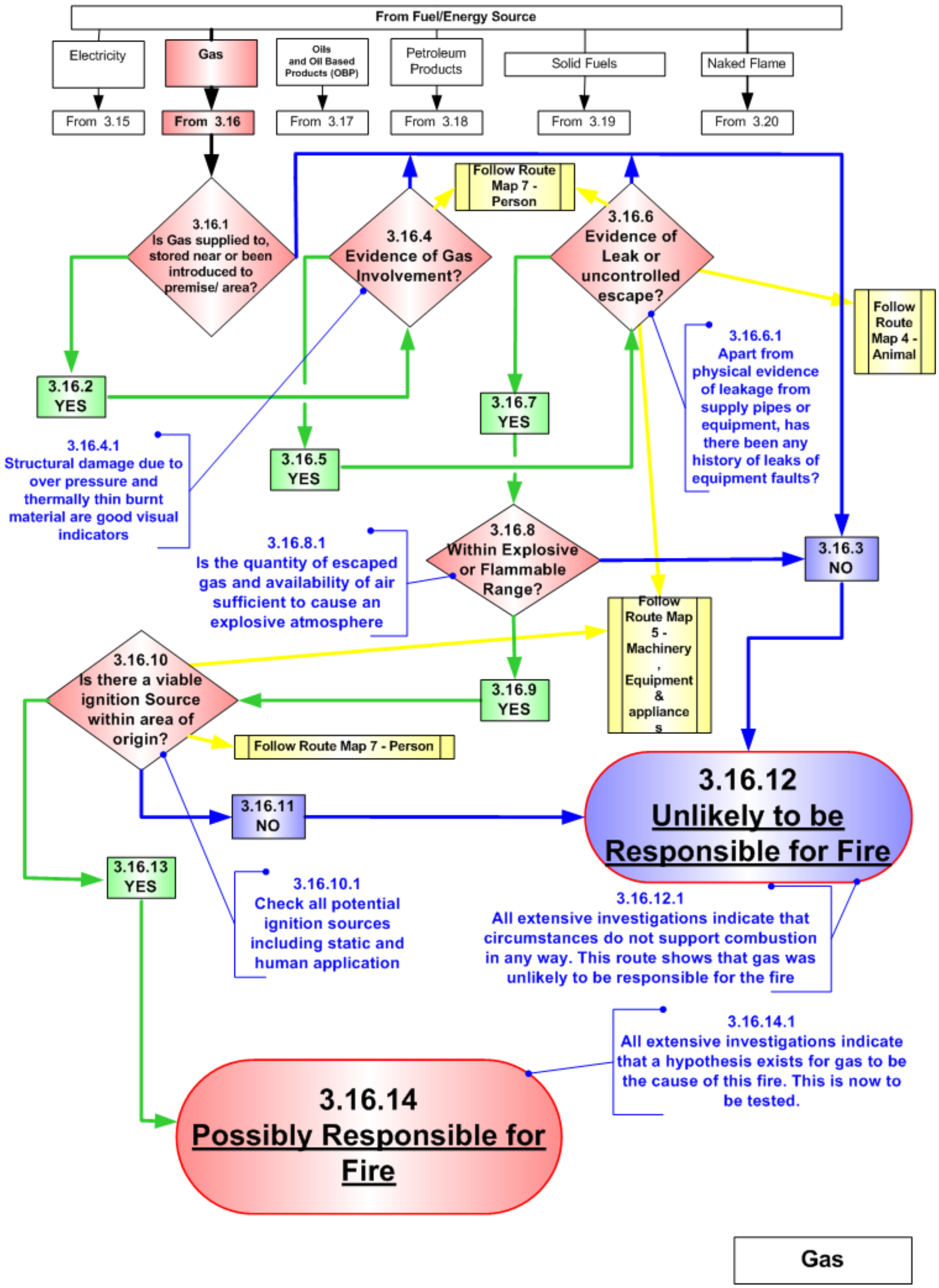
1 Process/ Substances
2 Structure
3 Fuel/Energy Source
4 Animal
5 Machinery/ Equipment
6 Weather/ Nature
7 Person
1.1 Storage & Packaging
1.1.1 Check all records and instructions regarding safe storage methods. This includes U.N. Transportation codes, ventilation requirements and temperature controls.
1.2 Separation & Residue
1.2.4 Ensure separation of reactive substances meets correct requirements. Ensure friction does not create static or process does not allow reactive substances to make contact in any way e.g. residual contaminated surfaces
1.3 Handling & Transportation
1.3.1 Check evidence of instruction, training and understanding of operatives who handle substances or influence the process
1.4 Process
1.4.1 If the process is well established, explore any potential changes or modifications. If it is a new process, ensure it is being carried out correctly.
1.5 Continuity
1.5.1 Does continuity effect any aspect of 1.1, 1.2, 1.3 or 1.4? This is particularly important when examining processes involving mixed chemicals, drying oils and rags.
Follow Route Map 7 - Person
Follow Route Map 5 - Machinery, Equipment & appliances
1.6 Is Everything Correct?
1.8 NO
1.9 Is there evidence of sabotage?
1.11 NO
1.7 YES
1.14 NO
1.12 Is Action Capable of Starting Combustion Process?
1.10 YES
1.12.1 Tests may need to be carried out off site
1.15.1 Any evidence of malicious human interference capable of causing a fire must be reported to the police
1.16.1 Tests may need to be carried out off site
1.19 Unlikely to be Responsible for Fire
1.13 YES
1.15 Inform Police
1.16 Is Action Capable of Starting Combustion Process?
1.18 NO
1.20 Possibly Responsible for Fire
1.17 YES
Processes & Substances

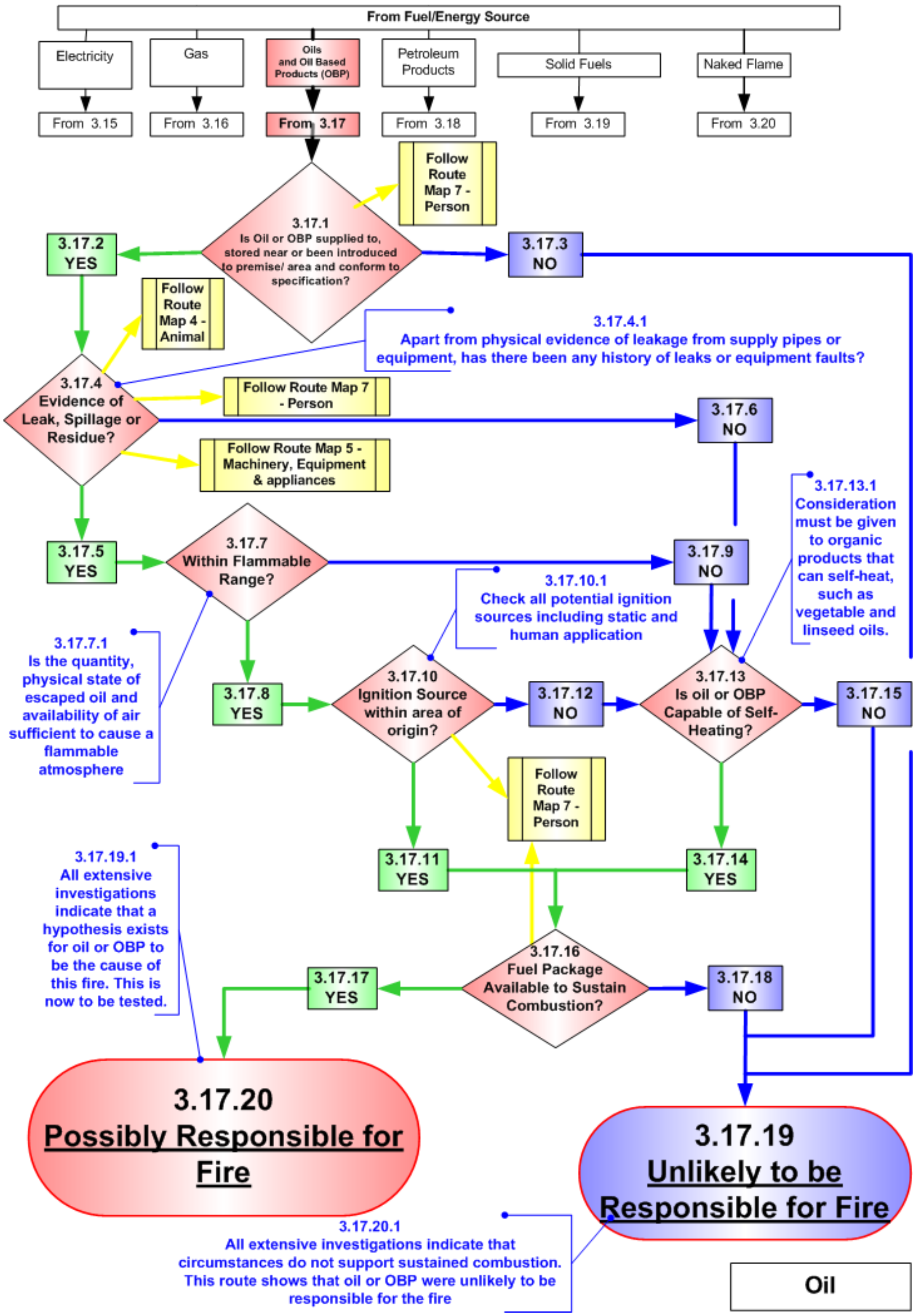
1 Process/ Substances
2 Structures
3 Fuel/Energy Source
4 Animal
5 Machinery/ Equipment & Appliances
6 Weather/ Nature
7 Person
2.5 Is there evidence of this action damaging supply pipes, conductors or creating a heat source?
Follow Route Map 3 - Energy Supply
Follow Route Map 6 - Weather/ Nature
2.1 Does any part of the structure or framework move against energy supply pipes or conductors (or Vice Versa) or create friction?
2.1.2 Building Regulation and/or Fire Prevention Systems should be explored
2.3 YES
2.1.1 This can range from minute movement caused by winds to structural collapse
2.5.1 Have these been chaffed, fractured or loosened allowing energy supply to leak or discharge
2.4 NO
2.8.2 Approved Design layouts and materials used needs to be considered
Follow Route Map 5 - Machinery, Equipment & appliances
Follow Route Map 1 - Process/ Substances
Follow Route Map 3.14 - Energy Supply
2.2 Is there evidence of structural damage, failures, no fire resistance, or failure to supply cooling or ventilation? Are plans, building regulation approvals, schematics, etc. available for inspection?
2.8.1 A controlled fire or heat process may not be adequately separated from combustible components
2.8 Has the structure allowed for convection, conduction or radiation of heat onto a fuel source?
Follow Route Map 6 - Weather/ Nature
2.14.1 A check of unaffected areas should be carried out
2.10 NO
2.11 Can the actions identified in 2.2, 2.5, 2.8 or 2.14 promote the combustion process
2.6 YES
2.9 YES
2.2.1 Building Regulation Approval and/ or Fire Prevention Systems should be explored, including sprinklers
2.14 Is housekeeping undesirable or is there evidence of hoarding?
2.13 NO
2.7 NO
2.19 Possibly Responsible for Fire or Fire Spread
2.12 YES
2.16 NO
2.15 YES
2.18 Unlikely to be Responsible for Fire
2.17 Follow Route Maps 1, 3, 4, 5, 6 & 7
Structure

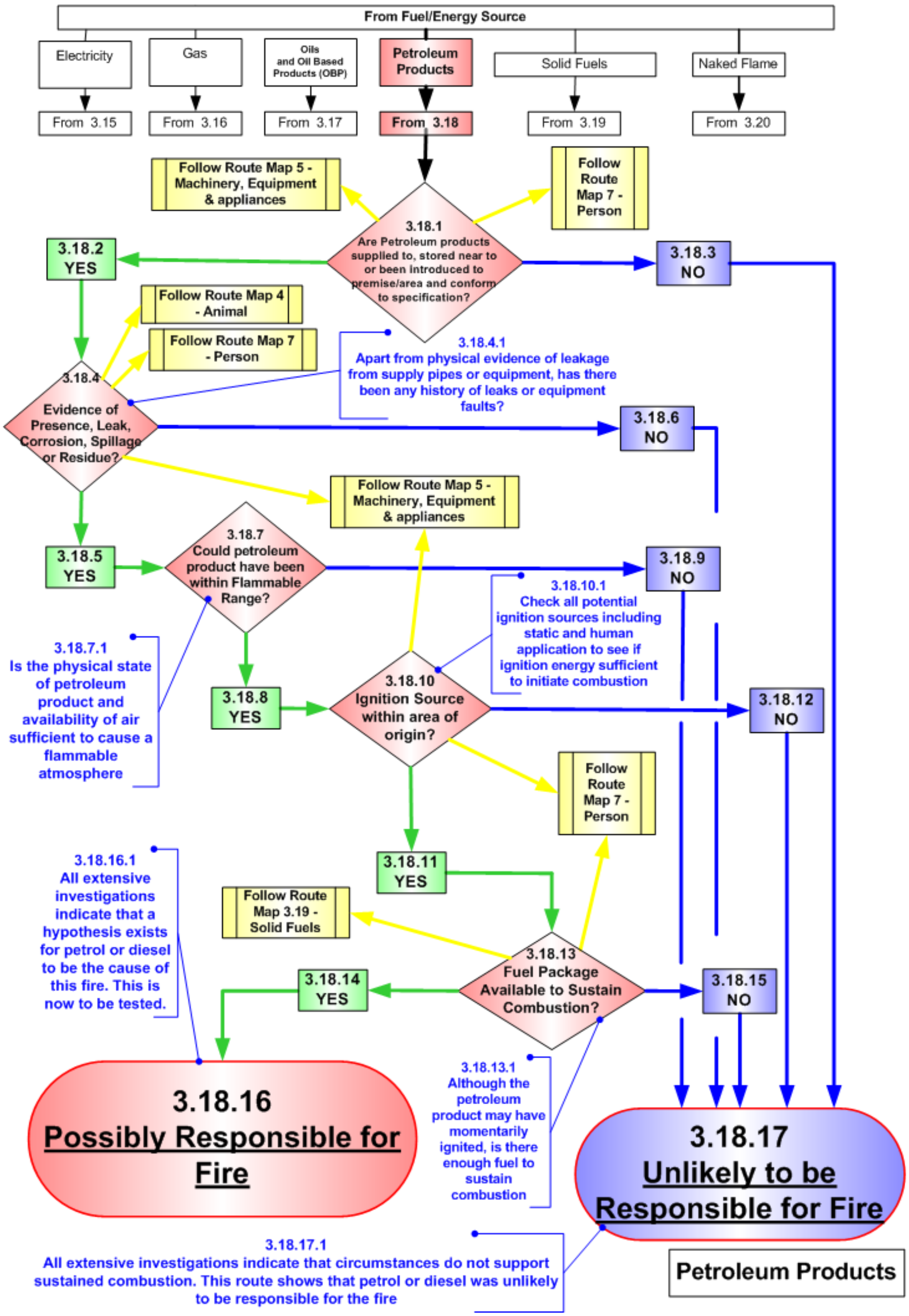


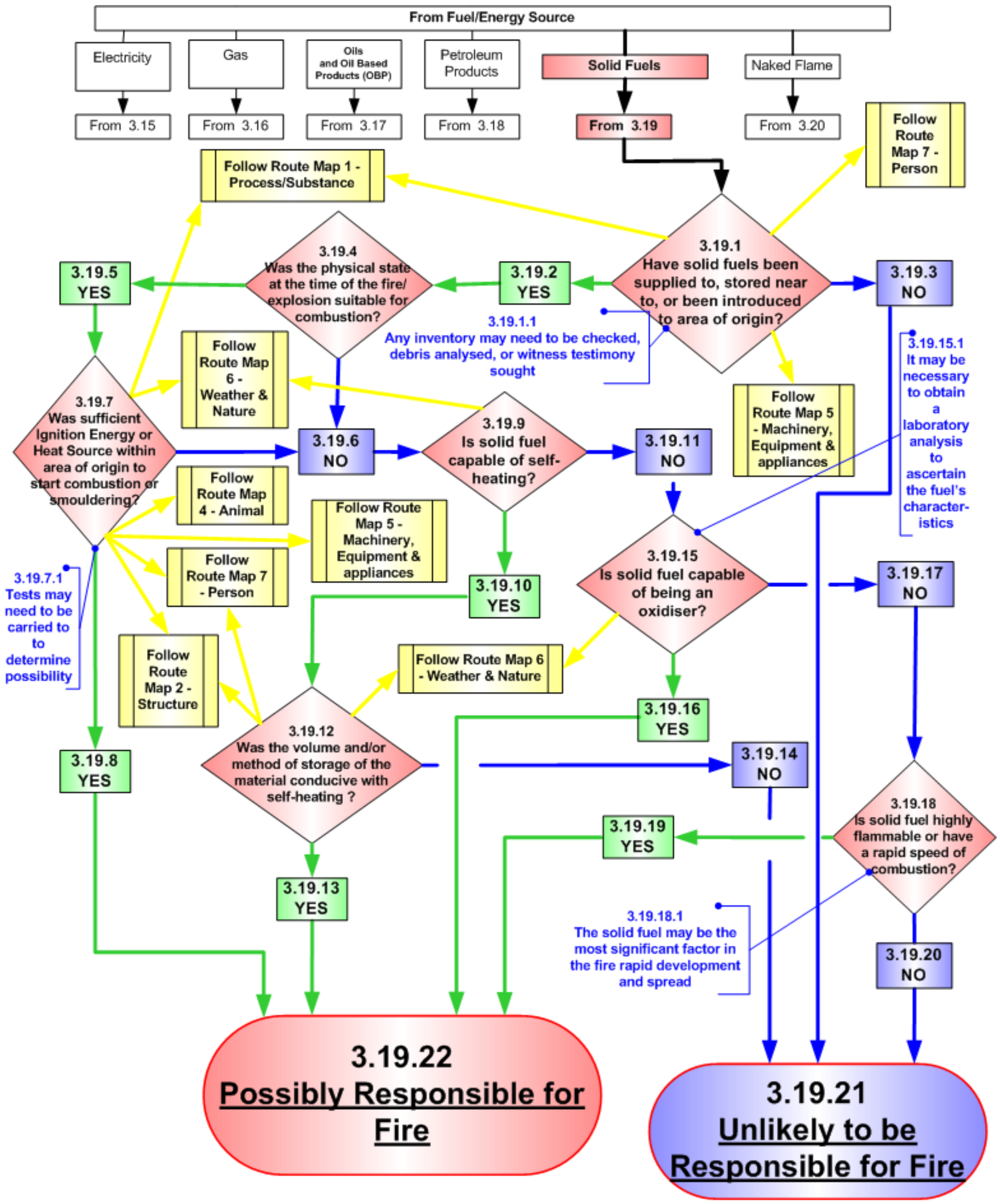
1 Process/ Substances
2 Structure
3 Fuel/Energy Source
4 Animal
5 Machinery, Equipment & Appliance
6 Weather/ Nature
7 Person
Follow Route Map 1 - Process/ substance
Follow Route Map 5 - Machinery, Equipment & appliances
3.4.1 Ensure correct fuel or load is being supplied. Thoroughly check manufacturers' specifications. Once correct fuel type or load determined, consider following routes 3.15, 3.16, 3.17, 3.18, 3.19, 3.20 & 3.21
3.1 Is there evidence of any energy supply(ies)?
3.2 YES
3.4 Is the energy identified as the correct source of energy for target use?
3.6 NO
Follow Route Map 7 - Person
3.3 NO
3.1.1 Energy supplies will include conduction, convection and radiation from heat sources
Follow Route Map 1 - Process/ substance
Follow Route Map 6 - Weather / Nature
3.5 YES
3.7 Can incorrect amount, type of fuel or load create a heat or ignition source
3.9 NO
3.7.1 If this cannot be determined at the scene, then consider carrying out controlled tests.
3.15 Electricity
3.16 Gas
3.17 Oils and Oil Based Products
3.18 Petroleum Based Products
3.19 Solid Fuels
3.20 Naked Flames
3.13 Unlikely to be Responsible for Fire
3.13.1 All extensive investigations indicate that circumstances do not support combustion in any way. This route shows that although fuel was incorrect quantity or type, it was unlikely to be responsible for the fire
3.10.1 Although heat or ignition source has been identified, positively identify fuel package(s). Carry out site test burns on materials if necessary
3.8 YES
3.10 Is there a fuel package available for the heat or ignition source?
3.12 NO
3.11 YES
3.14.1 All extensive investigations indicate that a hypothesis exists for the cause of this fire involving incorrect fuel supply. This is now to be tested.
3.14 Possibly Responsible for Fire
Continued on following pages of Energy Source
Fuel/Energy Source


From Fuel/Energy Source
Electricity
Gas
Oils and Oil Based Products (OBP)
Petroleum Products
Solid Fuels
Naked Flame
From 3.15
From 3.16
From 3.17
From 3.18
From 3.19
From 3.20
3.15.1 Is Electricity supplied to, generated within or stored at or near the premises or area of origin?
Follow Route Map 2 - Structure
3.15.3 NO
3.15.2 YES
3.15.4 Were switches, controllers or safety devices closed at the time of inspection?
3.15.6 NO
3.15.7 Were switches, controllers or safety devices closed at time of fire?
3.15.11 Is there any physical evidence of electrical activity on any closed circuits?
3.15.10 YES
Follow Route Map 5 - Machinery, Equipment & Appliances
3.15.12 YES
3.15.8 NO
Follow Route Map 7 - Person
3.15.16 Is installation and rating of protective devices for circuitry, machinery, equipment or appliances incorrect?
3.15.9 Is there any physical evidence of electrical activity on any open circuits?
3.15.33 Could static have been generated?
3.15.13 Can faulty, incorrect installation or by-passed safety systems be identified?
3.15.15 NO
Follow Route Map 5 - Machinery, Equipment & Appliances
3.15.17 NO
3.15.18 NO
3.15.19 Is there evidence of mechanical damage, ageing, recent or lack of maintenance?
3.15.23 Could static have been generated?
3.15.22 NO
Follow Route Map 7 - Person
3.15.21 Evidence of sabotage, theft of electricity or misuse of installation or equipment?
Follow Route Map 4 - Animal
3.15.34 NO
3.15.20 NO
Follow Route Map 2 - Structure
3.15.14 YES
Follow Route Map 3.19 - Solid Fuels
Follow Route Map 7 - Person
3.15.26 NO
3.15.35 Unlikely to be Responsible for Fire
3.15.29 Is there evidence that supports an accidental cause?
3.15.32 NO
3.15.24 Can anything identified provide suitable ignition source for available fuel package?
3.15.28 NO
3.15.36 Possibly Responsible for Fire
3.15.30 YES
3.15.27 Evidence supporting an incendiary cause?
3.15.25 YES
3.15.31 The Police must be informed of the findings of the Investigator
Electricity

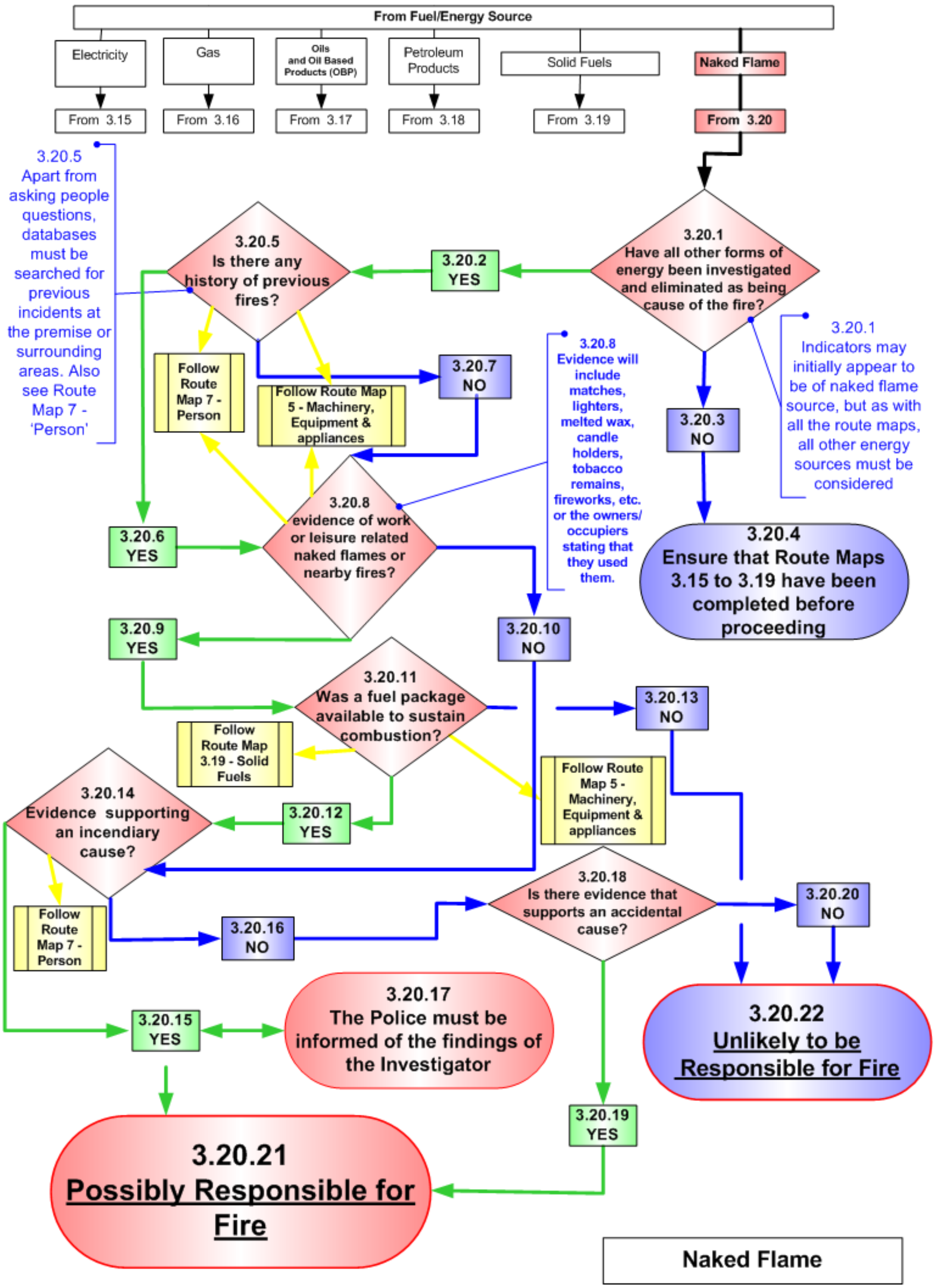

From Fuel/Energy Source
Electricity
Gas
Oils and Oil Based Products (OBP)
Petroleum Products
Solid Fuels
Naked Flame
From 3.15
From 3.16
From 3.17
From 3.18
From 3.19
From 3.20
3.16.1 Is Gas supplied to, stored near or been introduced to premise/ area?
3.16.4 Evidence of Gas Involvement?
Follow Route Map 7 - Person
3.16.6 Evidence of Leak or uncontrolled escape?
Follow Route Map 4 - Animal
3.16.2 YES
3.16.6.1 Apart from physical evidence of leakage from supply pipes or equipment, has there been any history of leaks of equipment faults?
3.16.7 YES
3.16.5 YES
3.16.4.1 Structural damage due to over pressure and thermally thin burnt material are good visual indicators
3.16.8.1 Is the quantity of escaped gas and availability of air sufficient to cause an explosive atmosphere
3.16.8 Within Explosive or Flammable Range?
3.16.3 NO
Follow Route Map 5 - Machinery, Equipment & appliances
3.16.10 Is there a viable ignition Source within area of origin?
3.16.9 YES
Follow Route Map 7 - Person
3.16.12 Unlikely to be Responsible for Fire
3.16.11 NO
3.16.13 YES
3.16.10.1 Check all potential ignition sources including static and human application
3.16.12.1 All extensive investigations indicate that circumstances do not support combustion in any way. This route shows that gas was unlikely to be responsible for the fire
3.16.14.1 All extensive investigations indicate that a hypothesis exists for gas to be the cause of this fire. This is now to be tested.
3.16.14 Possibly Responsible for Fire
Gas


From Fuel/Energy Source
Electricity
Gas
Oils and Oil Based Products (OBP)
Petroleum Products
Solid Fuels
Naked Flame
From 3.15
From 3.16
From 3.17
From 3.18
From 3.19
From 3.20
Follow Route Map 7 - Person
3.17.1 Is Oil or OBP supplied to, stored near or been introduced to premise/ area and conform to specification?
3.17.2 YES
3.17.3 NO
Follow Route Map 4 - Animal
3.17.4.1 Apart from physical evidence of leakage from supply pipes or equipment, has there been any history of leaks or equipment faults?
3.17.4 Evidence of Leak, Spillage or Residue?
Follow Route Map 7 - Person
3.17.6 NO
Follow Route Map 5 - Machinery, Equipment & appliances
3.17.13.1 Consideration must be given to organic products that can self-heat, such as vegetable and linseed oils.
3.17.5 YES
3.17.7 Within Flammable Range?
3.17.9 NO
3.17.10.1 Check all potential ignition sources including static and human application
3.17.7.1 Is the quantity, physical state of escaped oil and availability of air sufficient to cause a flammable atmosphere
3.17.8 YES
3.17.10 Ignition Source within area of origin?
3.17.12 NO
3.17.13 Is oil or OBP Capable of Self-Heating?
3.17.15 NO
Follow Route Map 7 - Person
3.17.11 YES
3.17.14 YES
3.17.19.1 All extensive investigations indicate that a hypothesis exists for oil or OBP to be the cause of this fire. This is now to be tested.
3.17.17 YES
3.17.16 Fuel Package Available to Sustain Combustion?
3.17.18 NO
3.17.20 Possibly Responsible for Fire
3.17.19 Unlikely to be Responsible for Fire
3.17.20.1 All extensive investigations indicate that circumstances do not support sustained combustion. This route shows that oil or OBP were unlikely to be responsible for the fire
Oil

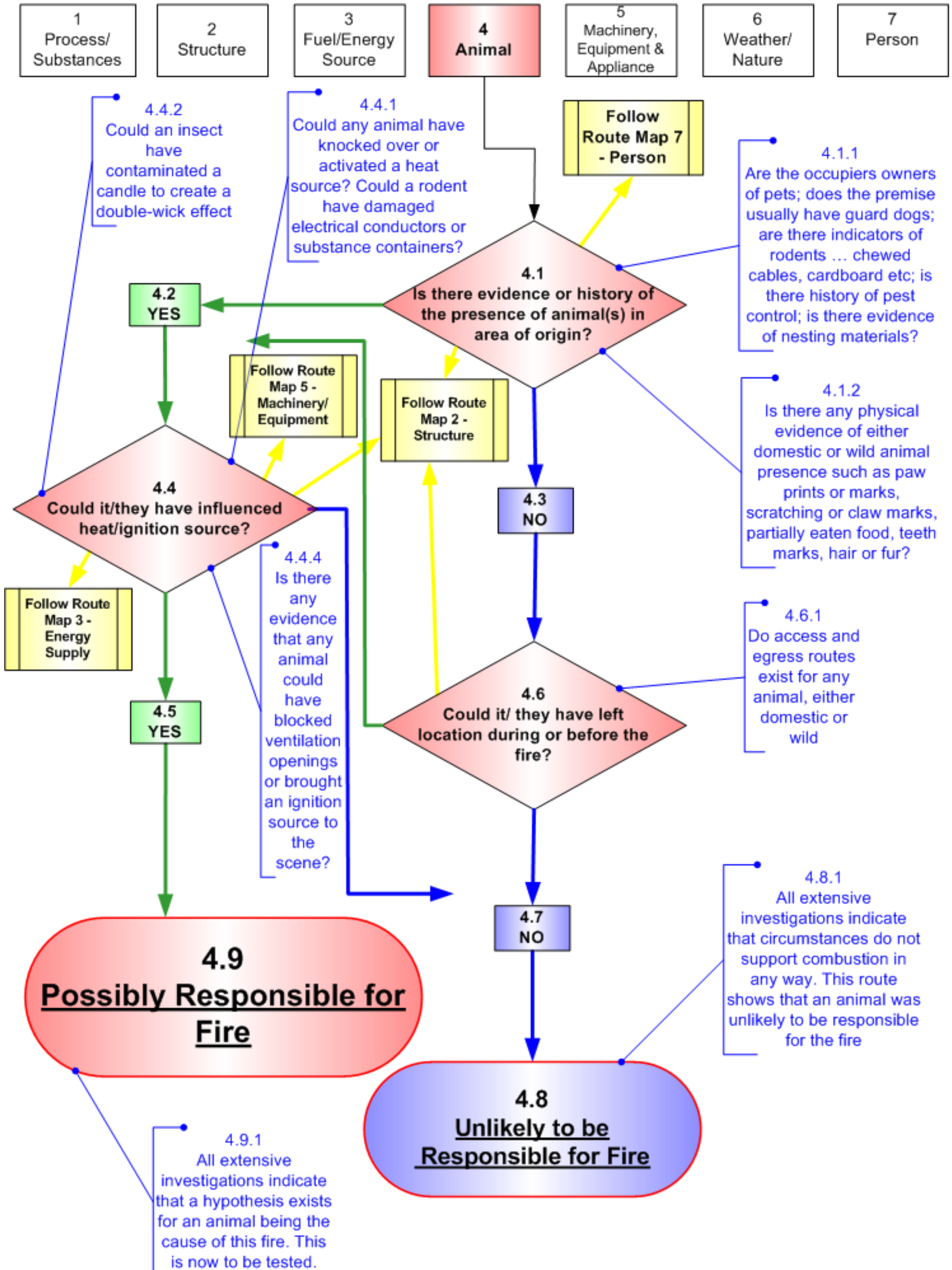

From Fuel/Energy Source
Electricity
Gas
Oils and Oil Based Products (OBP)
Petroleum Products
Solid Fuels
Naked Flame
From 3.15
From 3.16
From 3.17
From 3.18
From 3.19
From 3.20
Follow Route Map 5 - Machinery, Equipment & appliances
Follow Route Map 7 - Person
3.18.1 Are Petroleum products supplied to, stored near to or been introduced to premise/area and conform to specification?
3.18.2 YES
3.18.3 NO
Follow Route Map 4 - Animal
Follow Route Map 7 - Person
3.18.4.1 Apart from physical evidence of leakage from supply pipes or equipment, has there been any history of leaks or equipment faults?
3.18.4 Evidence of Presence, Leak, Corrosion, Spillage or Residue?
3.18.6 NO
Follow Route Map 5 - Machinery, Equipment & appliances
3.18.5 YES
3.18.7 Could petroleum product have been within Flammable Range?
3.18.9 NO
3.18.10.1 Check all potential ignition sources including static and human application to see if ignition energy sufficient to initiate combustion
3.18.7.1 Is the physical state of petroleum product and availability of air sufficient to cause a flammable atmosphere
3.18.8 YES
3.18.10 Ignition Source within area of origin?
3.18.12 NO
Follow Route Map 7 - Person
3.18.16.1 All extensive investigations indicate that a hypothesis exists for petrol or diesel to be the cause of this fire. This is now to be tested.
3.18.11 YES
Follow Route Map 3.19 - Solid Fuels
3.18.14 YES
3.18.13 Fuel Package Available to Sustain Combustion?
3.18.15 NO
3.18.13.1 Although the petroleum product may have momentarily ignited, is there enough fuel to sustain combustion
3.18.16 Possibly Responsible for Fire
3.18.17 Unlikely to be Responsible for Fire
3.18.17.1 All extensive investigations indicate that circumstances do not support sustained combustion. This route shows that petrol or diesel was unlikely to be responsible for the fire
Petroleum Products


From Fuel/Energy Source
Electricity
Gas
Oils and Oil Based Products (OBP)
Petroleum Products
Solid Fuels
Naked Flame
From 3.15
From 3.16
From 3.17
From 3.18
From 3.19
From 3.20
Follow Route Map 7 - Person
Follow Route Map 1 - Process/Substance
3.19.1 Have solid fuels been supplied to, stored near to, or been introduced to area of origin?
3.19.1.1 Any inventory may need to be checked, debris analysed, or witness testimony sought
3.19.2 YES
3.19.3 NO
3.19.4 Was the physical state at the time of the fire/ explosion suitable for combustion?
3.19.5 YES
3.19.6 NO
3.19.7 Was sufficient Ignition Energy or Heat Source within area of origin to start combustion or smouldering?
3.19.7.1 Tests may need to be carried to to determine possibility
Follow Route Map 6 - Weather & Nature
Follow Route Map 4 - Animal
Follow Route Map 5 - Machinery, Equipment & appliances
Follow Route Map 7 - Person
Follow Route Map 2 - Structure
3.19.8 YES
3.19.9 Is solid fuel capable of self-heating?
3.19.10 YES
3.19.11 NO
Follow Route Map 5 - Machinery, Equipment & appliances
3.19.15.1 It may be necessary to obtain a laboratory analysis to ascertain the fuel's character-istics
3.19.15 Is solid fuel capable of being an oxidiser?
3.19.16 YES
3.19.17 NO
Follow Route Map 6 - Weather & Nature
3.19.12 Was the volume and/or method of storage of the material conducive with self-heating ?
3.19.13 YES
3.19.14 NO
3.19.18 Is solid fuel highly flammable or have a rapid speed of combustion?
3.19.18.1 The solid fuel may be the most significant factor in the fire rapid development and spread
3.19.19 YES
3.19.20 NO
3.19.22 Possibly Responsible for Fire
3.19.21 Unlikely to be Responsible for Fire

Solid Fuels

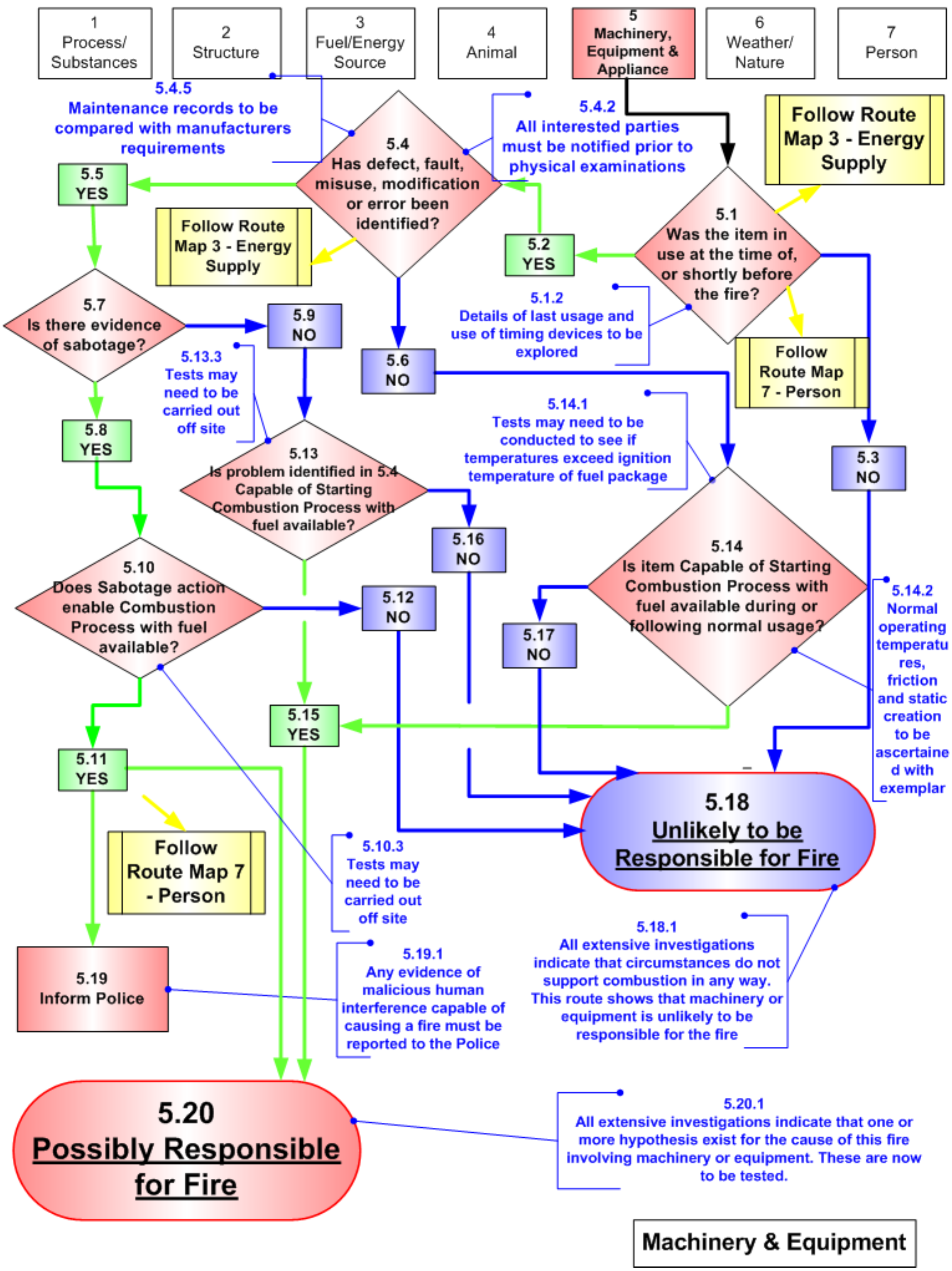


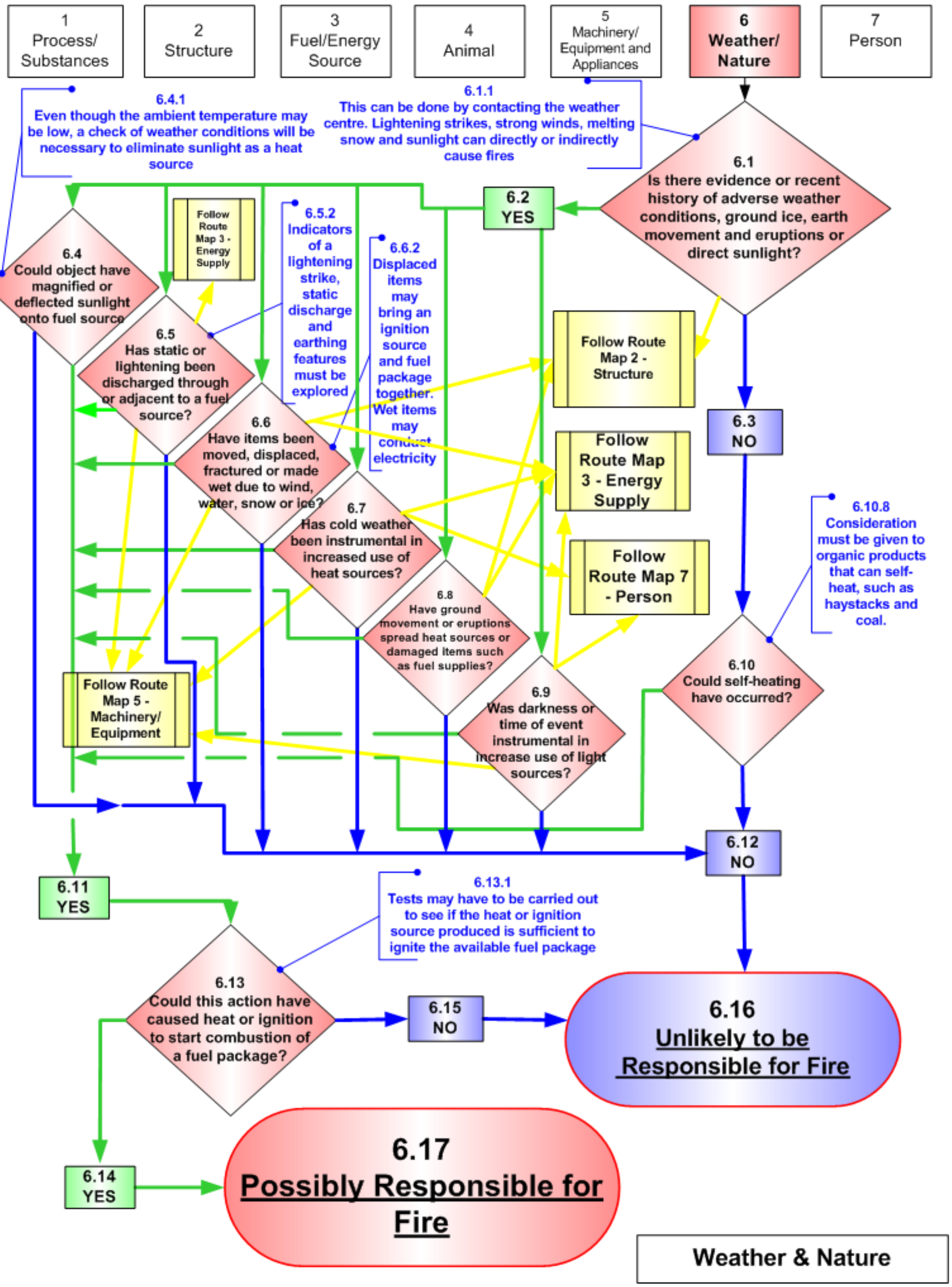
From Fuel/Energy Source
Electricity
Gas
Oils and Oil Based Products (OBP)
Petroleum Products
Solid Fuels
Naked Flame
From 3.15
From 3.16
From 3.17
From 3.18
From 3.19
From 3.20
3.20.1 Have all other forms of energy been investigated and eliminated as being cause of the fire?
3.20.2 YES
3.20.3 NO
3.20.1 Indicators may initially appear to be of naked flame source, but as with all the route maps, all other energy sources must be considered
3.20.4 Ensure that Route Maps 3.15 to 3.19 have been completed before proceeding
3.20.5 Apart from asking people questions, databases must be searched for previous incidents at the premise or surrounding areas. Also see Route Map 7 - 'Person'
3.20.5 Is there any history of previous fires?
Follow Route Map 7 - Person
Follow Route Map 5 - Machinery, Equipment & appliances
3.20.7 NO
3.20.6 YES
3.20.8 evidence of work or leisure related naked flames or nearby fires?
3.20.8 Evidence will include matches, lighters, melted wax, candle holders, tobacco remains, fireworks, etc. or the owners/ occupiers stating that they used them.
3.20.9 YES
3.20.10 NO
3.20.11 Was a fuel package available to sustain combustion?
Follow Route Map 3.19 - Solid Fuels
3.20.13 NO
Follow Route Map 5 - Machinery, Equipment & appliances
3.20.12 YES
3.20.14 Evidence supporting an incendiary cause?
Follow Route Map 7 - Person
3.20.16 NO
3.20.18 Is there evidence that supports an accidental cause?
3.20.20 NO
3.20.15 YES
3.20.17 The Police must be informed of the findings of the Investigator
3.20.22 Unlikely to be Responsible for Fire
3.20.19 YES
3.20.21 Possibly Responsible for Fire
Naked Flame



1 Process/ Substances
2 Structure
3 Fuel/Energy Source
4 Animal
5 Machinery, Equipment & Appliance
6 Weather/ Nature
7 Person
4.4.2 Could an insect have contaminated a candle to create a double-wick effect
4.4.1 Could any animal have knocked over or activated a heat source? Could a rodent have damaged electrical conductors or substance containers?
Follow Route Map 7 - Person
4.1.1 Are the occupiers owners of pets; does the premise usually have guard dogs; are there indicators of rodents … chewed cables, cardboard etc; is there history of pest control; is there evidence of nesting materials?
4.1 Is there evidence or history of the presence of animal(s) in area of origin?
4.2 YES
Follow Route Map 5 - Machinery/ Equipment
Follow Route Map 2 - Structure
4.1.2 Is there any physical evidence of either domestic or wild animal presence such as paw prints or marks, scratching or claw marks, partially eaten food, teeth marks, hair or fur?
4.3 NO
4.4 Could it/they have influenced heat/ignition source?
4.4.4 Is there any evidence that any animal could have blocked ventilation openings or brought an ignition source to the scene?
Follow Route Map 3 - Energy Supply
4.6.1 Do access and egress routes exist for any animal, either domestic or wild
4.6 Could it/ they have left location during or before the fire?
4.5 YES
4.8.1 All extensive investigations indicate that circumstances do not support combustion in any way. This route shows that an animal was unlikely to be responsible for the fire
4.7 NO
4.9 Possibly Responsible for Fire
4.8 Unlikely to be Responsible for Fire
4.9.1 All extensive investigations indicate that a hypothesis exists for an animal being the cause of this fire. This is now to be tested.

Animal


1 Process/ Substances
2 Structure
3 Fuel/Energy Source
4 Animal
5 Machinery, Equipment & Appliance
6 Weather/ Nature
7 Person
5.4.5 Maintenance records to be compared with manufacturers requirements
5.4 Has defect, fault, misuse, modification or error been identified?
5.4.2 All interested parties must be notified prior to physical examinations
Follow Route Map 3 - Energy Supply
5.5 YES
Follow Route Map 3 - Energy Supply
5.2 YES
5.1 Was the item in use at the time of, or shortly before the fire?
5.1.2 Details of last usage and use of timing devices to be explored
5.7 Is there evidence of sabotage?
5.9 NO
5.6 NO
Follow Route Map 7 - Person
5.13.3 Tests may need to be carried out off site
5.8 YES
5.14.1 Tests may need to be conducted to see if temperatures exceed ignition temperature of fuel package
5.13 Is problem identified in 5.4 Capable of Starting Combustion Process with fuel available?
5.3 NO
5.16 NO
5.10 Does Sabotage action enable Combustion Process with fuel available?
5.12 NO
5.14 Is item Capable of Starting Combustion Process with fuel available during or following normal usage?
5.14.2 Normal operating temperatures, friction and static creation to be ascertained with exemplar
5.17 NO
5.15 YES
5.11 YES
5.18 Unlikely to be Responsible for Fire
Follow Route Map 7 - Person
5.10.3 Tests may need to be carried out off site
5.18.1 All extensive investigations indicate that circumstances do not support combustion in any way. This route shows that machinery or equipment is unlikely to be responsible for the fire
5.19 Inform Police
5.19.1 Any evidence of malicious human interference capable of causing a fire must be reported to the Police
5.20 Possibly Responsible for Fire
5.20.1 All extensive investigations indicate that one or more hypothesis exist for the cause of this fire involving machinery or equipment. These are now to be tested.
Machinery & Equipment



1 Process/ Substances
2 Structure
3 Fuel/Energy Source
4 Animal
5 Machinery/ Equipment and Appliances
6 Weather/ Nature
7 Person
6.4.1 Even though the ambient temperature may be low, a check of weather conditions will be necessary to eliminate sunlight as a heat source
6.1.1 This can be done by contacting the weather centre. Lightening strikes, strong winds, melting snow and sunlight can directly or indirectly cause fires
6.1 Is there evidence or recent history of adverse weather conditions, ground ice, earth movement and eruptions or direct sunlight?
6.2 YES
6.3 NO
6.4 Could object have magnified or deflected sunlight onto fuel source
Follow Route Map 3 - Energy Supply
6.5.2 Indicators of a lightening strike, static discharge and earthing features must be explored
6.6.2 Displaced items may bring an ignition source and fuel package together. Wet items may conduct electricity
6.5 Has static or lightening been discharged through or adjacent to a fuel source?
6.6 Have items been moved, displaced, fractured or made wet due to wind, water, snow or ice?
6.7 Has cold weather been instrumental in increased use of heat sources?
6.8 Have ground movement or eruptions spread heat sources or damaged items such as fuel supplies?
6.9 Was darkness or time of event instrumental in increase use of light sources?
Follow Route Map 2 - Structure
Follow Route Map 3 - Energy Supply
Follow Route Map 7 - Person
Follow Route Map 5 - Machinery/ Equipment
6.10.8 Consideration must be given to organic products that can self-heat, such as haystacks and coal.
6.10 Could self-heating have occurred?
6.12 NO
6.11 YES
6.13.1 Tests may have to be carried out to see if the heat or ignition source produced is sufficient to ignite the available fuel package
6.13 Could this action have caused heat or ignition to start combustion of a fuel package?
6.15 NO
6.16 Unlikely to be Responsible for Fire
6.14 YES
6.17 Possibly Responsible for Fire
Weather & Nature

Chapter 5
Example applications of the use of Fire Investigation Road Maps (Non-Human Agency)

Retrospective and current applications of the Fire Investigation Road Maps are given in the examples below. Sections 5.1 and 5.2 are cases that were investigated prior to the commencement of this research, i.e. cold case reviews; Sections 5.3 and 5.4 are cases where the road maps have been actively applied.

5.1 Fatal fire in sheltered accommodation housing

At 20:39hrs on the 17th May 2003, a call was received by Mobilising Control to a smell of smoke at an elderly persons' sheltered accommodation flat in North London. The police were called to the scene by the victim's nephew who could not get a response from his aunt within her flat. As the police officers tried to gain entry, they could smell smoke within and subsequently called the fire brigade. When the fire officers gained entry to the flat, the aunt was found in her bedroom and pronounced dead at the scene. There was evidence of a small fire beside her bed and a burn mark following the route of a plastic tube leading to an oxygen concentrating machine in the hallway, which was still running. She was partially clothed and the bathroom basin hot tap was left running with indications of her washing at the basin. A mop bucket was found in the room of the fire with the victim and the kitchen cold tap was also left running. She was a known smoker with emphysema.

(a) Considering all of the Fire Investigation Road Maps, it was retrospectively decided that the following road maps were <u>not</u> applicable to this incident:

FIRM #3.17: 'Oil'; as the property was not supplied with oil nor were there any storage containers in or near the premises.

FIRM #3.18: 'Petrol/Diesel'; as the property was not supplied with petrol/diesel nor were there any containers in or near the premises.

FIRM #4: ‘Animals’; as there were no pets kept within the premises, no evidence of vermin infestation nor opportunity for any animal to enter or leave the premises as it was secure.
FIRM #6: ‘Weather/Nature’; as recent weather conditions and property layout could not have allowed concentrated sunlight and no lightning activity had recently occurred. There was also no evidence of any self-heating materials.

(b) It was therefore retrospectively decided that the following road maps could apply to this fire investigation and that these would be followed to test the accuracy of the earlier investigation:
FIRM #1: ‘Processes and Substances’; as there was evidence of a substance, oxygen enriched air, within the premises.
FIRM #2: ‘Structures’; to determine whether any aspect of the structure was responsible for the fire.
FIRM #3.15: ‘Electricity’; as there was electricity supplied to the building and many electrical items were within the flat.
FIRM #3.16: ‘Gas’; as the property had an oxygen concentrator within it, although it was not supplied by mains gas nor were there any cylinders in or near the premises.
FIRM #3.19: ‘Solid Fuels’; as there were plenty of furniture, furnishings and other combustible materials within the flat.
FIRM #3.20: ‘Naked Flame’; as evidence of smoking and the use of matches was available within the flat.
FIRM #5: ‘Machinery/Equipment/Appliances’; as there were many such items within the flat.

(c) The latter road maps were followed accordingly:
i) FIRM #1: Processes and substances; by following [1.1] to [1.5] it was demonstrated that although the oxygen concentrator was working correctly at the time of the fire, separation [1.2] between the enriched oxygen and an ignition source (see FIRM #3.19.7 below) was not sufficient. Substances can ignite at lower temperatures in enhanced oxygen atmospheres, therefore [1.8] applied. There was no evidence of

sabotage [1.9], therefore [1.11] applied. The discarded cigarette and smouldering tissues were capable of melting the plastic tubing carrying the oxygen rich air which was then capable of starting the combustion process, therefore [1.17] applied. The conclusion was that the substance (enriched oxygenated atmosphere) was possibly responsible for the cause of the fire.

ii) FIRM #2: Structures; the flat was built on concrete foundations and within a block made of brick with no movement due to wind or ground movement; therefore [2.1] did not apply. There was no evidence of structural damage, fire protection failures or failure to supply cooling or ventilation; therefore [2.2] did not apply. The structure had no influence on convection, conduction or radiation of heat onto a fuel source; therefore [2.8] did not apply. There was no evidence of bad housekeeping or hoarding; therefore [2.14] did not apply. The conclusion is that the structure was unlikely to be responsible for the fire [2.18].

iii) FIRM #3.15: Electricity; there was no physical evidence of electrical activity on any of the closed circuits; therefore [3.15.10] did not apply. The installation, rating of protective devices for the circuitry machinery, equipment and appliances were correct; therefore [3.15.15] did apply, however, there was no evidence of mechanical damage, ageing or lack of maintenance; therefore [3.15.18] did not apply. No evidence of sabotage, theft of electricity or misuse of installation or equipment existed; therefore [3.15.20] did not apply. No mechanism or conditions for creating static were identified; therefore [3.15.22] did not apply. Nothing presented a suitable ignition/ heat source for any available fuel package; therefore [3.15.23] did not apply. The conclusion is that electricity was unlikely to be responsible for the cause of the fire.

iv) FIRM #3.16: Gas; an oxygen concentrator supplied oxygen enriched air (approximately 52% oxygen) through plastic tubing to various outlets (cannulas) around the flat. Remains of tissue paper on top of a section of this tubing, which had started to smoulder and possibly burn, melted the tubing allowing the oxygen enriched air to ignite the paper and subsequently the tubing itself.

v) FIRM #3.19: Solid Fuels; solid fuels (tissue papers) were stored near to the area of origin; therefore [3.19.1] applied. The physical state (of the tissue papers) at the time of the fire was suitable for combustion; therefore [3.19.4] applied. There was evidence of sufficient heat source (smoking materials and matches) within the area of origin for the solid fuels (tissue papers) to start combustion or smouldering; therefore [3.19.7] applied. At this point in the road map, a negative check was made and it was considered whether the solid fuel was capable of self-heating or being an oxidiser, which it was not; therefore [3.19.9] and [3.19.15] did not apply. The solid fuel (tissue papers that were distributed haphazardly around the flat in small piles) are, however, highly flammable and have a rapid speed of combustion; therefore [3.19.18] did apply. The conclusion was that the solid fuels identified were possibly responsible for the fire.

vi) FIRM #3.20: Naked Flame; all other forms of energy have been eliminated as being a cause of the fire; therefore [3.20.1] applied. There was no history of previous fires at the premises; therefore [3.20.5] did not apply. There was evidence of leisure related naked flames (smoking materials); therefore [3.20.8] did apply. There was a fuel package (a loose pile of tissue papers) available to sustain combustion; therefore [3.20.11] did apply. There was no evidence to support an incendiary cause; therefore [3.20.14] did not apply. The conclusion was that either a naked flame or smoking materials were possibly responsible for cause of the fire.

vii) FIRM #5: Machinery, Equipment or Appliances; an electric bedside light was the only item within the area of origin; however an oxygen concentrator was connected to the suspected area of origin by burn patterns; therefore [5.1] applied. No defect, fault, misuse, modification or error had been identified with the bedside light, the oxygen concentrator or any leakages from the concentrator tubing connections; therefore [5.4] did not apply. The light fitting was not capable of starting a combustion process with the available fuel as the fuel was on the floor when the fire commenced and remote from the heat source (light bulb). The oxygen concentrator had no internal fire damage with only the external plastic tubing suffering fire damage. It was concluded that any ignition of the PVC tubing would allow the tubing to burn back towards (Wright, 2003) the concentrator, in the direction of the supply, and not away from it; therefore [5.14] did not apply. The conclusion was that any machinery, equipment or appliances were not responsible for the fire.

(d) The conclusion to the original investigation was that careless disposal of smoking materials by the occupier ignited tissue papers, which in turn melted and subsequently ignited the plastic tubing from the oxygen concentrator due to the oxygen enriched atmosphere. The tubing burned back to the oxygen concentrator machine (Wright, 2003) leaving a burn trail from the area of origin to the machine. By following the road maps retrospectively, the same conclusion was reached, clearly showing why the other road maps did not apply.

5.2 Waitrose Supermarket 20 Pump Fire

At 06:22hrs hrs on the 2nd June 2003 a call was received by the London Fire Brigade Mobilising Control to a fire in the store room of a large supermarket in North London. While the employee was making the call and talking to the fire brigade control officer, the automatic fire alarm operated. A security guard had tried, unsuccessfully, to tackle the fire before the arrival of the brigade. The incident required twenty pumping appliances to extinguish the subsequent blaze

(a) Considering all of the road maps, it was retrospectively decided that the following road maps were <u>not</u> applicable to this incident:

FIRM #3.16: 'Gas;' as gas was not supplied or stored near to the area of origin.

FIRM #3.17: 'Oil;' as oil was not supplied or stored near to the area of origin.

FIRM #3.18: ‘Petrol/Diesel;’ as neither were supplied to, stored near nor found to be near to the area of origin following the use of hydrocarbon detection equipment.

FIRM #4: ‘Animals;’ as there were no pets kept within the premises, no evidence of vermin infestation nor opportunity for any animal to enter or leave the premises, as it was secure.

(b) It was therefore retrospectively decided that the following road maps could apply to this fire investigation and that these would be followed to test the accuracy of the earlier investigation:

FIRM #1: ‘Processes/Substances’; to determine if any of the stored substances were responsible for the fire. (There were no processes within the area of origin, however many substances, some of them inherently hazardous, which were stored on shelving and pallets).

FIRM #2: ‘Structures’; to determine whether any aspect of the structure was responsible for the fire.

FIRM #3.15: ‘Electricity’; electricity was supplied to the building and electrical items were within the area of origin.

FIRM #3.19: ‘Solid Fuels’; as there were plenty of solid fuels within the area of origin in the form of toilet rolls, bar-b-que colas, fire lighters and cardboard boxes.

FIRM #3.20: ‘Naked Flame’; no evidence of naked flames or smoking materials existed within the area of origin.

FIRM #5: ‘Machinery/Equipment/Appliances’; as there was a lift adjacent to the area of origin and fluorescent light fittings.

FIRM #6: ‘Weather/Nature’; the time of the fire could not have allowed concentrated sunlight to be directed onto any fuel packages and no lightning activity had recently occurred. However, evidence of any self-heating materials or substances had to be established (as in FIRM #1 above).

(c) The latter road maps were followed accordingly:

i) FIRM #1 - Processes/Substances; the storage, packaging, separation and handling of all substances were correct at the time of the fire; there were no reported residues from containers or self-heating substances within the area of origin; therefore [1.7] applied although many of the substances were very flammable. The conclusion was that processes or substances were not responsible for the fire but would have assisted rapid fire spread.

ii) FIRM #2: Structures; the building was built with concrete block walls and steel trussed roof and had no movement due to wind or ground movement; therefore [2.1] did not apply. There was no evidence of structural damage, failures of fire protection or resistance, or failure to supply cooling or ventilation; therefore [2.2] did not apply. The structure had no influence on convection, conduction or radiation of heat onto a fuel source; therefore [2.8] did not apply. There was no evidence of bad housekeeping or hoarding; therefore [2.14] did not apply. The conclusion is that the structure was unlikely to be responsible for the cause of the fire.

iii) FIRM #3.15: Electricity; there was physical evidence of electrical activity on the lighting circuits immediately above the area of origin; therefore [3.15.10] applied. Faulty, incorrect installation or by-passed safety systems could not be identified. Close examination concluded that the damage was due to the fire attacking the circuits, which operated the safety devices; therefore [3.15.12] did not apply. The installation, rating of protective devices for the circuitry machinery, equipment and appliances were correct; therefore [3.15.15] applied. There was no evidence of mechanical damage, ageing or lack of maintenance; therefore [3.15.18] did not apply. No evidence of sabotage, theft of electricity or misuse of installation or equipment existed; therefore [3.15.20] did not apply. No mechanism or conditions for creating static were identified; therefore [3.15.22] did not apply. There was no evidence of a suitable ignition/ heat source for any available fuel package;

therefore [3.15.23] did not apply. The conclusion is that electricity was unlikely to be responsible for the cause of the fire.

iv) FIRM #3.19: Solid Fuels; stacked toilet rolls were stored within the area of origin; therefore [3.19.1] applied. The physical state (of the toilet rolls) at the time of the fire was suitable for combustion; therefore [3.19.4] applied. There was no evidence of a sufficient heat source (smoking materials or matches) within the area of origin for the solid fuels (toilet rolls) to start combustion or smouldering as subsequent tests demonstrated that discarded smoking materials would not have started the fire within the time frame available; therefore [3.19.7] did not apply. It was considered whether the solid fuel was capable of self-heating, which it was not; therefore [3.19.9] and [3.19.15] did not apply. The solid fuel (toilet rolls) were, however, highly flammable and have a rapid speed of combustion, especially with the stacking arrangements in place and existing voids within the shelving; therefore [3.19.18] did apply. The conclusion was that the solid fuels identified were possibly responsible for the fire.

v) FIRM #3.20: Naked Flame; all other forms of energy have been eliminated as being a cause of the fire; therefore [3.20.1] applied. There was history of previous fires at other premises of the same owner; therefore [3.20.5] did apply. There was no evidence of smoking materials in the form of discarded cigarettes and due to the time-frame of the fire growth these were eliminated; therefore [3.20.8] did not apply. There was a fuel package available to sustain combustion (toilet rolls); therefore [3.20.11] did apply. There was evidence to support an incendiary cause when considering the time one witness passed through the area with no fire being observed to the time of the discovery of the fire (both electronically confirmed times using phone records and alarm panel data); therefore [3.20.14] did apply. The conclusion was that a naked flame was possibly responsible for causing the fire.

vi) FIRM #5: Machinery/Equipment/Appliances; the only items that were anywhere near to the area of origin were a hydraulic goods lift, the lift motor room and fluorescent lighting; the lift was in use shortly before the fire, therefore [5.1] applied and the lighting was eliminated in FIRM #3.15 above. A defect had been reported with the working of the lift approximately a week prior to the fire, therefore [5.4] applied. There was no evidence of sabotage; therefore [5.7] did not apply. Examination of the outside of the lift door showed extensive heat damage as a result of radiated heat onto the metal concertina doors. The inside of the doors showed little damage indicating that the heat damage had been as a result of a fire in the store room side of the doors and not the lift motor room side. The outside of the lift motor room door was extensively fire damaged, as this was closer to what was determined as the area of origin, however the inside face of the same door was undamaged with smoke staining around the edges. The lift motor room was slightly smoke damaged with no evidence of fire or heat damage. There was no evidence of excess grease used on the machinery, grease degradation or heat damage. It was therefore concluded that neither the lift nor the lift motor was capable of starting the combustion process with the fuel available and [5.14] did not apply. It was subsequently concluded that machinery, equipment or appliances were not a cause of this fire.

vii) FIRM #6: Weather/Nature; there was no evidence of recent adverse weather conditions and due to the time of the fire, no possibility of direct sunlight; therefore [6.1] did not apply. An inventory was taken of the items within the area of origin (toilet rolls and paper kitchen towels) and none of them were capable of self-heating; therefore [6.10] did not apply. It was concluded that weather or nature were not responsible for the cause of this fire.

(d) Conclusion: The conclusion to the original investigation was that a deliberate application of a naked flame ignited a stack of toilet rolls. By following the road maps retrospectively, the same conclusion was reached, clearly showing why the other road maps did not apply.

5.3 Bethnal Green Road shop and dwellings – double fire-fighter fatalities

On the 20th July 2004, the London Fire Brigade received a call from a shop owner, who had made an escape from a fire up to, and was stranded on, the flat roof of his property with his elderly father. The shop sold clothing and was on the ground floor extending approximately twenty five metres from the front to the rear of the shop and had additional storage in a rear basement and rear first floor store room. There was residential accommodation on the first and second floors. Following the arrival of the fire brigade and the subsequent forced entry into the building, a fire was discovered in the basement store room of the building. Fire-fighters proceeded to attempt to extinguish the fire in the basement. After approximately one and a half hours after the first call, the fire developed so rapidly spreading into the ground floor shop that it trapped two fire-fighters within the building causing their deaths.

(a) Considering all of the road maps, it was decided at the time of the investigation that the following road maps were <u>not</u> applicable to this incident:

- FIRM #1: 'Processes and Substances'; as there were no evidence of any processes or substances, including self-heating substances, within the area of origin or anywhere else within the building.
- FIRM #3.16: 'Gas'; although the property was supplied with gas, there were no gas pipes or appliances within or near the area of origin nor were there any cylinders in or near the premises.
- FIRM #3.17: 'Oil'; as the property was not supplied with oil nor were there any storage containers in or near the premises.
- FIRM #3.18: 'Petrol/Diesel'; as the property was not supplied with petrol/diesel nor were there any containers in or near the premises; the premises was checked with hydrocarbon detection equipment.

o FIRM #4: ‘Animals’; as there were no pets kept within the premises, no evidence of vermin infestation nor opportunity for any animal to enter or leave the premises as it was secure.

o FIRM #6: ‘Weather/Nature’; as recent weather conditions and property layout could not have allowed concentrated sunlight and no lightning activity had recently occurred. There was also no evidence of any self-heating materials or substances (as in FIRM #1 above).

(b) The latter road maps were followed accordingly:

i) FIRM #2: Structures; the building was complex in layout, however it was built with brick outer walls with no possible movement due to wind or ground movement; therefore [2.1] did not apply. There was evidence of structural damage following the fire and obvious failures of fire protection and resistance; therefore [2.2] did apply. The structure had no influence on convection, conduction or radiation of heat onto a fuel source; therefore [2.8] did not apply. There was no evidence of bad housekeeping or hoarding; therefore [2.14] did not apply. However, the actions identified in [2.2] could not have promoted the combustion process [2.7]. The conclusion is that the structure was unlikely to be responsible for the cause of the fire [2.18].

ii) FIRM #3.15: Electricity; electricity was supplied to the area of origin [3.15.1] and light switches were open at the time of inspection [3.15.4]. There was physical evidence of electrical activity on one of the circuits; therefore [3.15.10] did apply. No faulty, incorrect installation or by-passed safety systems were found; therefore [3.15.12] did not apply. The installation, rating of protective devices for the circuitry machinery, equipment and appliances were correct; therefore [3.15.15] did not apply. However, there was no evidence of mechanical damage, ageing or lack of maintenance; therefore [3.15.18] did not apply. No evidence of sabotage, theft of electricity or misuse of installation or equipment existed; therefore [3.15.20] did not apply. No mechanism or conditions for creating static were identified; therefore

[3.15.22] did not apply. The conclusion is that electricity was unlikely to be responsible for the cause of the fire [3.15.34].

iii) FIRM #3.19: Solid Fuels; solid fuels (stocks of cardboard boxes, cotton fabrics, mixed man-made fibres) were stored within the area of origin in the basement; the walls were lined with timber decorative wall boards; therefore [3.19.1] applied. The physical state (of the stock) at the time of the fire was suitable for combustion; therefore [3.19.4] applied. There was evidence of viable heat source (smoking materials and disposable lighters) within the area of origin for the solid fuels (mixed stock) to start combustion or smouldering; therefore [3.19.7] applied. At this point in the road map, a negative check was made and it was considered whether of the materials was capable of self-heating, which it was not; therefore [3.19.9] and [3.19.15] did not apply. The solid fuel, (mixed stock), was not highly flammable and did not have a rapid speed of combustion due to the way it was tightly stacked with limited air supply; therefore [3.19.18] did not apply. The conclusion, having reached [3.19.7] was that the solid fuels identified were possibly responsible for the fire [3.19.22].

iv) FIRM #3.20: Naked Flame; all other forms of energy have been eliminated as being a cause of the fire; therefore [3.20.1] applied. There was no history of previous fires at the premises; therefore [3.20.5] did not apply. There was evidence of leisure related naked flames (smoking materials); therefore [3.20.8] did apply. There was a fuel package available to sustain combustion (mixed stock); therefore [3.20.11] did apply. There was evidence to support an incendiary cause; therefore [3.20.14] applied. The conclusion was that either a naked flame or smoking materials were possibly responsible for the fire [3.20.21]. Following extensive fire tests, deliberate application of naked flame was eliminated due to the timeline created regarding the fire’s development and smoking materials remained as a possible cause of the fire.

v) FIRM #5: Machinery, Equipment or Appliances; some items of electrical equipment were found in the debris but upon subsequent investigations were found to have fallen from floors above the basement following the structural collapse of those floors; therefore FIRM #5 did not apply. The conclusion was that no machinery, equipment or appliances were responsible for the fire.

(c) Conclusion: the conclusion to the investigation by following the Fire Investigation Road Maps was that careless disposal of smoking materials, and not a naked flame, ignited cardboard boxes, which in turn ignited the mixed stock in those boxes; the fire spread due to the combustible stock within the premises, including the timber decorative panels and wall battens.

5.4 Iron Mountain Data Storage Facility 20 Pump Fire

On the 12th July 2006 a call was made to the London Fire Brigade Mobilising Control at 23:33hrs by an alarm monitoring company to an automatic fire alarm actuating at a large sprinklered data storage (predominantly paper) facility in East London. Following the arrival of a single fire appliance and the inquiries of the Crew Manager, it was discovered that a fully developed fire was in progress with over 100 smoke detectors having been actuated. The rapidly developing fire caused two breathing apparatus teams to become momentarily disoriented and one of the crew to become detached from the rest of the teams. After becoming lost within the upper levels of the building, he managed to find a staircase and escape to the ground floor and out of the building. The subsequent fire required 20 pumping appliances to extinguish it over a period of six days. Extensive analysis of the smoke detection and sprinkler systems by the team of investigators and equipment engineers identified the area of origin as on the 4th floor level.

1) Considering all of the road maps, it was decided at the time of the investigation that the following road maps were not applicable to this incident:
    a) FIRM #1: ‘Processes and Substances’; as there were no evidence or history of any processes or substances, including self-heating substances, within the area of origin or anywhere else within the premises.

b) FIRM #3.16: ‘Gas’; although the property was supplied with gas, there were no gas pipes or appliances within or near the area of origin. There were cylinders fitted to fork-lift trucks on the ground floor level within the warehouse area. No reports of gas leaks or physical evidence of gas involvement from those cylinders were found. The gas used was propane, which is heavier than air; therefore any leak would have resulted in a potential ignition at ground floor level and not on the fourth level.
c) FIRM #3.17: ‘Oil’; as the property was not supplied with oil nor were there any storage containers in or near the premises.
d) FIRM #3.18: ‘Petrol/Diesel’; as the property was not supplied with petrol/diesel nor was there any containers in or near the premises and the fire was not accelerated by an ignitable liquid (as analysed by the sprinkler and smoke detection systems).
e) FIRM #4: ‘Animals’; as there were no pets kept within the premises and no evidence of vermin infestation.
f) FIRM #6: ‘Weather/Nature’; as recent weather conditions and property layout could not have allowed concentrated sunlight and no lightning activity had recently occurred. There was also no evidence of any self-heating materials or substances (as in FIRM #1 above).

2) The following Fire Investigation Road Maps were followed:
   i) FIRM #2: Structures; the building was built with block and sandwich panel outer walls with possible movement due to wind; therefore [2.1] applied, however, as the origin of the fire was well away from the outside structure and any conductors passing through them, [2.5] did not apply. The structure had influence on convection, due to its height and orientation of racking, conduction, due to the four-hour steel wall separating compartments and radiation, due to its insulated roof panel structure onto a fuel source, those being the 1.4 million cardboard boxes stored within the warehouse; therefore [2.8] applied, however, this influence could not have initiated the combustion process; therefore [2.11] did not apply. The conclusion is that the structure

was unlikely to be responsible for the cause of the fire [2.18] although it was considered responsible for the rapid spread of the fire.

ii) FIRM #3.15: Electricity; there was no available physical evidence of electrical activity on any of the circuits due to the total destruction of the building so it was taken that there was a supply of electrical circuits as described by the site manager; therefore [3.15.10] did apply. No faulty, incorrect installation or by-passed safety systems were found in the control panels away from the storage areas involved; therefore [3.15.12] did not apply. The installation, rating of protective devices for the circuitry machinery, equipment and appliances were correct; therefore [3.15.15] did not apply, however, there was no evidence of mechanical damage that could be clearly identified or of value due to the total destruction of the building. 'As installed' drawings showed all conductors to be run in metal conduit within the area of origin so it was taken that no mechanical damage existed, based also on witness testimony. Ageing or lack of maintenance was not an issue due to the age of the installation and the maintenance regime in place; therefore [3.15.18] did not apply. No evidence of sabotage, theft of electricity or misuse of installation or equipment existed; therefore [3.15.20] did not apply. No mechanism or conditions for creating static were identified; therefore [3.15.22] did not apply. Nothing presented a suitable ignition/ heat source for any available fuel package following extensive tests on an exemplar light fitting; therefore [3.15.23] did not apply. The conclusion is that electricity was unlikely to be responsible for the cause of the fire [3.15.35].

iii) FIRM #3.19: Solid Fuels; solid fuels (stocks of cardboard boxes filled, predominantly with paper records) were stored within the area of origin on the fourth floor level; therefore [3.19.1] applied. The orientation and composition (of the stock) at the time of the fire was suitable for combustion; therefore [3.19.4] applied. There was no evidence of a sufficient heat source within the area of origin for the solid fuels to start combustion or smouldering due to the total destruction by fire; therefore [3.19.7] did not apply; (it is important to now cross-reference with FIRM #7 – Person). It was considered whether there were any solid fuels that were either capable of self-heating [3.19.9] or being an oxidiser [3.19.15], which it was not. Therefore [3.19.9] and [3.19.15] did not apply. The solid fuel was highly flammable due to the method of open rack storage, availability of air to the boxes and also had a rapid spread of combustion; therefore [3.19.18] applied. The conclusion was that the solid fuels identified were possibly responsible for the fire [3.19.22].

iv) FIRM #3.20: Naked Flame; all other forms of energy have been eliminated as being a cause of the fire; therefore [3.20.1] applied. There was no history of previous fires at the premises; therefore [3.20.5] did not apply. There was no evidence of leisure related naked flames (smoking materials) as no employees smoked on site; therefore [3.20.8] did not apply. There was a fuel package available to sustain combustion (mixed stock); therefore [3.20.11] did apply. There was evidential data from the alarm and sprinkler actuations to support an incendiary cause based on the location of the fire's origin and fire spread; therefore [3.20.14] applied. The conclusion was that a naked flame was possibly responsible for the fire.

v) FIRM #5: Machinery, Equipment or Appliances; no items of electrical equipment were found [5.1] in the debris due to the size of the scene following the fire. No appliances, equipment or machinery were reported to have been in the area of origin by reputable witnesses; therefore FIRM #5 did not apply. The conclusion was that any machinery, equipment or appliances were not responsible for the fire [5.20].

(c) The conclusion to the investigation by following the Fire Investigation Road Maps was that the application of a naked flame ignited cardboard boxes, which in turn ignited the mixed stock in those boxes and demonstrated why the other road maps did not apply. The intent of the application of naked flame could not be determined.

Chapter 6

Human agency involvement

Fires are started, it is said amongst the fire investigation community, by three possible groups; men, women and children! It can be seen in the previous 12 Fire Investigation Road Maps that acts of nature and animals may also have a part to play in the initiation of the combustion process, but most of the time it is some act or omission by human agency involvement that a fire is started.

During 2001, 'deliberate damage by fire' (See Chapter 1.2.2 'Criminal Damage Act 1971') was responsible for approximately 64% of all the fires that the London Fire Brigade attended; these statistics were similar throughout the United Kingdom. With the introduction of Arson Task Forces, where the police and fire services work together to address this serious issue, deliberate fires had fallen to approximately 50% in 2007. Fire Investigation Road Map #7 and its sub-FIRMs are designed to identify any possible human agency act(s) or omission(s) in the initiation of the fire or explosion; it is not designed to deal in depth with any human behaviour(s) once the fire has been initiated but will address any actions or inactions which may have encouraged the fire to develop.

This section addresses the *roles* of people involved in relation to the location and time of the fire as opposed to their potential motive. For example, a Company Director could be studying for a degree or a tradesperson could be undertaking a City and Guilds at his or her local college; that person will be deemed to be a 'student' and not identified by their main professional role in society, although it may be necessary to consider their associated technical knowledge if it could be relevant when investigating a fire. The purpose for this is that interactions between people are normally 'role' specific; there could be a disconnection between a Managing Director of a company and his part time teacher if that person was not identified as one of the teacher's students.

6.1 Categorising fires started by a person

As discussed in Section [1.3] people are involved with fires in various ways, which include:

(i) causing the fire by accident or design

(ii) becoming a victim of fire, suffering injury or death

(iii) being the rescuer/fire-fighter

(iv) acting as a witness

(v) undertaking the subsequent investigation.

When a fire is proved to have been set wilfully and maliciously causing the destruction of property or criminal damage by fire, it is deemed an arson or incendiary fire.

Understanding or proving 'how' and 'why' a person would start such a fire or fires is very complex, as is identifying an unknown arsonist because it may involve many specialist disciplines such as psychology, psychiatry, fire science, fire dynamics and fire investigation to name but a few. Without a thorough understanding of why this act is committed, the prevention, prosecution or treatment of such offenders will be minimised. Canter (1995b) outlines an approach to identify a suspect, which has not only been used in books such as Sherlock Holmes' and Agatha Christie's novels, but also in current television crime dramas and true life investigations; the approach identifies the 'character' of the criminal and the circumstances where their characteristics were out of place with their alibi or normal activities, focusing detailed investigative attention upon them. He discusses the behavioural traces he or she may leave at the crime scene, beyond the usual list of clues in order to recognise a pattern or an identifiable silhouette; a distinct 'criminal shadow' cast by the offender (Canter, 1995a). Sherlock Holmes was famous for saying: 'Data! Data! Data!' for without it, a criminal will not be prosecuted. What Canter is promoting is that if the investigator does not have the expertise to interpret the vast amounts of data held in organisational databases, he or she may become overwhelmed and the interpretation of those criminal shadows cannot be identified.

Motives of fire setting behaviour have been wide and varied and predominantly driven by organisations that have instigated studies into the problem.

In Chapter One, Section [1.2] of this study, the 'motives' of fire setting were outlined using the same categories referred to by the National Centre for the Analysis of Violent Crime (NCAVC) at the Federal Bureau of Investigation (FBI) Academy in Quantico, Virginia, USA (Sapp et al., 1998). They are:

- Profit
- Vandalism
- Excitement
- Revenge
- Crime Concealment
- Extremism (this has been added since the 1998 report)

In 1986, a sub-unit was established within NCAVC, called the Arson and Bombing Investigative Services Sub-unit (ABIS), to carry out a study on arsons and bombings and included representatives from the Bureau of Alcohol, Tobacco and Firearms (now called the Bureau of Alcohol, Tobacco, Firearms and Explosives). In 1992, staff at the NCAVC was joined by faculty members from major universities, members of the mental health and medical professions and other law enforcement representatives.

In 1988 the Federal Emergency Management Agency (FEMA) identified arson as the second leading cause of deaths in residential fires. The Uniform Crime Reports produced by the FBI in 1992 identified that through 1991 arsons caused over one billion dollars in property loss. A concern about the extent of serial arson in the United States prompted 'The Study of Serial Arsonists' (Sapp et al., 1998). Despite this, relatively little research had been carried out on arsonists. Most of the research is clinical and based on a small number of convicted arsonists. Sapp et al. also highlighted five problematic areas associated with the study of arson:

- Few arsonists have been apprehended (by comparison to other crimes)

- Only a small number are convicted due to lack of evidence
- Many arsonists plead lesser charges which are then processed and awarded
- A systematic, psychological study has not been completed on previous research
- Most research comes from biased populations and incomplete data.

During the 1990's in the United Kingdom, much was written about the possible motivations for arson and deliberate fire setting (Home Office, 2003b). However, most of the research was focussed on the psychological mind-set of the offender. Depending upon the researcher or organisation conducting the research, classification categories can range from three to about 200 sub-categories, leading to confusion and hindering ways in which to identify and control the problem. There are dangers in classifying an offender into one particular group however that classification is listed (Barker, 1994).

6.2 Overview of the categories of the FIRMs relating to human agency involvement:

The FIRMs relating to the 'person' have been sub-divided into the following 11 groups based on the role of the person at the time of the fire:

6.2.1 The Person (FIRM #7)

This is defined as any human being actually involved with or with a potential to have been involved with the fire scene. The investigator must not only establish if any person(s) had access to the area of origin at the time of, or shortly before the fire, but identify any persons that may have contributed to the initiation of the fire by accident or design. This will involve the usual cross-referencing of FIRMs to consider other influences; for example, FIRM #5 – Machinery, Equipment and Appliances, where the maintenance regime will need to be examined to ensure correct maintenance has been carried out to any identified items. An example of this may be the cleaning (or lack of it) of cooking extractor hoods and associated ducting, for example the Burger King fire at Heathrow Airport's Terminal 1 in 1997. Previous history of involvement with fire must be considered in all of the sub-FIRMs for the 'Person'. Any person(s) must be positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed.

6.2.2 Owner/ Occupier (FIRM #7.22)

This person will have overall or partial responsibility for the property at the time of the incident. This will include managers, head teachers, landlords, inmates of detention centres and persons residing at a premise without lawful reason, e.g. a squatter or protester. It will also include the employer of another person(s). This person can also be referred to as the 'key holder' for the premise in most cases. The owner/occupier must be positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed.

6.2.3 Child (FIRM #7.23)

This will include all children up to the age of 10 years old (after this age a youth may be prosecuted for arson) and anyone older than 10 years old of any age where their learning difficulties or mental state has not allowed them to develop to maturity. It may be necessary in certain circumstances to cross-reference this FIRM with FIRM #7.25 – Mental or Physical Impairment, depending upon the age of the person. Children must be positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed.

6.2.4 Immediate family, relative or friend (FIRM #7.24)

This person(s) will be related to the person who was involved in, or associated with the fire or explosion and will be a lawful (step/foster/-in-law, in all cases) father, mother, sister, brother, (grand) son, (grand) daughter, aunt, uncle, nephew, niece or cousin. It will also include current and recent friends of any of those persons mentioned above. Family, relative(s) or friend(s) must be positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed.

6.2.5 Employee (FIRM #7.25)

This person will be employed by another and will include paid or voluntary working personnel. The individual will have a 'line manager' who has overall responsibility for the area where the incident occurred. Any employee(s) must be positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed.

6.2.6 Pupil or Student (FIRM #7.26)

This person will include all people who are being taught at an establishment of learning and are, or have been at the scene for lawful educational reasons. The main role of the person in society will not be considered when selecting this FIRM; for example, if a fire fighter attends evening classes to learn about electronics, he or she will be regarded as a student. However, FIRM #7.28 may be identified as being relevant during the investigation when using this FIRM #7.26, as may other FIRMs. Any pupil(s) or student(s) must be positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed.

6.2.7 Visitor or Contractor (FIRM #7.27)

This person will be, or have been lawfully at the scene of the incident, due to their interest in, or association with that scene, and will be known by the owner/occupier of the scene or their members of staff. This may involve persons that have not been at the scene for some time but could be relevant to the scene, for example a sprinkler pump engineer who services the pumps on a monthly basis. Most visitors to premises have to report to a member of staff before they are allowed into that premise; this is not only for security purposes but also for fire safety compliance. A visitor to a shopping complex or a cinema, for example, would be categorised as a Member of Public (see FIRM #7.29 below) as they do not have to identify themselves before entering the premises. Any visitor(s) contractor(s) must be positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed.

6.2.8 Emergency Personnel (FIRM #7.28)

This applies to employees in their role when responding to an emergency and the group will include all personnel commonly regarded as emergency workers and not only the fire, police and paramedic services; it will also include roadside mechanics, voluntary rescue workers and anyone that falls within the common perception of this group. This FIRM may need to be cross-referenced with FIRM #7.25 – Employees. Although it is abhorrent to imagine any emergency personnel abusing the trust given to them by society, many have been known to start fires for a variety of reasons, such as the 'hero syndrome', boredom or financial gain, to mention but a few. Any emergency personnel must be positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed.

6.2.9 Member of the Public (FIRM #7.29)

Although the word 'public' is understood to mean 'the community or people in general' it is important that the investigator views a member of public as being identifiable to them in their role as a member of the public. This group will include any person that is not known to the owner/occupier of the scene but may have been at the scene for a specific time frame, for example, to see a film at the cinema. They may be identified by their credit card booking, CCTV images or other means. This may also include a person that has discovered a fire and called the emergency services or any identifiable individual observed on CCTV as being in the area at the time of the fire but not associated with it. A member(s) of the public must be identifiable and positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed. If the person cannot be identified, follow FIRM #7.31.

6.2.10 Mental/ Physical Impairment (FIRM #7.30)

This group will include any person that has any mental or physical impairment irrespective of the degree of severity. This FIRM may be cross-referenced to many of the other FIRMs within the 'Person' group, depending on their role associated with the incident. The elderly should be considered as to whether they will come within this group, depending upon their physical or mental condition. Any person(s) with mental or physical impairment must be positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed.

6.2.11 Unknown Person (FIRM #7.31)

This is a person that cannot be identified by lawful name nor their role at the scene established. This may include a witness account of an individual seen within the vicinity of the incident or observed on CCTV but that individual is not known to those observers. It may also include evidence of unidentified human presence at the time of, or shortly before the incident. Any unknown person(s) must be positively excluded from having any involvement with the scene if the application of this FIRM is not to be followed

A systematic fire and explosion investigation methodology has been designed to address all human agency involvement with fires and to reflect the non-human agency FIRMs that will assist the prosecution services in obtaining sound forensic evidence to warrant taking a prosecution case of arson into Court. It will also enable the Court, being the Judge, the Jury or the Justice of the Peace, to come to a sound verdict and increase the existing low prosecution rates for arson.

The data gathered and recorded during an investigation using these FIRMs may also be used by other services for many reasons, as accurate investigations would have been completed and good data recorded. An example would be the human agency involvement and the environmental conditions relating to the fire; was the ease of escape, ease of rescue, early warning and the physical and/ or mental state of the person adequate to prevent injury or save life from fire and its products of combustion? This type of data is relevant to fire and rescue services, health authorities, fire engineers, fire safety specialists, planning and building regulators.

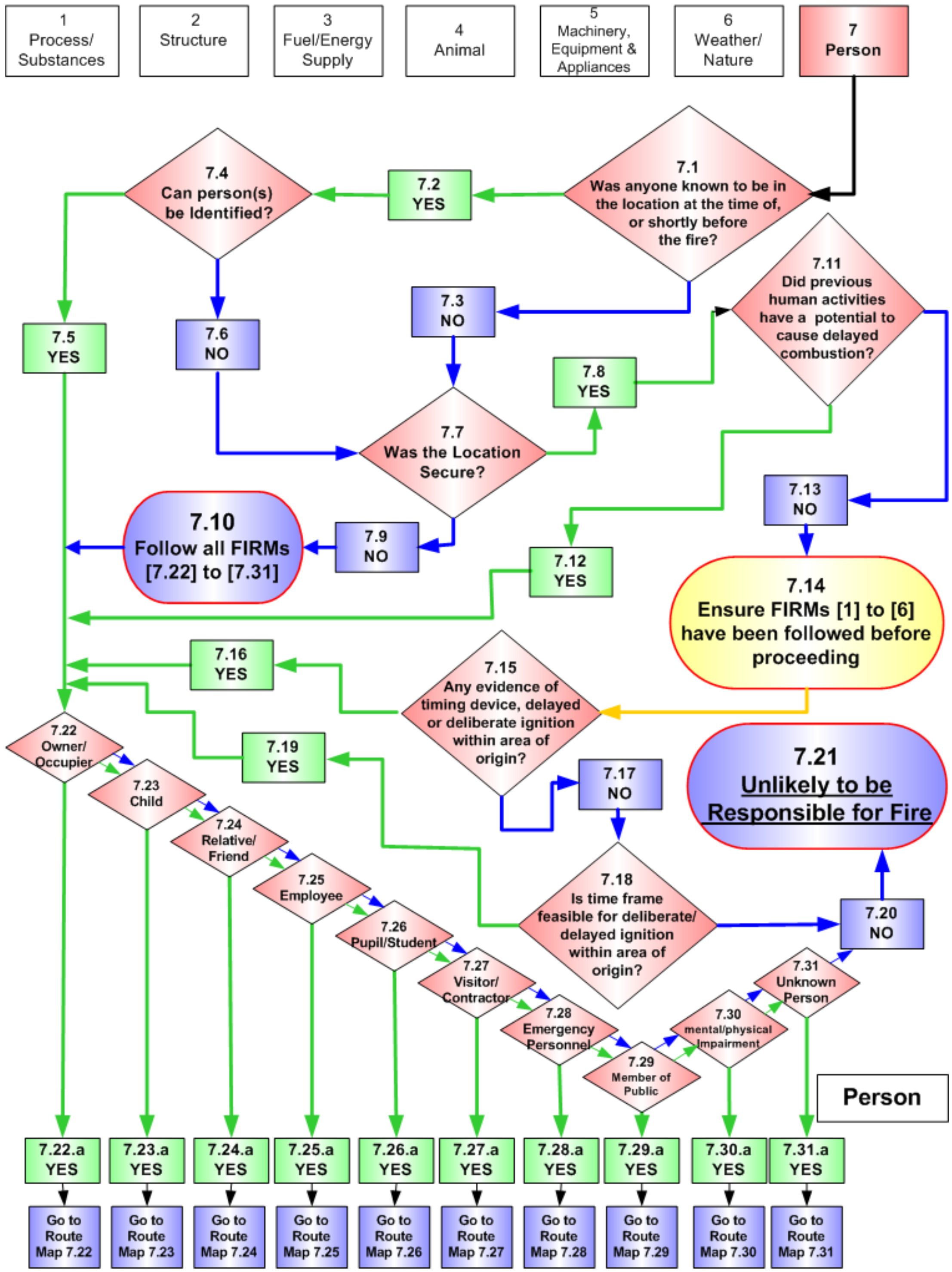
Chapter 7

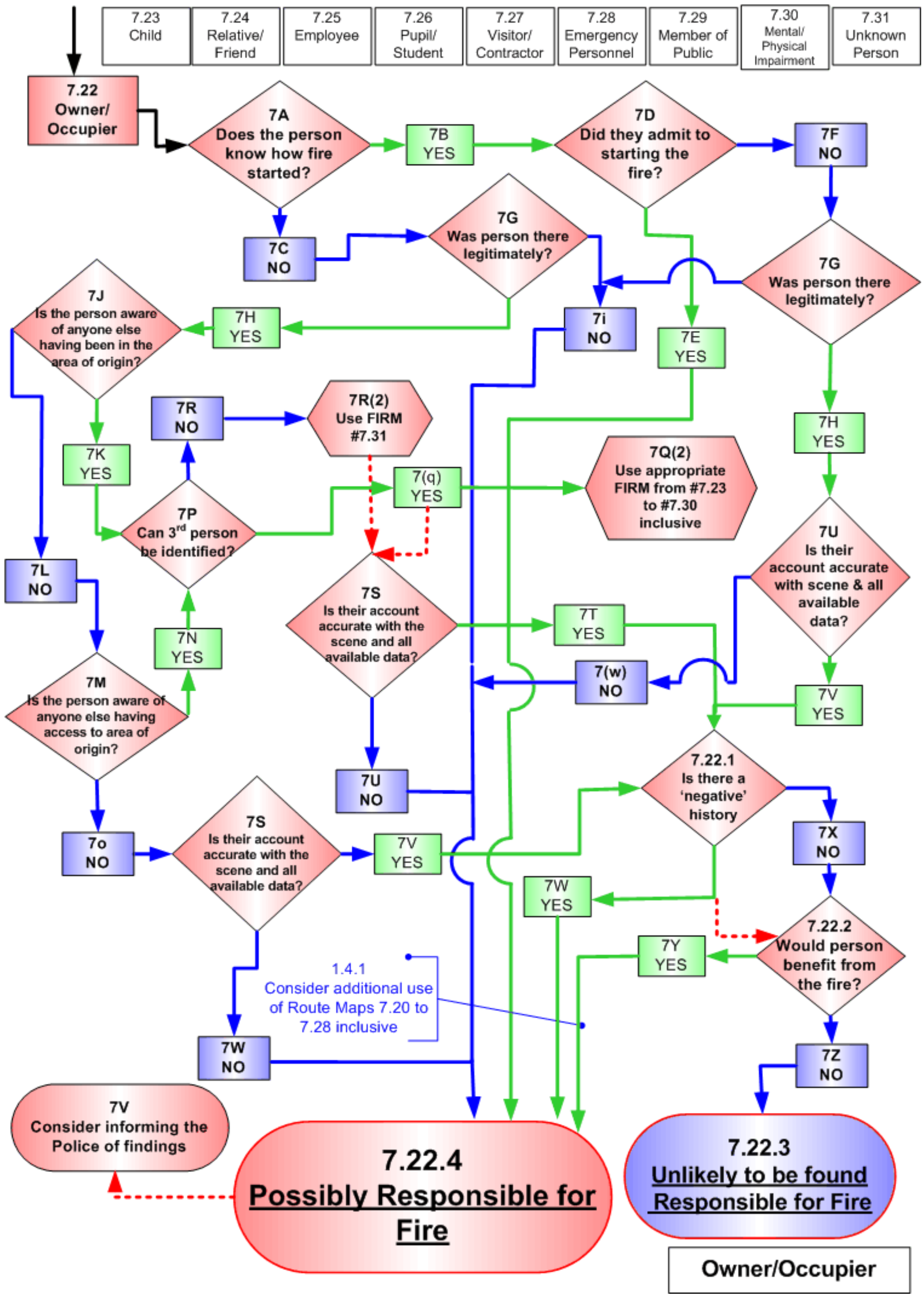
Fire Investigation Road Maps (FIRMs) Human agency

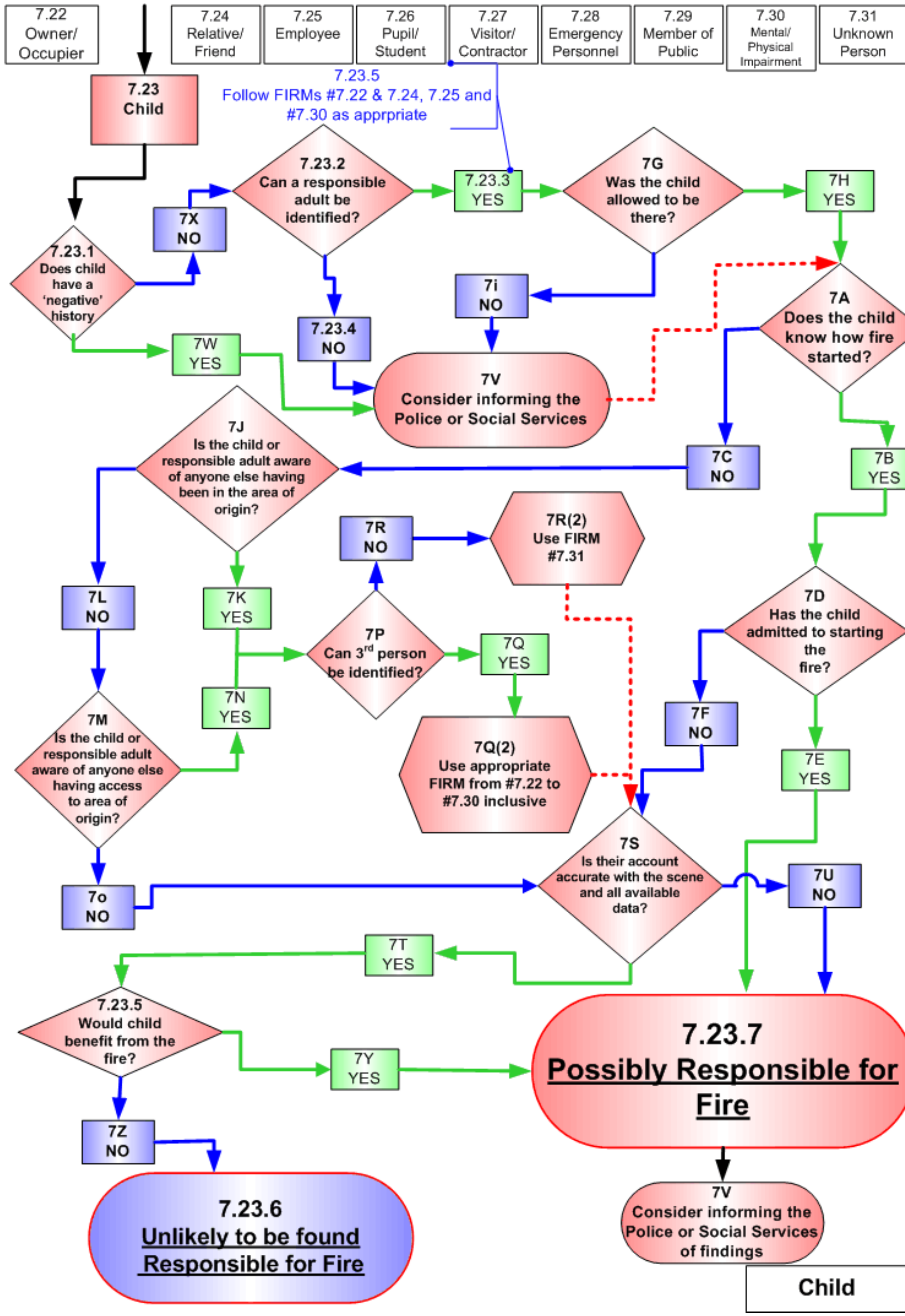
The Fire Investigation Road Maps (FIRMs) within this chapter address the human agency element of fires as outlined in Chapter Six. Detailed instructions on how to use the FIRMs can be found in Volume 2.

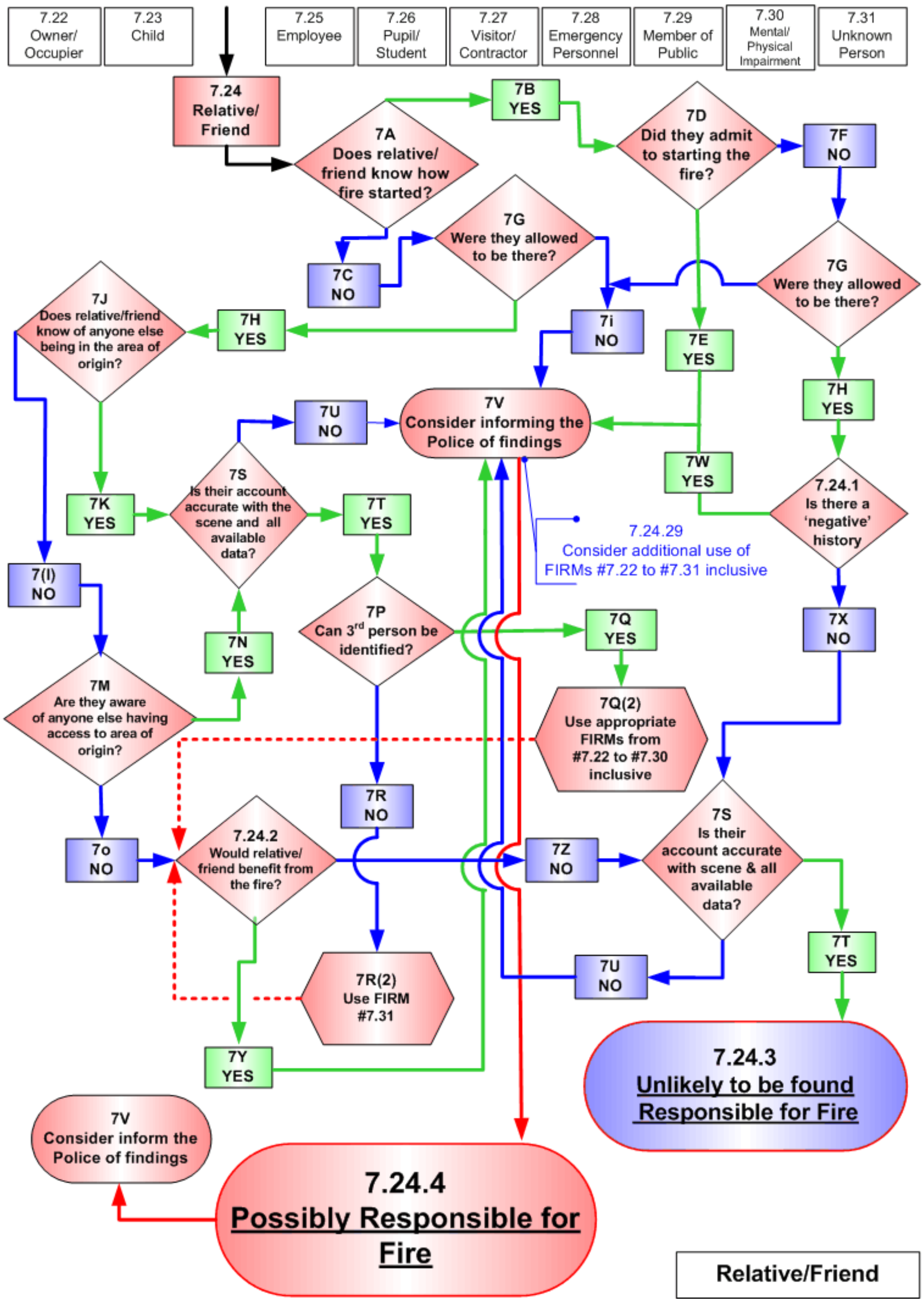
Table 7.1

Fire Investigation Road Map (FIRM) Index (Human Agency Involvement)

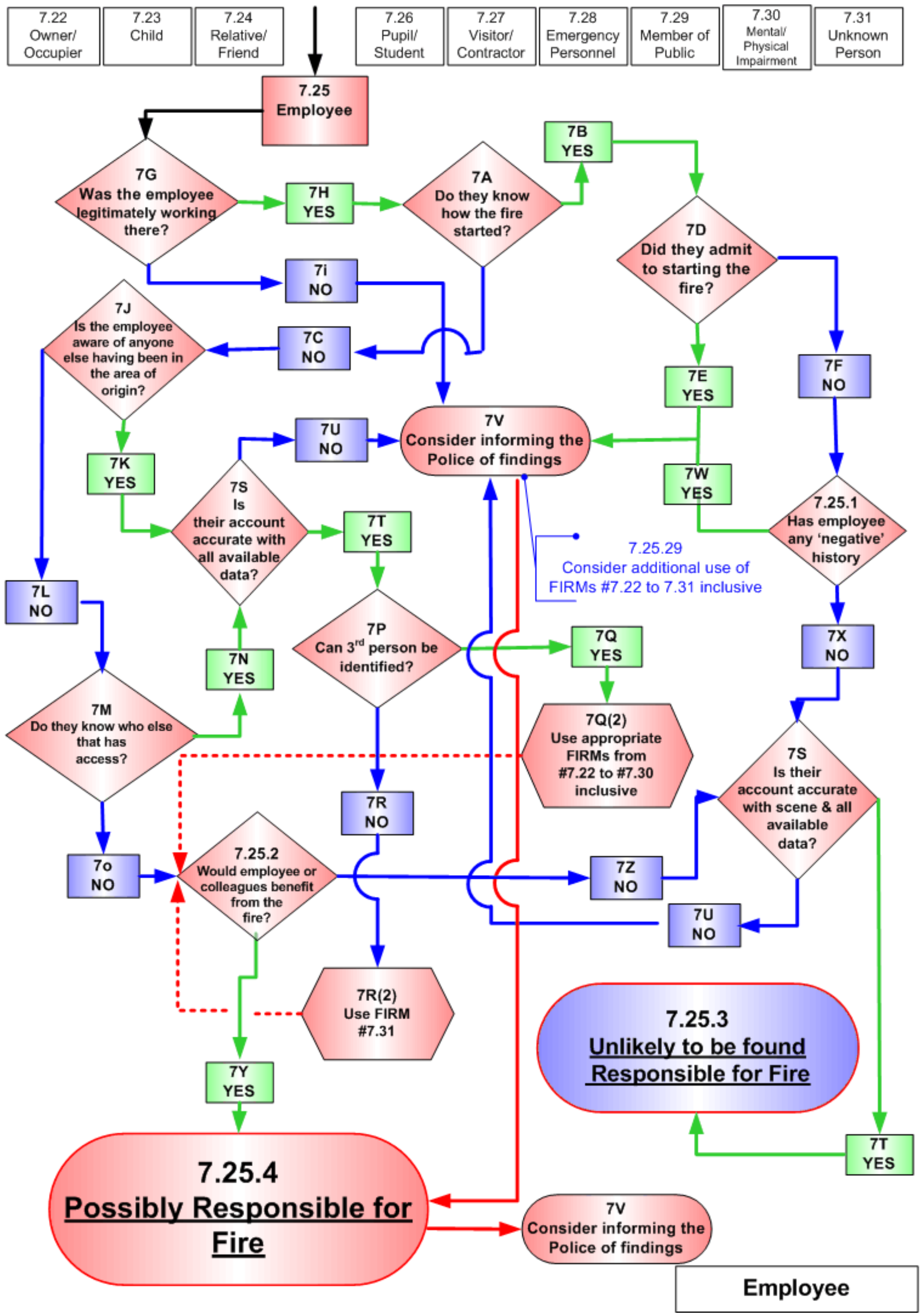

1 Process/ Substances
2 Structure
3 Fuel/Energy Supply
4 Animal
5 Machinery, Equipment & Appliances
6 Weather/ Nature
7 Person
7.1 Was anyone known to be in the location at the time of, or shortly before the fire?
7.2 YES
7.3 NO
7.4 Can person(s) be Identified?
7.5 YES
7.6 NO
7.7 Was the Location Secure?
7.8 YES
7.9 NO
7.10 Follow all FIRMs [7.22] to [7.31]
7.11 Did previous human activities have a potential to cause delayed combustion?
7.12 YES
7.13 NO
7.14 Ensure FIRMs [1] to [6] have been followed before proceeding
7.15 Any evidence of timing device, delayed or deliberate ignition within area of origin?
7.16 YES
7.17 NO
7.18 Is time frame feasible for deliberate/ delayed ignition within area of origin?
7.19 YES
7.20 NO
7.21 Unlikely to be Responsible for Fire
7.22 Owner/ Occupier
7.23 Child
7.24 Relative/ Friend
7.25 Employee
7.26 Pupil/Student
7.27 Visitor/ Contractor
7.28 Emergency Personnel
7.29 Member of Public
7.30 mental/physical Impairment
7.31 Unknown Person
Person
7.22.a YES
7.23.a YES
7.24.a YES
7.25.a YES
7.26.a YES
7.27.a YES
7.28.a YES
7.29.a YES
7.30.a YES
7.31.a YES
Go to Route Map 7.22
Go to Route Map 7.23
Go to Route Map 7.24
Go to Route Map 7.25
Go to Route Map 7.26
Go to Route Map 7.27
Go to Route Map 7.28
Go to Route Map 7.29
Go to Route Map 7.30
Go to Route Map 7.31


7.23 Child
7.24 Relative/ Friend
7.25 Employee
7.26 Pupil/ Student
7.27 Visitor/ Contractor
7.28 Emergency Personnel
7.29 Member of Public
7.30 Mental/ Physical Impairment
7.31 Unknown Person
7.22 Owner/ Occupier
7A Does the person know how fire started?
7B YES
7D Did they admit to starting the fire?
7F NO
7C NO
7G Was person there legitimately?
7G Was person there legitimately?
7J Is the person aware of anyone else having been in the area of origin?
7H YES
7i NO
7E YES
7R NO
7R(2) Use FIRM #7.31
7K YES
7(q) YES
7Q(2) Use appropriate FIRM from #7.23 to #7.30 inclusive
7H YES
7P Can 3rd person be identified?
7U Is their account accurate with scene & all available data?
7L NO
7S Is their account accurate with the scene and all available data?
7T YES
7N YES
7(w) NO
7V YES
7M Is the person aware of anyone else having access to area of origin?
7U NO
7.22.1 Is there a 'negative' history
7o NO
7S Is their account accurate with the scene and all available data?
7V YES
7X NO
7W YES
7.22.2 Would person benefit from the fire?
7Y YES
1.4.1 Consider additional use of Route Maps 7.20 to 7.28 inclusive
7W NO
7Z NO
7V Consider informing the Police of findings
7.22.4 Possibly Responsible for Fire
7.22.3 Unlikely to be found Responsible for Fire
Owner/Occupier

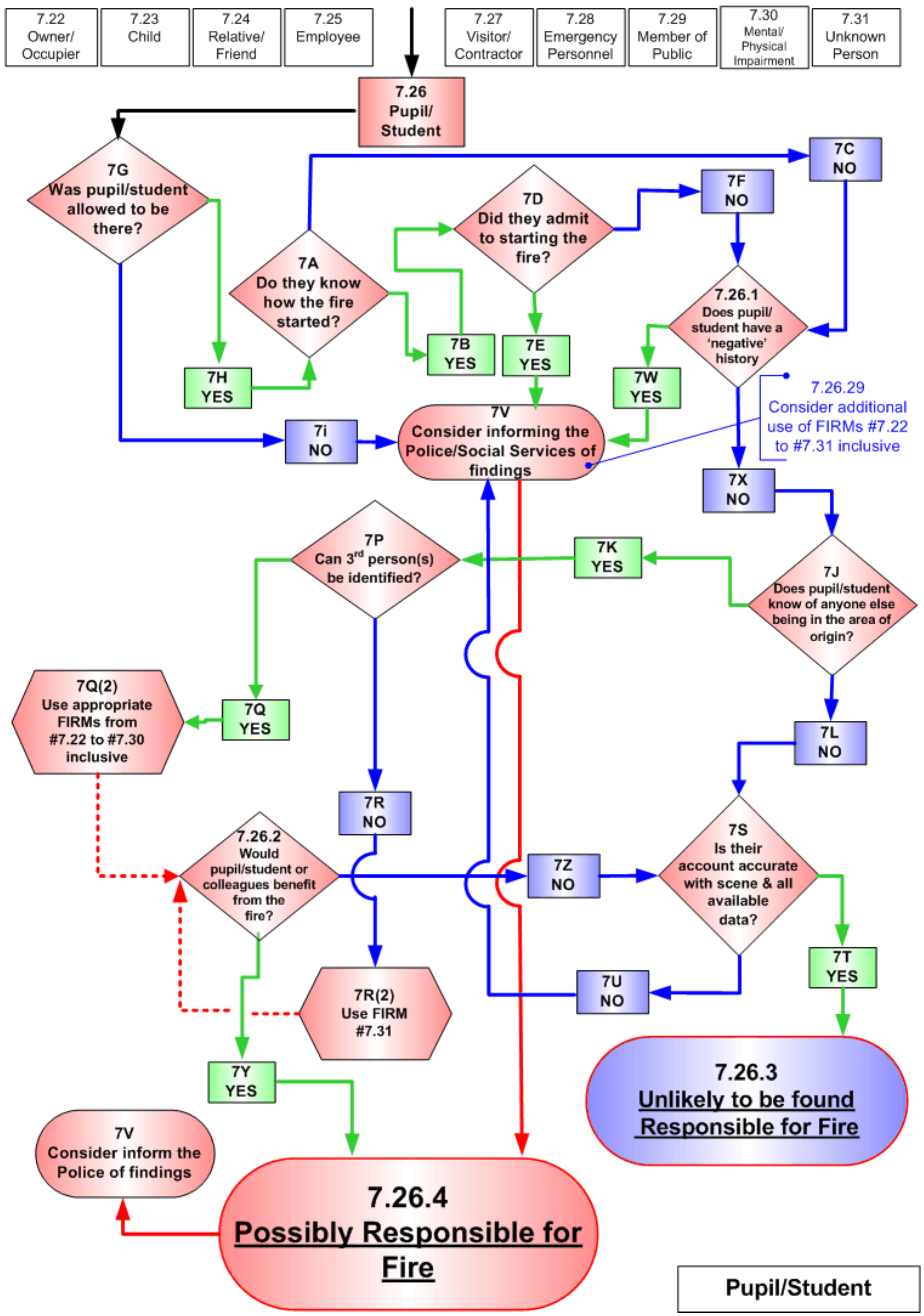

7.22 Owner/ Occupier
7.24 Relative/ Friend
7.25 Employee
7.26 Pupil/ Student
7.27 Visitor/ Contractor
7.28 Emergency Personnel
7.29 Member of Public
7.30 Mental/ Physical Impairment
7.31 Unknown Person
7.23 Child
7.23.5 Follow FIRMs #7.22 & 7.24, 7.25 and #7.30 as apprpriate
7.23.1 Does child have a 'negative' history
7X NO
7.23.2 Can a responsible adult be identified?
7.23.3 YES
7G Was the child allowed to be there?
7H YES
7W YES
7.23.4 NO
7i NO
7A Does the child know how fire started?
7V Consider informing the Police or Social Services
7J Is the child or responsible adult aware of anyone else having been in the area of origin?
7C NO
7B YES
7R NO
7R(2) Use FIRM #7.31
7L NO
7K YES
7P Can 3rd person be identified?
7Q YES
7D Has the child admitted to starting the fire?
7N YES
7M Is the child or responsible adult aware of anyone else having access to area of origin?
7Q(2) Use appropriate FIRM from #7.22 to #7.30 inclusive
7F NO
7E YES
7S Is their account accurate with the scene and all available data?
7o NO
7U NO
7T YES
7.23.5 Would child benefit from the fire?
7Y YES
7.23.7 Possibly Responsible for Fire
7Z NO
7.23.6 Unlikely to be found Responsible for Fire
7V Consider informing the Police or Social Services of findings
Child

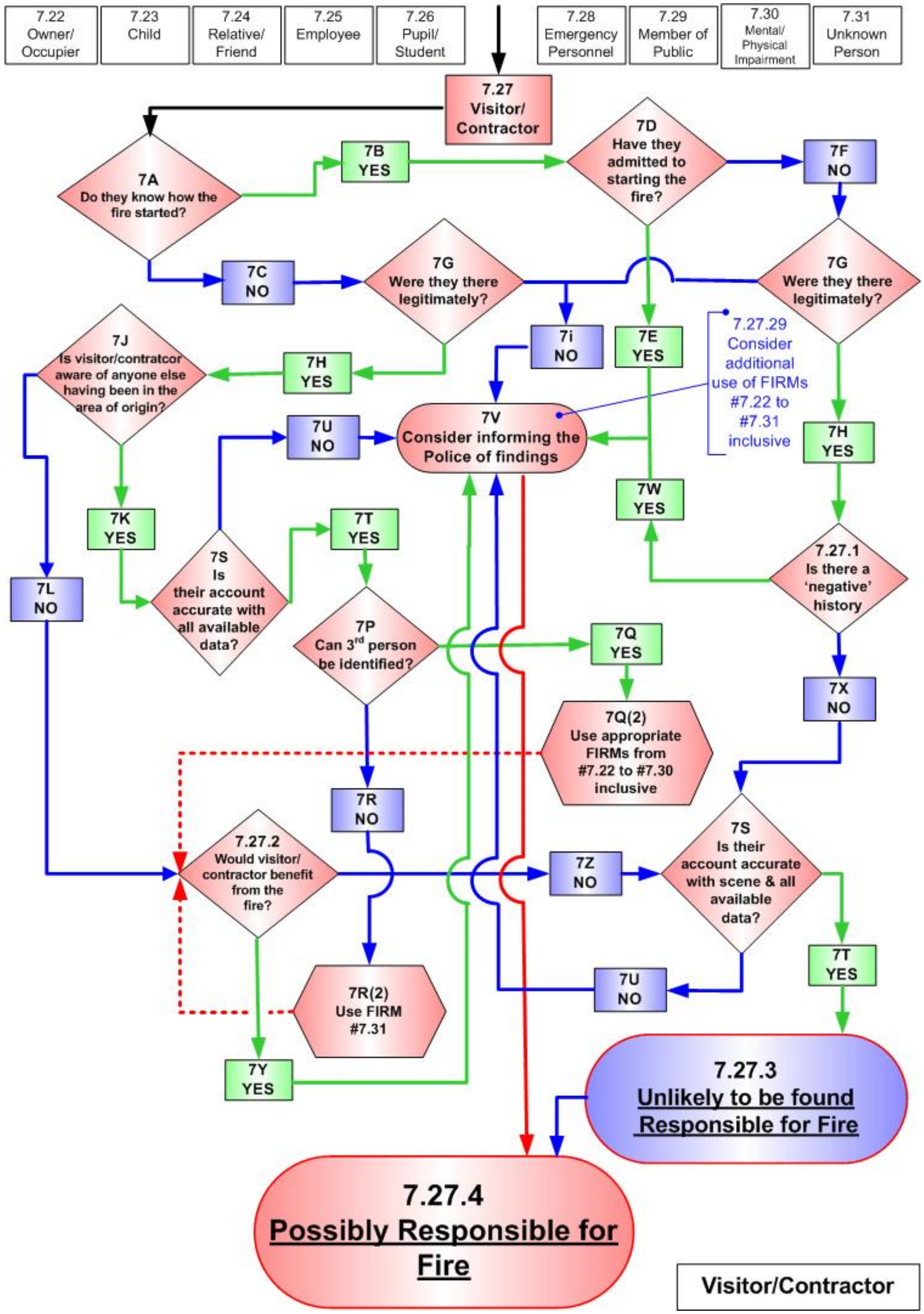


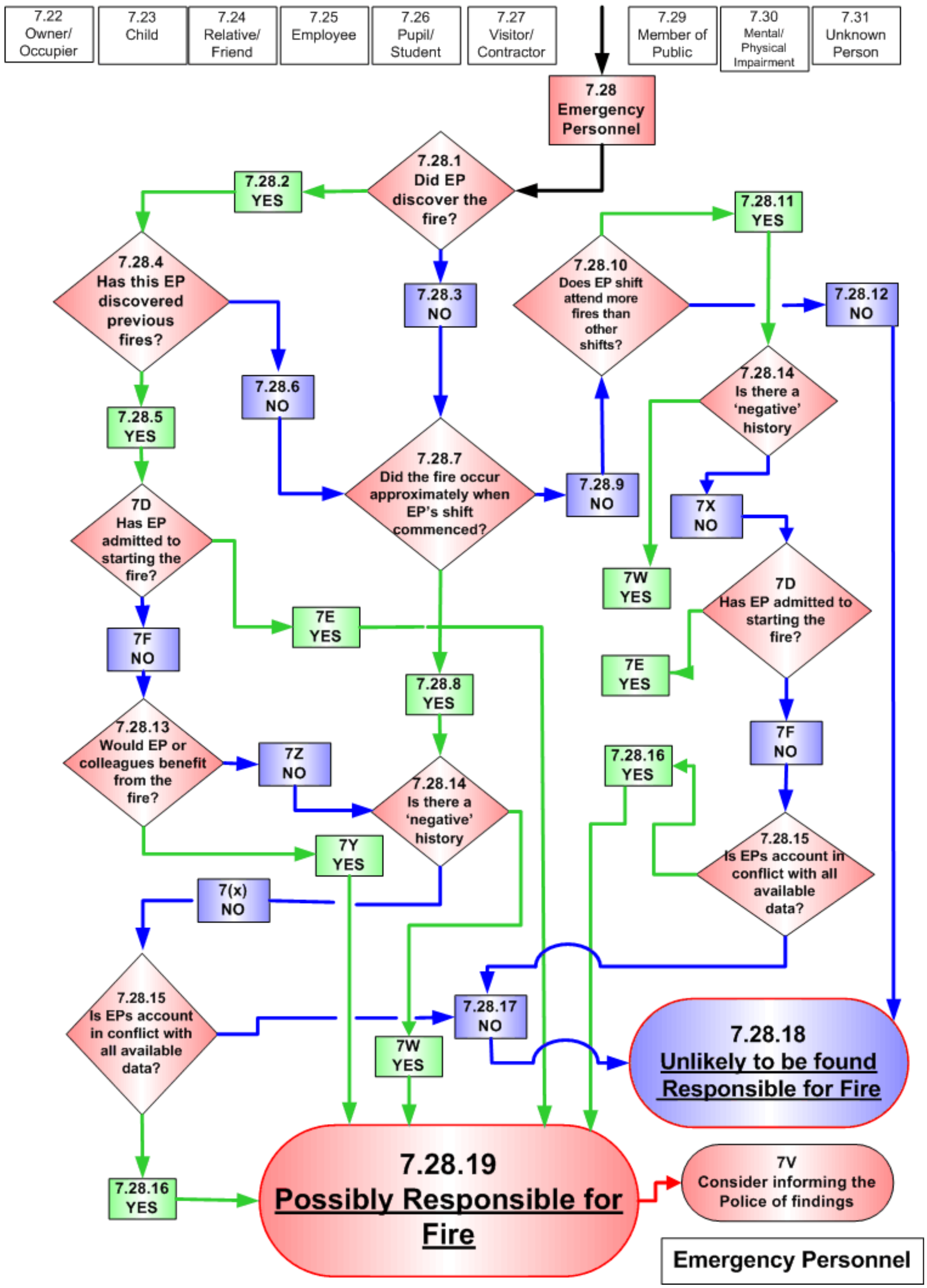
7.22 Owner/ Occupier
7.23 Child
7.25 Employee
7.26 Pupil/ Student
7.27 Visitor/ Contractor
7.28 Emergency Personnel
7.29 Member of Public
7.30 Mental/ Physical Impairment
7.31 Unknown Person
7.24 Relative/ Friend
7A Does relative/ friend know how fire started?
7B YES
7C NO
7D Did they admit to starting the fire?
7F NO
7G Were they allowed to be there?
7G Were they allowed to be there?
7H YES
7i NO
7E YES
7J Does relative/friend know of anyone else being in the area of origin?
7H YES
7U NO
7V Consider informing the Police of findings
7W YES
7.24.1 Is there a 'negative' history
7K YES
7S Is their account accurate with the scene and all available data?
7T YES
7.24.29 Consider additional use of FIRMs #7.22 to #7.31 inclusive
7(I) NO
7P Can 3rd person be identified?
7Q YES
7X NO
7N YES
7M Are they aware of anyone else having access to area of origin?
7Q(2) Use appropriate FIRMs from #7.22 to #7.30 inclusive
7R NO
7o NO
7.24.2 Would relative/ friend benefit from the fire?
7Z NO
7S Is their account accurate with scene & all available data?
7U NO
7T YES
7R(2) Use FIRM #7.31
7Y YES
7.24.3 Unlikely to be found Responsible for Fire
7V Consider inform the Police of findings
7.24.4 Possibly Responsible for Fire
Relative/Friend



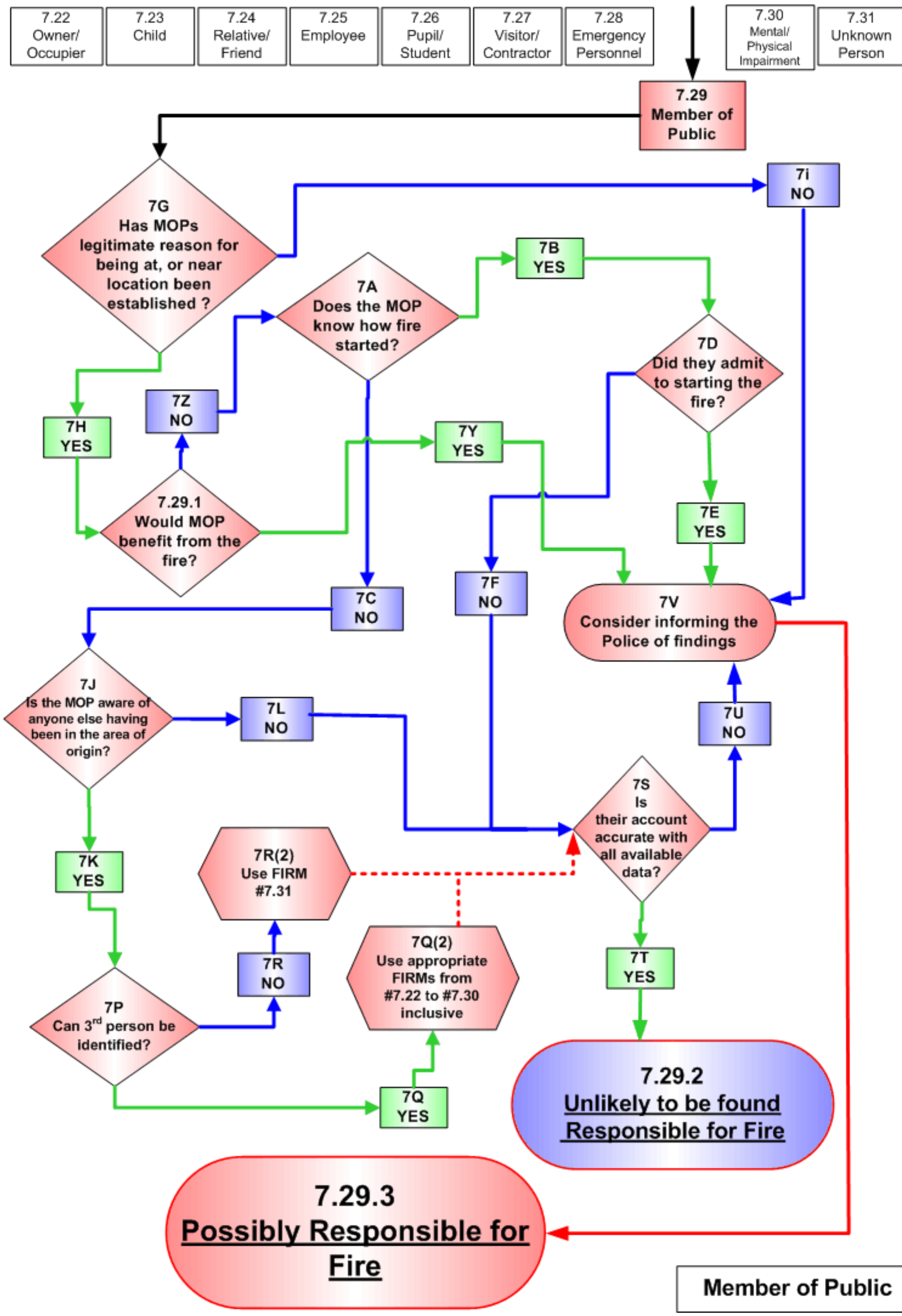
7.22 Owner/ Occupier
7.23 Child
7.24 Relative/ Friend
7.26 Pupil/ Student
7.27 Visitor/ Contractor
7.28 Emergency Personnel
7.29 Member of Public
7.30 Mental/ Physical Impairment
7.31 Unknown Person
7.25 Employee
7G Was the employee legitimately working there?
7H YES
7A Do they know how the fire started?
7B YES
7D Did they admit to starting the fire?
7i NO
7J Is the employee aware of anyone else having been in the area of origin?
7C NO
7E YES
7F NO
7V Consider informing the Police of findings
7U NO
7K YES
7S Is their account accurate with all available data?
7T YES
7W YES
7.25.1 Has employee any 'negative' history
7.25.29 Consider additional use of FIRMs #7.22 to 7.31 inclusive
7L NO
7P Can 3rd person be identified?
7Q YES
7X NO
7N YES
7M Do they know who else that has access?
7Q(2) Use appropriate FIRMs from #7.22 to #7.30 inclusive
7S Is their account accurate with scene & all available data?
7R NO
7o NO
7.25.2 Would employee or colleagues benefit from the fire?
7Z NO
7U NO
7R(2) Use FIRM #7.31
7.25.3 Unlikely to be found Responsible for Fire
7Y YES
7T YES
7.25.4 Possibly Responsible for Fire
7V Consider informing the Police of findings
Employee


7.22 Owner/ Occupier
7.23 Child
7.24 Relative/ Friend
7.25 Employee
7.27 Visitor/ Contractor
7.28 Emergency Personnel
7.29 Member of Public
7.30 Mental/ Physical Impairment
7.31 Unknown Person
7.26 Pupil/ Student
7G Was pupil/student allowed to be there?
7C NO
7F NO
7D Did they admit to starting the fire?
7A Do they know how the fire started?
7.26.1 Does pupil/ student have a 'negative' history
7H YES
7B YES
7E YES
7W YES
7.26.29 Consider additional use of FIRMs #7.22 to #7.31 inclusive
7i NO
7V Consider informing the Police/Social Services of findings
7X NO
7P Can 3rd person(s) be identified?
7K YES
7J Does pupil/student know of anyone else being in the area of origin?
7Q(2) Use appropriate FIRMs from #7.22 to #7.30 inclusive
7Q YES
7L NO
7R NO
7.26.2 Would pupil/student or colleagues benefit from the fire?
7Z NO
7S Is their account accurate with scene & all available data?
7T YES
7U NO
7R(2) Use FIRM #7.31
7Y YES
7.26.3 Unlikely to be found Responsible for Fire
7V Consider inform the Police of findings
7.26.4 Possibly Responsible for Fire
Pupil/Student

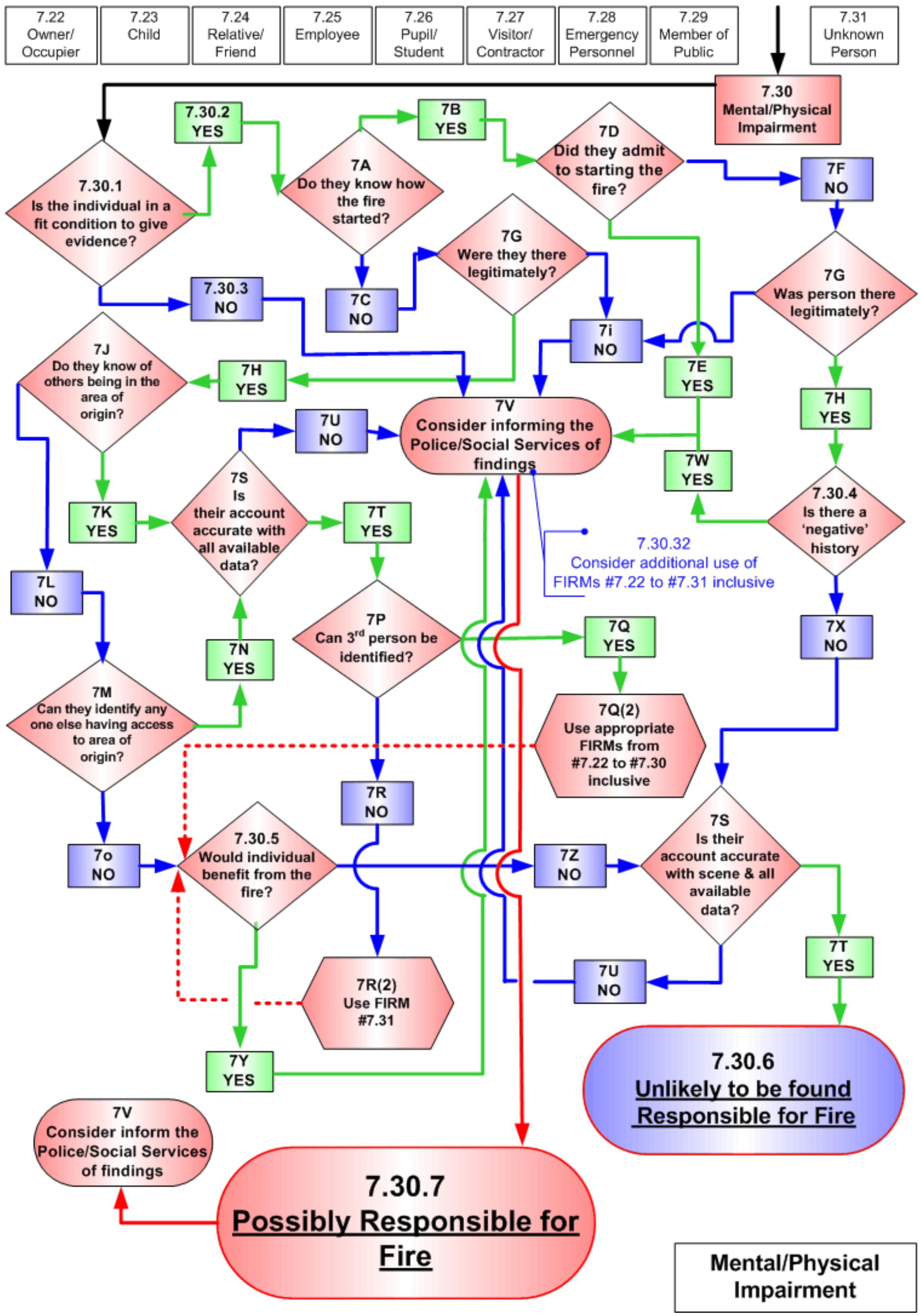

7.22 Owner/ Occupier
7.23 Child
7.24 Relative/ Friend
7.25 Employee
7.26 Pupil/ Student
7.28 Emergency Personnel
7.29 Member of Public
7.30 Mental/ Physical Impairment
7.31 Unknown Person
7.27 Visitor/ Contractor
7A Do they know how the fire started?
7B YES
7C NO
7D Have they admitted to starting the fire?
7F NO
7G Were they there legitimately?
7G Were they there legitimately?
7i NO
7E YES
7.27.29 Consider additional use of FIRMs #7.22 to #7.31 inclusive
7J Is visitor/contratcor aware of anyone else having been in the area of origin?
7H YES
7V Consider informing the Police of findings
7U NO
7H YES
7W YES
7K YES
7T YES
7S Is their account accurate with all available data?
7.27.1 Is there a 'negative' history
7L NO
7P Can 3rd person be identified?
7Q YES
7X NO
7Q(2) Use appropriate FIRMs from #7.22 to #7.30 inclusive
7R NO
7S Is their account accurate with scene & all available data?
7.27.2 Would visitor/ contractor benefit from the fire?
7Z NO
7T YES
7U NO
7R(2) Use FIRM #7.31
7Y YES
7.27.3 Unlikely to be found Responsible for Fire
7.27.4 Possibly Responsible for Fire
Visitor/Contractor

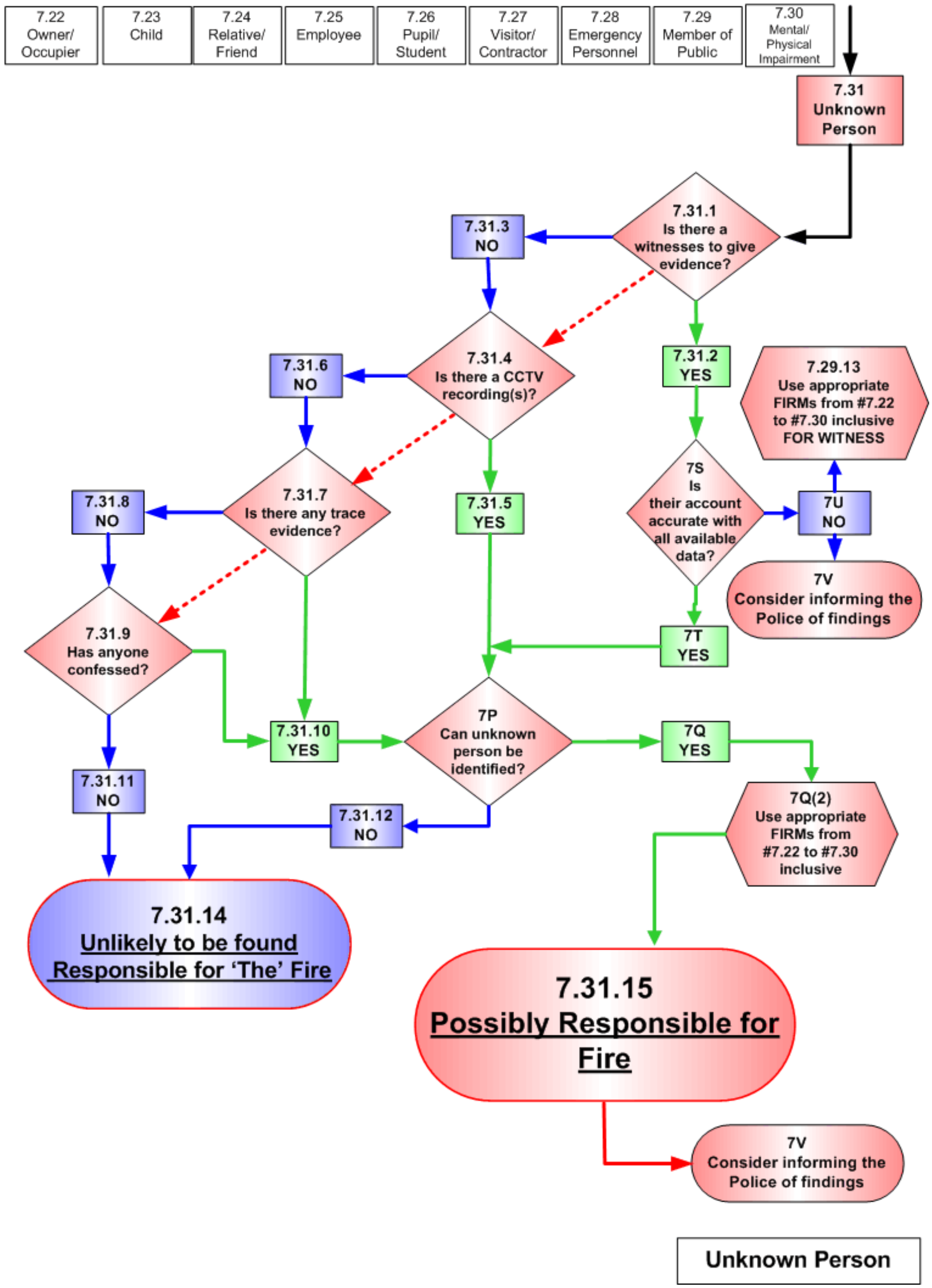


7.22 Owner/ Occupier
7.23 Child
7.24 Relative/ Friend
7.25 Employee
7.26 Pupil/ Student
7.27 Visitor/ Contractor
7.29 Member of Public
7.30 Mental/ Physical Impairment
7.31 Unknown Person
7.28 Emergency Personnel
7.28.1 Did EP discover the fire?
7.28.2 YES
7.28.3 NO
7.28.4 Has this EP discovered previous fires?
7.28.5 YES
7.28.6 NO
7.28.7 Did the fire occur approximately when EP's shift commenced?
7.28.8 YES
7.28.9 NO
7.28.10 Does EP shift attend more fires than other shifts?
7.28.11 YES
7.28.12 NO
7.28.14 Is there a 'negative' history
7X NO
7W YES
7D Has EP admitted to starting the fire?
7E YES
7F NO
7.28.16 YES
7.28.15 Is EPs account in conflict with all available data?
7D Has EP admitted to starting the fire?
7E YES
7F NO
7.28.13 Would EP or colleagues benefit from the fire?
7Z NO
7.28.14 Is there a 'negative' history
7Y YES
7(x) NO
7.28.15 Is EPs account in conflict with all available data?
7.28.17 NO
7W YES
7.28.18 Unlikely to be found Responsible for Fire
7.28.16 YES
7.28.19 Possibly Responsible for Fire
7V Consider informing the Police of findings
Emergency Personnel



Member of Public


7.22 Owner/ Occupier
7.23 Child
7.24 Relative/ Friend
7.25 Employee
7.26 Pupil/ Student
7.27 Visitor/ Contractor
7.28 Emergency Personnel
7.29 Member of Public
7.31 Unknown Person
7.30 Mental/Physical Impairment
7.30.1 Is the individual in a fit condition to give evidence?
7.30.2 YES
7.30.3 NO
7A Do they know how the fire started?
7B YES
7C NO
7D Did they admit to starting the fire?
7F NO
7G Were they there legitimately?
7G Was person there legitimately?
7i NO
7E YES
7H YES
7J Do they know of others being in the area of origin?
7H YES
7U NO
7V Consider informing the Police/Social Services of findings
7W YES
7.30.4 Is there a 'negative' history
7K YES
7S Is their account accurate with all available data?
7T YES
7.30.32 Consider additional use of FIRMs #7.22 to #7.31 inclusive
7L NO
7P Can 3rd person be identified?
7Q YES
7X NO
7N YES
7M Can they identify any one else having access to area of origin?
7Q(2) Use appropriate FIRMs from #7.22 to #7.30 inclusive
7R NO
7o NO
7.30.5 Would individual benefit from the fire?
7Z NO
7S Is their account accurate with scene & all available data?
7T YES
7R(2) Use FIRM #7.31
7U NO
7Y YES
7.30.6 Unlikely to be found Responsible for Fire
7V Consider inform the Police/Social Services of findings
7.30.7 Possibly Responsible for Fire
Mental/Physical Impairment


7.22 Owner/ Occupier
7.23 Child
7.24 Relative/ Friend
7.25 Employee
7.26 Pupil/ Student
7.27 Visitor/ Contractor
7.28 Emergency Personnel
7.29 Member of Public
7.30 Mental/ Physical Impairment
7.31 Unknown Person
7.31.1 Is there a witnesses to give evidence?
7.31.3 NO
7.31.2 YES
7.31.4 Is there a CCTV recording(s)?
7.31.6 NO
7.31.5 YES
7.29.13 Use appropriate FIRMs from #7.22 to #7.30 inclusive FOR WITNESS
7S Is their account accurate with all available data?
7U NO
7V Consider informing the Police of findings
7.31.7 Is there any trace evidence?
7.31.8 NO
7T YES
7.31.9 Has anyone confessed?
7.31.10 YES
7P Can unknown person be identified?
7Q YES
7.31.11 NO
7.31.12 NO
7Q(2) Use appropriate FIRMs from #7.22 to #7.30 inclusive
7.31.14 Unlikely to be found Responsible for 'The' Fire
7.31.15 Possibly Responsible for Fire
7V Consider informing the Police of findings
Unknown Person

Chapter 8
Example applications of the use of Fire Investigation Road Maps (FIRMs) relating to human agency involvement

The following two incidents have been anonymised as they are still subject to police investigations. They have been selected to demonstrate how the FIRMs can be applied to identify how human agency involvement can be a contributory factor in the cause of a fire. In these cases, human agency involvement occurs at the beginning of the fires, during the course of the fires' development and at the end of the fire during the fires suppression and extinction.

8.1 Two fatalities in residential flats fire

A fire had occurred within the living room of a flat on a weekday afternoon, which subsequently spread beyond the front door of that flat, into the common corridor and then into another flat off of that corridor on the same level causing the death of two neighbours. Whilst it is evidence that there were two people involved in this fire (the victims), the application of FIRM #7: Persons, identified other key players who may have been responsible for the fire's initiation and development.

All 23 FIRMs were applied to this incident to include FIRM #7: 'Person' and all sub-FIRMs for the person.

a) FIRM #1: Processes & Substances; it was confirmed very early into the investigation that there were no processes being carried out within the premises or any substances being used or stored there. FIRM #1 was eliminated as a potential cause or fire spread mechanism of the fire.

b) FIRM #2: Structures; a visual inspection was conducted and there was no evidence of any structural issues that may have been responsible for the cause of the fire. When considering the development of the fire [2.2] it was identified that a non-conforming fire door on the entrance to the flat of the victims allowed products of combustion into their flat [2.8] and [2.11]. Cross-checking FIRM #2, it was evident [2.14] that the housekeeping of the premises was unsatisfactory with evidence of the hoarding of combustible materials in the form of furniture [see FIRM #3.19 below]. This had an influence on the development of the fire. This FIRM [2.14] directed the investigation to follow the remaining FIRMs to see if a viable ignition source could have ignited this material. It was considered that structural issues may have been responsible for the fire spread into an adjoining flat [2.19] during this fire's development.

c) FIRM #3: Fuel/Energy Source; all energy sources were considered within the flat, including introduced sources such as bottle gas, where no mains gas supply existed. Following this FIRM it was identified that Electricity [FIRM #3.15], Petroleum Based Products [3.18], Solid Fuels [FIRM #3.19] and Naked Flame [FIRM #3.20], due to the ready accessibility of the flat, should be considered during this investigation.

   Gas [FIRM #3.16], Oils and Oil Based Products [FIRM #3.17] were eliminated as potential energy sources available or present within the flat at the time of the fire following a thorough excavation.

d) FIRM #3.15: Electricity; the electrical system was examined in accordance with [3.15.1] to [3.15.7] inclusive. It was identified at [3.15.7] that although there were electrical items within the premises, the house fuse had been removed so that electricity could not be used as the owner had been evicted. Therefore no electrical supply was available for the conductors or equipment within the flat and no evidence of electrical activity at the fuse board. Electricity was therefore eliminated as a cause of the fire.

e) FIRM #3.18: Petroleum Products; during the excavation and investigation enquiries, it was clear that an ignitable liquid had been present due to, not only the strong smell of petrol or spirits when turning over various materials, but also the rapid development of the fire as reported by witness testimony. The hydrocarbon detector canine was used and samples retrieved (subsequently proving positive for lighter fuel). This was regarded as a potential cause of the fire. See FIRM #7.22 below in Section l).

f) FIRM #3.19: Solid Fuels; there were an abundance of mixed solid fuels, which included bedding, timber upholstered furniture and magazines within the flat, which would have been suitable for the fire's rapid development given a viable ignition source. Solid fuels were also considered potentially responsible for the fire's development.

g) FIRM #3.20: Naked Flame; with the absence of any other energy supply it was considered that a naked flame may have been a viable ignition source for the white spirit and solid fuels. In accordance with the FIRM, the police were informed of these findings.

h) FIRM #4: Animal; there was no evidence of animals having been in the area of origin shortly before or at the time of the fire. This interaction with the scene was eliminated as a potential cause of the fire. Following the complete extinguishment and cooling of the fire scene, the London Fire Brigade's hydrocarbon detector dog completed a search of the premises and was the only animal connected with the scene.

i) FIRM #5: Machinery, Equipment and Appliances; appliances, such as an old television, electric heater and a washing machine were in the area of origin of the fire. Electricity has been eliminated due to the supply being isolated, therefore this FIRM was concluded as [5.18] unlikely to be responsible for the fire.

j) FIRM #6: Weather/Nature; following [6.1] there was evidence of direct sunlight at the time of the fire but not through the window of the room of origin as this window faced east; the fire started in the afternoon when the sun was on the west elevation of the building. There were no reports of lightning strikes in the area that day and no evidence of materials that would be prone to self-heating. Weather and nature have been eliminated as being the potential cause of the fire.

k) FIRM #7: Person; the premises had been secured by the local authority following the eviction of the occupier a week earlier. Following [7.1] to [7.7] it could be suspected that the metal door that had been fitted had been recently damaged by someone forcing the door plate allowing access to the premises. [7.10] was followed to ensure all possible persons that may have been within the premises were identified.

l) FIRM #7.22: Owner/Occupier; the owner/occupier had been evicted one week earlier. She was seen by fire service personal outside the building on their arrival at the scene. The person denied having anything to do with the fire even before being asked about the fire. Following decision point [7G] the person was not there legitimately and the police were informed. The hydrocarbon detector canine was allowed to smell around this person and 'hit' on the hands of this person indicating a possible liquid accelerant (subsequently proving positive for lighter fuel). Also see FIRM #7.30 below). The evicted occupier was considered as possibly responsible for the fire [7.22.4].

m) FIRM #7.23: Child; there was evidence of children in the area at the time of the fire although it was considered unlikely that a child would have the strength to force the metal door. Following [7.23.2] a responsible adult was found for each of the children and [7G] that the children were playing outside the building and were allowed to be there. When following [7J] the children admitted to seeing the previously evicted owner [7P] leaving the building shortly before the fire was seen. The account of the children concurred with the available data [7S] and it was concluded that the children would not have benefitted from the fire [7o]. Children were excluded as a potential cause of ignition [7.23.6].

n) FIRM #7.24: Relative/Friend/Neighbour; the evicted occupier stated that no relatives or friends had been in the area that day. CCTV fitted to the front entrance system confirmed this as fact. Relatives or friends were excluded as being responsible for the fire. As neighbours fall within this category of ‘person’, all neighbours that were affected by the fire, including the two victims, were considered with regard to their interactions and reactions with the event. Apart from the two victims, all were interviewed about their actions when they discovered the fire and what they did following that discovery. The victims were on the telephone to the fire brigade control centre and the emergency voice recordings were subsequently listened to and analysed. It was concluded that they had opened their front door, allowing smoke to enter their flat (opposite the flat of origin) and they then moved away from their front door leaving it open. They were then over-come by the smoke entering their flat and subsequently died of their injuries. All other neighbours’ actions were accounted for and were excluded as being contributory to the cause or spread of the fire.

o) FIRM #7.25: Employee; no employee of the local authority had been within the building on the day of the fire. Employees were excluded as being responsible for the fire.

p) FIRM #26: Pupil or Student; as this was not an educational establishment then this category was ignored as being responsible for the fire.

q) FIRM #27: Visitor or Contractor; there were no contactors working in the building on the day of the fire or the week prior to the fire. There were visitors to other residents shortly before the time of the fire. Visitors that had entered or exited the building shortly before the time of the fire, due to the speed of growth of the fire, were traced using the entrance CCTV and questioned about their potential involvement. They all stated that they did not know how the fire started [7A] and confirmed that they were there legitimately [7G]. Two stated that they saw the person, now known to be the occupier of the premises, near to the same floor level as the fire [7J]. Their accounts agreed with the available information [7S] and the 3rd person was identified [7P]. None of the visitors would have benefitted from the fire [7.27.2] and it was concluded that this category of person could be eliminated as a potential cause of the fire [7.27.3].

r) FIRM #7.28: Emergency Personnel; there were no emergency personnel within the area of the building shortly before the fire. This category was excluded as a potential cause of the fire.

s) FIRM #7.29: Member of Public; one member of public was observed walking their dog at the time of the fire [7G] and following [7.29.1] there would be no benefit from the fire for this person. The member of the public was questioned about his knowledge of the fire [7A]. He had seen the person [7J] identified as the evicted occupier [7P] acting agitatedly outside the building at the time of the fire and before the fire service arrived. His account concurred with all the available data [7S] and it was concluded that he was unlikely to be found responsible for the fire [7.29.2].

t) FIRM #7.30: Mental/Physical Impairment; the evicted person identified in FIRM #7.22 appeared to be under the influence of alcohol or drugs. When applying this FIRM with FIRM #7.22 it was considered that the evicted occupier was fit to be spoken to and give evidence [7.30.1]. She denied knowing how the fire started [7A] but was not there legitimately [7G]. The police had been informed of these facts [7V] and it was considered that the evicted owner occupier was possibly responsible for the fire [7.30.7].

u) FIRM #7.31: Unknown Person; other than the member of public in FIRM #7.29, there were no other persons seen in or around the area or building of origin by any of the other persons already identified or by the entry system CCTV shortly before the time of the fire. Unknown persons were unlikely to be found responsible for the cause of the fire and this category was eliminated as a cause of the fire [7.31.14].

Using all the data gathered by applying the 23 FIRMs and conducting a thorough scene excavation, allowing the investigation methodology to be thorough and structured, demonstrated a rigorous approach in developing, testing and eliminating all available hypotheses.

The evicted occupier is under arrest awaiting trial for the murder of the two neighbours caused by igniting white spirit vapour; the liquid had been poured onto solid fuels (furniture and bedding) within the flat. This accelerated ignition to the contents of the flat allowed the fire to spread faster than a normal fire development of the same contents. The two victims became aware of the fire and called the fire brigade and then went and opened their front door. They then ran back into their kitchen away from the fire leaving the front door open allowing the products of the fire that were now filling the common corridor to enter their flat. They were heard on the telephone carrying out these actions. Had the door been fitted with a self-closing device, they would have been protected from the fire until it was extinguished by fire crews. A family of four who lived opposite the victims stayed within their flat and were physically unaffected by the fire due to the protection of their front door.

8.2 Multiple fatalities in high rise building fire

Several people were killed in their flats but remote from the original fire following a fire in a high-rise block of flats. The fire had spread up the outside of the building from the flat of origin with products of combustion spreading throughout the building. A fire investigation was conducted which took over two years to complete due to the complexities surrounding the fire and smoke spread within and outside the building. Due to wind direction and internal geometries, smoke entered compartments that were some considerable distance from the origin of the fire.

The positive use of the 23 FIRMs in this investigation concluded the origin and cause of the fire within two weeks of the investigation starting.

All 23 FIRMs were applied to this incident to include the ‘Person’ FIRMs.

a) FIRM #1: Process/Substance; there were no processes going on within the privately owned flat. The occupier, however, was in the course of redecorating the flat at ad hoc times before the day of the fire. There was a bottle of white spirit on the upper level above the room of origin ([1.1] to [1.5] inclusive) but no evidence or reported storage of any other substances. This category was eliminated as a cause of the fire [1.19].

b) FIRM #2: Structure; there was no evidence or reported problems with any part of the structure damaging energy supplies to potentially cause a fire ([2.1] to [2.11] inclusive). The general housekeeping [2.14] was good and therefore this category was eliminated as a potential cause of the fire [2.18].

c) FIRM #3: Fuel/Energy Supply; there was evidence of energy supplies [3.1] in the form of an electrical system [3.15], a gas supply pipe [3.16] and solid fuels [3.19]. There was no evidence of naked flames however naked flames [3.20] were considered in this investigation. Energy sources were therefore considered as potentially responsible for the fire [3.14].

d) FIRM #3.15: Electricity; there was an energised electrical system within the premises at the time of the fire [3.15.1]. The switches in the room of origin were closed and fully functional at the time of inspection [3.15.4 and there was evidence of electrical activity adjacent to a fire damaged television set [3.15.10]. This electrical activity, which was identified by the use of arc mapping and the examination of the sequence of activated protection devices, indicated that the fire started within the television set and spread to the materials adjacent to it. Upon inspection of the television set, a fault with the on/off switch was identified as generating resistive heating between the contactors [3.15.12]. It was evident that this fault was capable of generating enough heat to become a viable ignition source for the surrounding plastic casing of the switch [3.15.23] representing a possible accidental ignition of the television [3.15.28]. The television was therefore possibly responsible for the fire [3.15.25].

e) FIRM #3.16: Gas; there was evidence of a gas riser pipe running through the premises [3.16.1]. There was evidence from the fire crews that what appeared to be a gas jet was emanating from the entrance to the flat [3.16.4]. There was no evidence of a leak or uncontrolled escape of gas as the outlet within the flat had been capped off by the gas provider and following tests by the gas authority it was proven that there was no damage or leak from that riser. It was concluded that the gas jet observed by the crews was a result of the intense fire within the flat mixing with the strong wind blowing through the flat creating a 'Bunsen burner' effect and projecting the flames into the corridor. There were no gas appliances within the flat [3.16.6]. Gas was therefore eliminated as a cause of the fire [3.16.12].

f) FIRM #3.17: Oils and Oil Based Products; there was no evidence of oils or oil based products within the premises or having been in the premises at the time of or shortly before the fire. This category was excluded as potentially being responsible for the fire.

g) FIRM #3.18: Petroleum Products; white spirit was reported to have been within the premises on the upper level of the flat and used during redecoration works [3.18.1]. The decorating was not being carried out in the room of origin or on the floor of origin. The white spirit was in a cupboard on the upper floor. The room of origin was tested using a portable hydrocarbon detector and also a hydrocarbon detector dog but there was no evidence of any flammable liquid present [3.18.4]. Petroleum products were therefore eliminated as a cause of the fire [3.18.17].

h) FIRM #3.19: Solid Fuels; there were many items of solid fuels in the room of origin such as beds, soft furnishings, curtains, canvas furniture and plastic cased electrical equipment. [3.19.1]. All of the solid fuels were in a suitable state for combustion at the time of the fire [3.19.4]. Several ignition sources were identified as being within the area of origin at the time of the fire [3.19.7] (See FIRM #3.15: Electricity above and FIRM #6: Weather and Nature below). Solid fuels, e.g. electrical equipment casings, bedding and furniture, were considered as potentially responsible for the fire's origin [3.19.22].

i) FIRM #3.20: Naked Flame; all other forms of energy have been considered during this investigation [3.20.1] and there was no history of previous fires [3.20.5]. The occupier was a smoker and used a disposable lighter but claimed to never have smoked in the premises due to a small child living there [3.20.8]. A lighter would have been capable of lighting much of the solid fuels in the room of origin [3.20.11] however there was no evidence to support an incendiary cause of the fire [3.20.14] following extensive interviews with the occupier by the investigator and the police. The police treated the occupier as a witness of truth. As there was substantial evidence that supported an accidental cause [3.20.18] this category was subsequently considered to be unlikely as a cause of the fire [3.20.22].

j) FIRM #4: Animal; there were no animals within the premises at the time of, or shortly before the fire [4.1] and none could have accessed or left the premises as the occupier was present when the fire started [4.6]. This category was therefore eliminated as a cause of the fire [4.8].

k) FIRM #5: Machinery, Equipment and Appliances; there were domestic appliances in the room of origin at the time of the fire and two of them (a mobile phone charger and a television) were in use at the time of or shortly before the fire [5.1]. No defect or electrical activity was found within the mobile phone charger. A defect within the television switch was identified as causing resistive heating around the switch assembly [5.4] (See FIRM #3.15: Electricity above). There was no evidence of sabotage within the television set [5.7] following extensive examinations [5.10] and linked with FIRM #3.15 above the television therefore was identified as being responsible for the fire [5.20].

It is important to note that although a hypothesis identifying an ignition source and fuel package had been developed and tested, the investigation did not end and all of the subsequent FIRMs were used to eliminate all other potential causes of the fire.

l) FIRM #6: Weather/Nature; at the time of the fire the sun was shining directly into the room and onto the area of origin [6.1] and a mirror was identified as being in the area of origin [6.4]. However, the mirror was flat with bevelled edges and not a concave mirror so was incapable of directing the sun's rays onto a solid fuel, such as the curtains [6.13]. The suns rays were therefore eliminated as a potential ignition source for this fire [6.17].

m) FIRM #7: Person; it was established that the occupier was in the premises with a 15 month old child at the time of the fire [7.1] and [7.4] and that neither had any physical or mental impairment. It was also established that no other person was in the area of origin at the time of, or shortly before the fire and therefore [7.24] to [7.31] were eliminated as being involved with the fire. Due to the child's young age, only 15 months old and physical limitations [7.23] were also eliminated as a cause of the fire.

n) FIRM #7.22: Owner/ Occupier; the occupier denied knowing how the fire started [7A] and she was in the premises legitimately as she lived there [7G]. No one else had been in the area of origin that day [7J] except the child. No one else had access to the area of origin [7M] and their account was accurate with all the available data relating to the fire discovery, development and spread within the property [7S]. There was no evidence of negative history with regard to the owner or the premises [7.22.1] nor would the occupier have benefitted from the fire in any way [7.22.2]. The occupier was therefore eliminated as being the cause of the fire [7.22.3].

Using all the data gathered by applying the 23 FIRMs and conducting a thorough scene excavation, allowing the investigation methodology to be thorough and structured, demonstrated a rigorous approach in developing, testing and eliminating all available hypotheses.

A defect within the television switch contactors was recorded as being responsible for the initiation of the fire, igniting the surrounding switch casing, spreading to the ignition of the television casing and then spreading to the surrounding solid fuels. The fire continued to develop beyond the confines of the flat and spread externally to an upper floor level flat where heat and smoke killed an occupant within it. Smoke also travelled internally and externally into other flats on other floor levels, causing the asphyxiation of occupants within a flat on a higher floor than the flat of the fire's origin.

Chapter 9
Validation of the reliability of Fire Investigation Road Maps

9.1 Aim

The aim of this validation exercise was to devise a rigorous test to assess the reliability of the Fire Investigation Road Maps (FIRMs) when applied to case studies of fire investigations conducted by professionals from various stand-points, i.e. different backgrounds, and in a controlled environment using table top exercises.

9.2 Objectives

a) To demonstrate a consistent, structured, repeatable and auditable methodology during a fire investigation.

b) To gather qualitive and quantitive data using table-top fire investigations of real case studies by:

   i. Recording the ease by which fire investigators reached their conclusions.

   ii. Recording the time taken by each investigator, from the six identified agency 'groups' associated with fire scene investigations, to conclude their investigation of the two table top exercises.

   iii. Comparing the accuracy and thoroughness of the investigations using the table top exercises to the associated actual 'real' investigation conclusions using:

      1. all data gathered during the case study scene investigation compared to that of the table top exercises;
      2. all questions asked by the fire investigator at the case study fire scene to those asked during the table top exercises;
      3. the analysis, interpretation and conclusions of all data at the case study fire scene compared to those at the table top exercises.

   iv. Establishing whether the investigators preferred using their own methodologies or combining their methodology with that of the FIRMs during this exercise.

c) To evaluate whether the use of FIRMs has a positive or negative effect on a fire investigation.
d) To establish if the FIRMs are currently in a user friendly format and the process followed within the FIRMs is a reliable methodology (some of the FIRMs used during the validation process have been slightly modified to be more functional).

9.3 Methodology

Careful consideration was given to developing a methodology that allowed observations to be made and quantified of a fire investigator carrying out an investigation using their own methodology and subsequently carrying out an investigation using the FIRMs. Two fire investigations are never precisely the same, therefore it was concluded that the only way to compare an investigator's methodology was to attend and observe two similar fire investigations for all of the investigators that took part in the validation of the FIRMs. This allowed the observer (the author of this thesis) to maintain consistency with the available data that the investigator would need to acquire and consider. It is difficult to predict what an investigation will entail until at the scene, therefore it was deemed to be an extremely onerous if not impossible task to be able to successfully 'shadow' and observe one investigator, let alone a representative group. The time scale for one investigator could run into months and the comparison of these fire investigations to other fire investigators yet to be selected for observation could take years; even then, the differentials in the fire scenes could be prohibitive to formulate successful conclusions.

There needed to be a consistent approach where the outcomes were measurable, using more than one case study per investigator to allow a comparison to be made.
Initially it was decided that training scenarios would be the most practical arena to observe two similar fire investigations by the same investigator. Consideration was given to attend the fire investigation practical training facility at Gardiner Associates in Wethersfield, Essex, where pre-designed scenarios are set fire to for syndicates of candidates to carry out their fire investigations. The author would therefore know how

the fire started and monitor the methodology of selected investigators. The problems identified with this approach were:

- Candidates were predominantly fire and rescue service personnel.
- A few candidates were from police forces
- Rarely, candidates were from the insurance industry
- It was unpredictable which type of candidates would be on a course and when they would be on those courses
- The courses were paid for by the candidates' organisations and the observation process when using the FIRMs may influence the course structure and outcomes
- Although in syndicates of up to eight candidates, it would only be practical to observe one candidate at a time, and that candidate may be influenced by others within their syndicate
- Candidates could only successfully complete one full fire scene investigation on a one week course.

It was therefore decided that this approach would be too time restrictive, too intrusive on a pre-structured course and would not allow for the observations of fire investigators from other agencies in a controlled environment.

Table-top exercises are used in the emergency services to test operational response procedures and are often used within multi-agency exercises. Due to the complexities of a complete and thorough fire investigation, it was decided to conduct two table-top exercises of well documented fire investigations that were of similar origin, cause, development and human agency involvement to enable a consistent evaluation by the observer. It would have been too arduous on the fire investigators to have completed more than two table top-exercises on the same day. These exercises could then be repeated across all agencies identified as being involved in the fire investigation discipline.

Two similar case studies were eventually selected that had been comprehensively documented with supporting evidence including contemporaneous notes, photographs, sketches, plans, incident logs, telephone logs and other available data. The similarity of the cases used enabled a consistent approach by the observer when recording each of the fire investigators' methodologies during their investigations. It was considered that, had two different types of case studies been used, for example, one residential fire investigation and one industrial fire investigation, the assessor would not have been able to make consistent observations between the two 'agency investigators' when swapping the case studies around. The sequence of the case studies between the two investigators were exchanged, e.g. Fire Investigator #1 from Agency 'X' completed Fire Scene 'A' without the FIRMs, then Fire Scene 'B' using the FIRMs, whereas Fire Investigator #2 from Agency 'X' completed Fire Scene 'B' without the FIRMs then Fire Scene 'A' with the FIRMs allowing the observer to record whether the FIRMs were applied to both exercises with a consistent methodology.

The evidence that was available for both cases provided the potential for a range of approaches to be taken. Both fires also included casualties that had suffered fatal injuries. Any relevant information that had to be obtained about them needed to be sought from others; this encouraged the positive use of FIRM #7: 'The Person' and its associated sub-FIRMs when they were being utilised during the second table-top exercise by the fire investigators.

Once the case studies were prepared and the validation methodology determined, it was necessary to trial them with sample fire investigators to identify potential short-falls before undertaking the full validation of the FIRMs and their applicability. An initial validation trial using 10 fire investigators from a fire brigade's Fire Investigation Team was conducted as the standards of their training, development, job description and the remit of their role was consistent. It was also considered that with the wide range of fire investigations that this team conduct, including fatal fires that result in a Coroner's inquest, fires that result in a criminal conviction and fires that result in civil action, this representative group would be best for validating the use of the FIRMs and the width of their applicability.

Following the initial trial exercises, it was decided that two investigators would be a reasonable representation from each of the organisations to be used during the full validation. Therefore, a representative sample of two investigators from the following agency ‘groups’ identified as being involved with fire investigation were used to demonstrate a potentially varying range of investigative styles and group ‘focus’. It also meant that 12 fire investigators were employed and, though not as statistically significant as one would wish, would provide an indicative response for the profession as a whole. Therefore the results of 20 trained fire investigators were included in the validation.

1. Fire and rescue service (FRS #1 and FRS #2)
    - Sample group (FRS #3 to FRS #10)
2. Police service (PS #1 and PS #2)
3. Forensic science provider (FSP #1 and FSP #2)
4. Forensic insurance investigation provider (FII #1 and FII #2)
5. Fire scientist/engineer (FSE #1 and FSE #2)
6. Fire investigation training provider. (FTP #1 and FTP #2)

Anonymity was maintained by coding the individuals as bracketed above.

Although some of the participating investigators were known to the assessor, i.e. FRS #1 and FRS #2 while another eight were used as control samples (FRS #3 to FRS #10), the investigators were reassured of their anonymity within the thesis and were asked that if they recognised any of the incidents, Fire ‘A’ or Fire ‘B’ at any time during the process, they would let it be known and the observer (the author of this thesis) would stop their investigation. This situation did not occur in any of the exercises with any of the fire investigators in this validation process. The fires selected were relatively common types of fire.

Each investigator was advised that they could use note pads, pre-printed or formatted contemporaneous notebooks or any other means that they or their organisation normally uses for making notes.

The first fire investigator from each organisation investigated ‘Fire A’ without using the FIRMs. This enabled the observer to record the methodology used by the first investigator from an organisation and later compare their methodology with that of their colleague from the same organisation when also investigating a scene without the use of the FIRMs. Those that first investigated ‘Fire A’ then investigated ‘Fire B’, but this time they had access to the FIRMs and were encouraged to refer to them at least once during their investigation.

The second investigator from each organisation investigated ‘Fire B’ first, without using the FIRMs. This allowed the assessor to have a direct comparison of the two fire investigators’ methodologies from the same organisation when investigating different fires scenes without the use of the FIRMs. Those investigators then investigated ‘Fire A’ using the FIRMs, again allowing the assessor to compare the same two investigators’ methodologies when using the FIRMs on different fire scenes.

This process allowed a comparison of outcomes between each organisation, whereby one of its investigators had used the FIRMs on ‘Fire A’ and the other on ‘Fire B’. The investigators were then asked to complete a short questionnaire (Table 9.10) to evaluate whether or not they thought the FIRMs were a beneficial aide to their investigation, with a scoring range from 1 (strongly disagree) to 5 (strongly agree). The qualitative outcomes of the questionnaire were entered into the Validation Outcomes Table – Tables 9.3 to 9.9 below. The observer also gathered quantitative data by scoring the investigators during their data gathering stages of the two exercises.

9.3.1 The Scoring System

Two scoring systems were used; one was a quantitative scoring system used by the observer during each exercise, which allowed points to be applied by the observer to each of the investigators’ methodologies based on the depth of the investigator’s inquiry. The other was a qualitative scoring system, used by each of the investigators and detailed in 9.4.3 below, relating to their positive and negative opinions regarding the application of the FIRMs when combined with their own methodology.

It was originally considered that a simple '0' and '1' scoring system would identify whether the investigator had considered all available hypotheses relating to the incidents or not; in other words, if the investigator discussed 'electricity' he or she would be awarded 1 point and if they did not, they would be awarded '0' points.

This, however, did not measure the depth of their enquiries and did not record how far they would have travelled along the associated FIRM.

The scoring system that was used by the observer applied directly to the FIRMs' subject groups and the depth of enquiry that those FIRMs presented. Every FIRM was divided into three levels of enquiry, dependent upon the data required to complete it:

- 'Level 1' included the title of the group and superficial exploration of its involvement. If the investigator does not explore beyond this level of data, a '1' would be awarded.
- 'Level 2' included a more thorough exploration of the subject group which required the investigator to progress along the road map asking additional questions about its involvement in relation to the fire's 'cause' and also included cross-mapping of the FIRMs due to the nature of the questions required. An example of this is FIRM #3.15.20 '*Is there evidence of sabotage, theft of electricity or mis-use of installation or equipment?*' which requires the investigator to consider at this point, FIRM #5: '*Machinery, Equipment and Appliances*' and also FIRM #7 '*Person*'. If the investigator gathers this depth of data but goes no further then a '2' would be awarded.
- 'Level 3' included analysing all the relevant data to either form a hypothesis about that subject group's involvement in relation to the cause of the fire or dismiss it from their enquiries; this would attract a score of '3' for this FIRM.

An illustrative example using FIRM #3.15: 'Electricity' is shown in below:

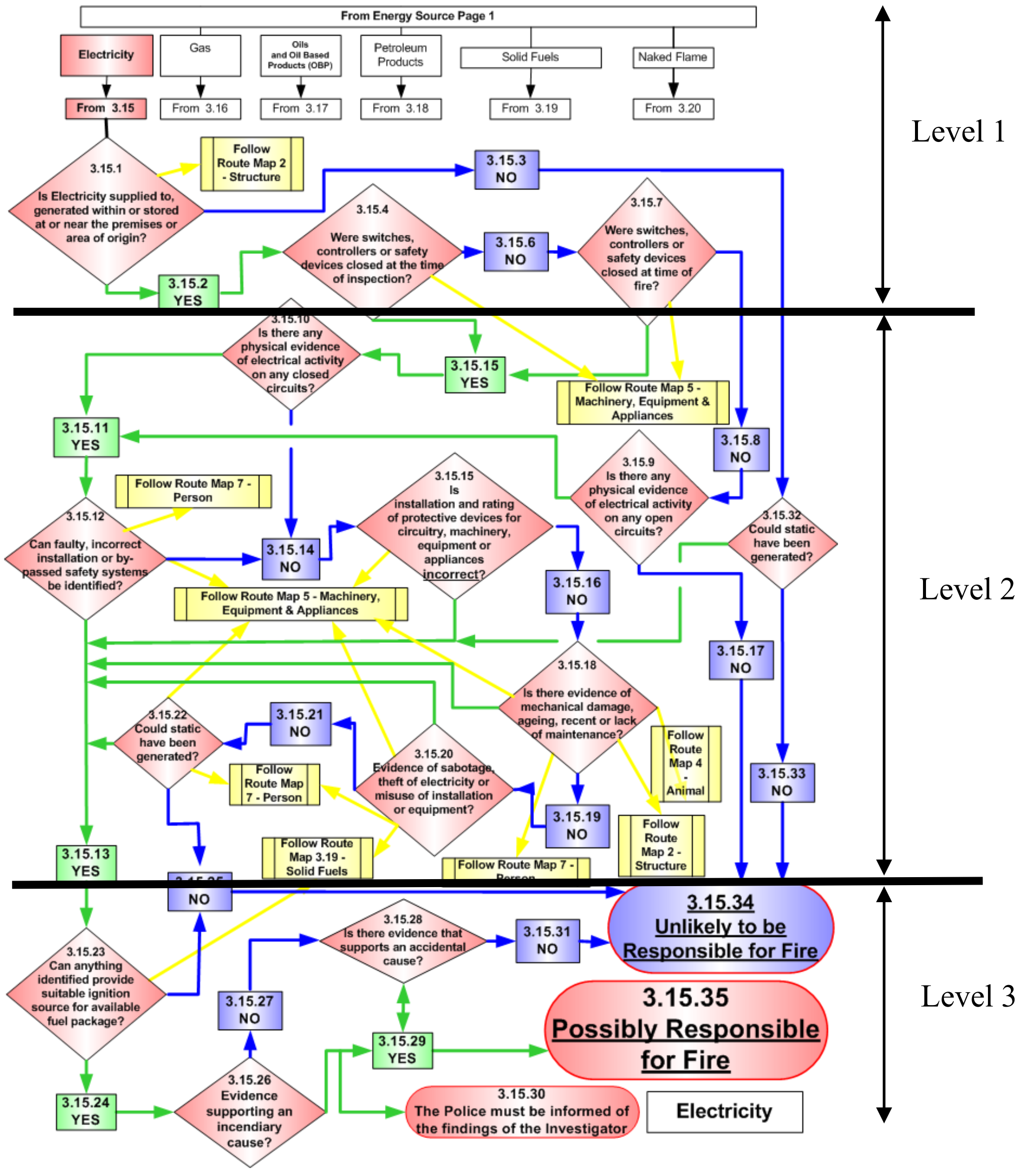


Figure 9.1 Point Application System using Three Levels within FIRM

If an investigator did not ask about one of the subject groups' involvement, e.g. Weather/Nature, they would be marked '0'. If they asked questions within the 'Level 1' area of the FIRM, they were awarded 1 point. If they progressed and asked questions within the 'Level 2' area of the FIRM, they were awarded 2 points. If they completed their enquiries and encompassed questions within the 'Level 3' area of the FIRM, and either considered a hypothesis for that group or dismissed it, they were awarded 3 points. The highest mark in the range carried the score to the total; for example if the use of electricity was mentioned, the investigator was awarded 1 point. If they then proceeded to ask for more data about the electrical involvement with the fire, therefore carrying them along the road map into the 'Level 2' area, they were awarded 2 points. If they developed a hypothesis for electricity as being the potential cause of the fire or discarded it as being a cause of the fire, taking them into the 'Level 3' area of the FIRM, they would be awarded 3 points and therefore the 3 points only would be added to their score. (See examples in Tables 9.1 and 9.2 below)

A debriefing following the exercises explained that their feed-back and the observer's data would be valuable to the development of the FIRMs. The investigators were also asked to provide both negative and positive feed back and that they should be truthful and critical as all of their comments and observations were needed to validate the application of the FIRMs successfully.

9.3.2 Fire 'A'

This scenario involved a double fatality fire in a mid-terraced, two storey house; this had a small front garden leading from the pavement of a main road and a back garden, which was accessed through the kitchen. The house was brick built, circa 1930, with metal 'Crittal' single glazed windows and a traditional pitched and tiled roof. The house consisted of a lounge, kitchen and bathroom on the ground floor and two bedrooms on the first floor. Both occupants were found deceased on the ground floor but in separate rooms; one in the lounge and the other in the kitchen area.

A scoring system was developed whereby marks were attributed to data gathered during the table-top exercise's evidence collection process and awarded using the following aspects of the case:

- A bath tap was found running into a bath and down the unplugged drain and an empty, dry bucket was located beside the bath, but with no water in it.
- A section of gas pipe was missing from the gas meter.
- The male casualty was 67 years old and had sustained a head injury prior to falling to the floor; (blood could be seen as having been running down the side of his face).

- The male casualty had heavy smoke depositions around his nostrils and mouth and reddening of the face.
- The kitchen area, where the male casualty was found, had partial fire damage with severe heat damage throughout, however the lounge, where the female casualty was found, had developed to flashover conditions during the fire's development.
- The couple were married and lived alone with their pets.
- The female was 75 years old and was a known alcoholic by her neighbours. She used to drink herself to sleep on the sofa. The husband would leave her there and go to bed upstairs.
- There was information regarding previous accidental fires from the fire brigade and a neighbour due to her careless smoking habits.
- The fire was seen by a passer-by who alerted a neighbour to call the fire brigade. The premise was secure when the fire brigade arrived. The passer-by had seen flames within the front room.
- The neighbour forced the front door prior to the arrival of the fire brigade and observed thick smoke in the hallway, and then the fire developed throughout the ground floor.
- The lounge door was found to be closed during the fire's development.
- The back door was found to have been opened from the inside during the fire's development.

It was anticipated that by using the 'Person' FIRMs and finding out about previous personal history of the occupants, all of the fire investigators would establish that the female had most probably fallen asleep under the influence of alcohol and had carelessly discarded a cigarette onto the non-combustion modified sofa, causing a smouldering fire. The husband most probably smelt this from his bedroom upstairs and come down to discover a smoke filled lounge. He had shut the lounge door behind him, most probably to stop the smoke spreading upstairs, opened the back door to let one of the dogs out and ventilate the smoke. There was an open sliding door between the lounge and the kitchen and opening the back door had the effect of ventilating the fire, causing it to develop into a free flaming fire. He had tried to get water into a bucket from the bath tap but had been overcome by smoke and collapsed onto the floor in the kitchen area. He had caught the side of his head on a kitchen cupboard as skin had been found there, and his cut had bled whilst he was trying to get the water. The passer-by saw the flames and when the neighbour forced the front door, ventilated the lounge causing the fire to develop to flashover. Toxicology results were also available to the investigators, which would indicate an extremely high alcohol level for the female and a reasonably high level for the male. The female had relatively low carboxy-haemoglobin levels, which were attributed to her frail condition, her most probably being asleep or intoxicated whilst lying down and having direct bodily involvement with the fire. She appears to have died from a combination of smoke inhalation and heat trauma whereas the male had over 50% carboxy-haemoglobin levels due to him being mobile, active and agitated whilst breathing in the smoke.

Scores were awarded for key factors relating to the fire scene that should have been addressed by the investigator, which would have them progress their investigation in a positive direction, ensuring all potential ignition sources were addressed. Those scores were inserted into a table and shown in the example in Table 9.1 below:

Fire 'A' Billet Road Used FIRMs Did not use FIRMs	Each key item missed = 0; L1=1; L2=2; L3=3		
	Data Requested/Identified		
Details Relating to FIRMs	**Level 1**	**Level 2**	**Level 3**
Any use of chemicals or substances (paint, etc)	0	-	-
Any structural issues (defects, movement, etc)	0	-	-
Electricity supplied	1	2	3
Gas supplied	1	2	-
Oils present (e.g. wood working)	0	-	-
Petrol/diesel present in any quantity	1	2	3
Solid fuels (fuel loading of furniture, etc)	1	2	-
Naked flames	1	2	3
Animals present	0	-	-
Machinery, Equipment and/or Appliances	1	2	3
Weather/ Nature	0	-	-
Role of person involved	1	2	-
Systematic consideration for each role identified	0	-	-
CCTV for unknown persons	0	-	-
Contact details for relative, friend, neighbour	1	2	3
Total score out of 45		**6**	**+ 15=21**
Percentage of expected information requested	**46.6%**		

Table 9.1 – Example Results of Fire 'A'

9.3.3 Fire 'B'

This scenario was chosen for its similarity to Fire 'A', which enabled a consistent approach by the assessor when observing each of the fire investigators' methodologies during their investigations. This fire involved a single fatality fire in a three bedroom flat within a purpose built block of flats on the top (second) floor level. The flats were traditional brick built circa 1970, with timber-framed single glazed windows and a traditional pitched and tiled roof and common roof void. The flat consisted of a lounge, kitchen and bathroom and three bedrooms. The lounge had double aspect windows with one of them being described as a 'Juliet' balcony (an inward opening door with a flat railing across the opening but no external ledge to stand on). The male occupant was found in the lounge area.

The same scoring system was used whereby marks were attributed to data gathered during the table-top exercise's evidence collection process and awarded using the following aspects of the case:

- A bathroom basin tap was running with a garden hose going out of the window into a garden area to the rear of the flats.
- A kitchen tap was found running.
- Two cooking pans were found in the lounge, one with various coins in it as it was used to collect loose change.
- The male casualty was 82 years old.
- The male casualty had heavy smoke depositions around his nostrils and mouth and had been severely burnt.
- The lounge had developed to flashover during the fire's development.
- The whole flat was smoke damaged with the only other fire and heat damage was to the ceiling in the hallway outside the lounge internal door.
- The male casualty lived alone.
- There was information regarding the male victim's careless smoking habits from his son; he used to discard spent matches onto the carpet.
- The fire was seen by a neighbour who alerted her husband to go and assist whilst she called the fire brigade. The premise was secure when the fire brigade arrived. The neighbour had seen black smoke and flames coming from within the front room via the 'Juliet' balcony.
- The neighbour's husband looked through the letter box of the front door and observed thick smoke in the hallway so decided not to force the door.

It was anticipated that all of the fire investigators would establish that the male had been working on his allotment at the rear of the flats, watering his plants via the garden hose from the bathroom tap extending out of the bathroom window. He had come up to the flat for a cup of tea and to smoke a cigarette whilst he called and spoke to his son, approximately 20 miles away, on the telephone in the hall way.

A time line could be obtained from the itemised telephone bill and the time of call to the fire brigade. Due to his reported habit of discarding matches and evidence within the flat of spent matches on the carpets, it is most probable that he initiated and discovered a free burning fire and had tried to extinguish it by filling up two available cooking pots from the kitchen, one containing his loose change, which would have made the pot heavier than if it just had water in it.

Upon his return into the lounge, he was overcome by smoke and collapsed backwards onto a coffee table. The fire developed until the glass in the 'Juliet' door failed and the neighbour saw the thick black smoke followed by the flames. The back window soon failed after this, ventilating the lounge causing the fire to develop to flashover. Toxicology results were also available to the investigators, which would indicate no identifiable alcohol level but a relatively high carboxy-haemoglobin of over 50%.

Scores were awarded as in Fire 'A' and detailed in the example table below:

Fire 'B' Ivy Road **Used FIRMs/ Did not use FIRMs**	**Each key item missed = 0; L1=1; L2=2; L3=3**		
Details Relating to FIRMs	**Data Requested/Identified**		
	Level 1	**Level 2**	**Level 3**
Any use of chemicals or substances (paint, etc)	1	2	-
Any structural issues (defects, movement, etc)	1	2	3
Electricity supplied	1	2	3
Gas supplied	1	2	3
Oils present (e.g. wood working)	1	-	-
Petrol/diesel present in any quantity	1	2	3
Solid fuels (fuel loading of furniture, etc)	1	2	3
Naked flames	1	2	3
Animals present	1	-	-
Machinery, Equipment and/or Appliances	1	2	3
Weather/ Nature	1	2	3
Role of person involved	1	2	3
Systematic consideration for each role identified	1	2	3
CCTV for unknown persons	0	-	-
Contact details for relative, friend, neighbour	1	2	3
Total score out of 45	**2**	**+ 2**	**+33=37**
Percentage of expected information requested	**82.2%**		

Table 9.2 – Example Results of Fire 'B'

9.3.4 The Exercises

Two exercise sessions were set up for the validation; for the first participants, the first scene was 'Fire A' and the second scene 'Fire B'. These exercises were reversed for each of the second participants from the same organisation, i.e. the first exercise was Fire 'B' and the second was Fire 'A'. This was to enable identification of potential patterns or trends in organisational methodologies and focus.

Each investigator was given a scripted brief throughout the exercises to ensure consistency. The investigators were given the initial incident information and shown photos of the outside of the premises, detailing what they would see upon their arrival at the scene. They were then able to ask questions as they would normally do at a fire scene investigation. The answers would be consistent with the available data and the observer's knowledge of the incident. Once they had identified and progressed into the room of origin, A1 size photographs showing the four sides of the compartment of origin were displayed on four walls in the validation exercise room so that the investigator could orientate themselves within the room of origin. All other available images taken of the scenes were made available, giving the investigators comprehensive visual data of the scenes.

Each exercise folder contained contemporaneous notes from the real fire investigation case study and all other related data that had been collected. The investigator did not have access to the folders but could ask any questions about the incident and they were then given scripted answers immediately. In reality, some of the answers would have taken considerable time to acquire, even weeks when such requests as itemised telephone bills were asked for. However, to extend the time frame of the responses to questions in order to make it more realistic would have been impractical and time restrictive for these exercises. Each table-top exercise ran for approximately one hour; however more time was allocated if the participating investigator requested it.

Table 9.3 - Validation Outcomes Table – Fire & Rescue Service

Name of Fire Investigator	FRS #1						Fire & Rescue Service	
	Use of FIRMs?	Time to Conclusion	Observer's score* L1	L2	L3	Total	Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
Fire A	No	1hr 15mins	Nil	13.3%	33.3%	46.6%	82.2%	82%
Fire B	Yes	0hr 55 mins	4.4%	4.4%	73.4%	82.2%		
Name of Fire Investigator	**FRS #2**						**Fire & Rescue Service**	
	Use of FIRMs?	Time to Conclusion	Observer's score* L1	L2	L3	Total	Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
Fire A	Yes	1hr 8mins	2.2%	8.8%	66.6%	77.7%	77.7%	82%
Fire B	No	1hr 35mins	4.4%	17.7%	13.4%	35.5%		

** The observer's score is derived from the evaluation and scoring of the investigator's outcomes for each fire. (Appendix 3)*

Table 9.4 - Validation Outcomes Table – Police

Name of Fire Investigator	PS #1						Police	
	Use of FIRMs?	Time to Conclusion	Observer's score* L1	L2	L3	Total	Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
Fire A	No	0hr 40mins	6.6%	8.8%	13.4%	28.8%	48.8%	90%
Fire B	Yes	0hr 25mins	11.1%	17.7%	20%	48.8%		
Name of Fire Investigator	**PS #2**						**Police**	
	Use of FIRMs?	Time to Conclusion	Observer's score* L1	L2	L3	Total	Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
Fire A	Yes	0hr 42mins	4.4%	17.7%	53.4%	75.5%	75.5%	98%
Fire B	No	0hr 45mins	Nil	22.2%	13.3%	35.5%		

** The observer's score is derived from the evaluation and scoring of the investigator's outcomes for each fire. (Appendix 3)*

Table 9.5 - Validation Outcomes Table – Forensic Service Provider

Name of Fire Investigator	FSP #1						Forensic Service Provider	
	Use of FIRMs?	Time to conclusion	Observer's score* L1	L2	L3	Total	Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
Fire A	No	1hr 0mins	Nil	8.8%	46.7%	55.5%	100%	70%
Fire B	Yes	1hr 20mins	Nil	Nil	100%	100%		
Name of Fire Investigator	**FSP #2**						**Forensic Service Provider**	
	Use of FIRMs?	Time to conclusion	Observer's score* L1	L2	L3	Total	Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
Fire A	No	0hr 55mins	4.4%	4.4%	33.2%	42%	88.8%	66%
Fire B	Yes	1hr 15mins	Nil	8.8%	80%	88.8%		

** The observer's score is derived from the evaluation and scoring of the investigator's outcomes for each fire. (Appendix 3)*

Table 9.6 - Validation Outcomes Table – Forensic Insurance Investigator

Name of Fire Investigator	FII #1						Forensic Insurance Investigator	
	Use of FIRMs?	Time to conclusion	Observer's score* L1	L2	L3	Total	Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
Fire A	No	1hr 20mins	6.7%	13.3%	13.3%	33.3%	88.8%	74%
Fire B	Yes	1hr 5mins	4.4%	17.7%	66.7%	88.8%		
Name of Fire Investigator	**FII #2**						**Forensic Insurance Investigator**	
	Use of FIRMs?	Time to Conclusion	Observer's score* L1	L2	L3	Total	Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
Fire A	Yes	1hr 0mins	6.6%	13.4%	60%	80%	80%	64%
Fire B	No	1hr 15mins	4.4%	8.9%	20%	33.3%		

** The observer's score is derived from the evaluation and scoring of the investigator's outcomes for each fire. (Appendix 3)*

Table 9.7 - Validation Outcomes Table – Fire Investigation Training Provider

Name of Fire Investigator	FITP #1						Fire Investigation Training Provider	
	Use of FIRMs?	Time to conclusion	Observer's score*				Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
			L1	L2	L3	Total		
Fire A	No	1hr 42mins	6.6%	17.7%	13.4%	37.7%	86.6%	80%
Fire B	Yes	1hr 23mins	2.2%	17.7%	66.7%	86.6%		
Name of Fire Investigator	**FITP #2**						**Fire Investigation Training Provider**	
	Use of FIRMs?	Time to Conclusion	Observer's score*				Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
			L1	L2	L3	Total		
Fire A	Yes	0hr 47mins	4.4%	17.7%	53.4%	75.5%	75.5%%	92%
Fire B	No	1hr 08mins	2.2%	13.3%	13.3%	28.8%		

** The observer's score is derived from the evaluation and scoring of the investigator's outcomes for each fire. (Appendix 3)*

Table 9.8 - Validation Outcomes Table – Fire Scientist/Engineer

Name of Fire Investigator	FSE #1						Fire Scientist/Engineer	
	Use of FIRMs?	Time to conclusion	Observer's score* L1	L2	L3	Total	Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
Fire A	No	1hr 45mins	11.1%	4.4%	26.7%	42.2%	82.2%	84%
Fire B	Yes	1hr 35mins	4.4%	4.4%	73.4%	82.2%		
Name of Fire Investigator	**FSE #2**						**Fire Scientist/Engineer**	
	Use of FIRMs?	Time to Conclusion	Observer's score* L1	L2	L3	Total	Observer's score - Positive use of FIRMs	Investigator's score - Positive use of FIRMs (Appendix 2)
Fire A	Yes	1hr 05mins	Nil	8.8%	80%	88.8%	88.8%	82%
Fire B	No	0hr 53mins	2.2%	13.3%	13.3%	28.8%		

** The observer's score is derived from the evaluation and scoring of the investigator's outcomes for each fire. (Appendix 3)*

Table 9.9 - Validation Outcomes Table - Summary

	Total Non-use of FIRMs	Total Use of FIRMs	Average Time to conclusion of the fire's origin and cause	Observer's Average score – L1 FIRMs not used / FIRMs used	Observer's Average score – L2 FIRMs not used / FIRMs Used	Observer's Average score – L3 FIRMs not used / FIRMs used	Observer's Average Total Score FIRMs not used / FIRMs Used	Investigators' Average score - Positive use of FIRMs (Qualitative)
Fire A - no FIRMs	7		1hr 14mins	4.05%	12.17%	21.1%	37.32%	80.33%
Fire A FIRMs used		5	0hr 56mins					
Fire B – no FIRMs	5		1hr 07mins	3.67%	11.42%	66.13%	81.22%	
Fire B FIRMs used		7	1hr 08mins					

Time taken to complete Fire Investigations				
Organisation	**Fire A No**	**Fire A Yes**	**Fire B No**	**Fire B Yes**
FRS	01:15:00			00:55:00
		01:08:00	01:35:00	
PS	00:40:00			00:25:00
		00:42:00	00:45:00	
FSP	01:00:00			01:20:00
	00:55:00			01:15:00
FII	01:20:00			01:05:00
		01:00:00	01:15:00	
FITP	01:42:00			01:23:00
		00:47:00	01:08:00	
FSE	01:45:00			01:35:00
		01:05:00	00:53:00	
Total	**08:37:00**	**04:42:00**	**05:36:00**	**07:58:00**
Average	**01:13:51**	**00:56:24**	**01:07:12**	**01:08:17**
Average time for non-use of FIRMs				**01:10:32**
Average time for positive use of FIRMs				**01:02:21**

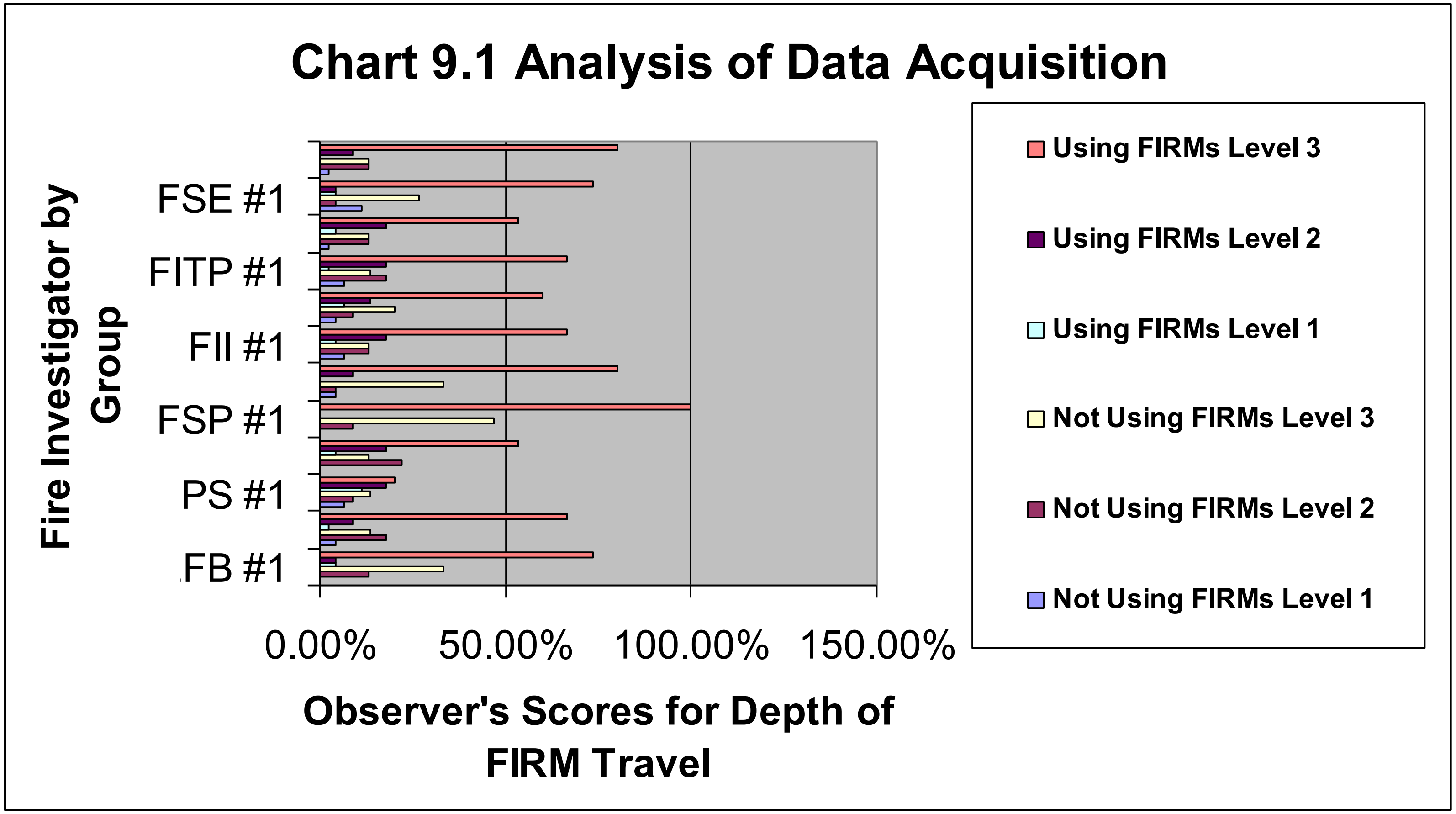


Chart 9.1 Analysis of data acquisition

9.4 Analysis of quantitative (statistical) data

The 'Validation Outcomes Table - Summary' (detailed in Table 9.9 above) collated all of the scores attributed by both the observer (the author of this thesis) and the investigators for all 24 table-top exercises. The additional eight investigators that were used as a control sample were not included in this analysis. It is estimated that the total time spent on the validation exercise process was approximately 144 hours.

The most important aspects of the table identify:

- that the time taken to complete the exercises was not an important factor;
- that although most investigators completed the second investigations when using the FIRMs more quickly than their first investigation without the use of the FIRMs, there was no correlation between the time taken and the thoroughness of their investigations;
- that those investigators that used the FIRMs extensively ensured thoroughness of the data gathering process and achieved high scores;
- the importance of the investigator's initial enquiries to ensure full depth of travel along the FIRMs and the acquisition of additional relevant data;
- the depth of enquiry the fire investigators achieved in concluding both fire investigations when actively using all of the FIRMs during the second exercise along with their own methodology.

The scores attributed by the fire investigators when answering questions about their opinions of the effective use of the FIRMs is important, but are put into context with the qualitative (anecdotal) data in 9.5 below.

9.4.1 The average time to conclude the investigations when NOT using FIRMs during the first exercise

Once the fire investigators were fully briefed about their first exercise, then given the ordering information and shown external photographs of the building upon their arrival, eight of the 12 (fire and rescue service, forensic insurance investigators, fire investigation training providers and fire scientist/engineer) then started to gather information about the buildings, the internal layout and the construction. The four that did not focus on the building before entering it were more focused on preserving the scene and identifying a crime or liability, which reflected their roles within the discipline; these four were Crime Scene Investigators and Forensic Scientists. As the exercises progressed, a plethora of questions were asked by the investigators about the incidents, however, all but two failed to gather data in a systematic or structured way. (The author has observed these behaviours at fire scenes and recognise this ‘scatter gun’ approach as being ‘responsive’ to the vast quantity of data that is available at the beginning of a fire investigation.) Several made pages of notes, whilst others made very few notes. All were advised that they could use their own organisational note books or aide memoires, but none of them did.

Once they started to obtain data about the potential cause of the fire, it was evident that they started to form a hypothesis and continued to gather data to re-enforce that hypothesis, sometimes repeating the request for a certain piece of data that had already been given to them. The depth and thoroughness of the questioning appeared to be limited by the investigators’ capacity to apply some form of logical methodology from ‘memory’. Several openly stated that they must try to consider another hypothesis as they thought the exercises were leading them down an ‘obvious’ path and there may be a ‘twist’ to the investigations’ conclusions. This demonstrated a failure of applying a logical and systematic approach to their investigations.

Using the observer’s marking sheets the following data were recorded when the investigators were not using the FIRMs during their first investigation:

- <u>Any use of chemicals or substances (paint, etc)?</u>

  Only one investigator (8%) considered the use of chemicals or substances as a potential ignition source. This demonstrated the importance for all fire investigators to adopt and apply a systematic and rigorous investigation methodology when developing hypotheses for the cause of a fire. All other 11 investigators were not applying any format that would allow them to systematically progress through their investigation.

- Any structural issues (defects, movement, etc)?

  Again, the same investigator (8%) considered the possibility of a structural issue being the potential for initiating the fire. This was predominantly due to his background as a fire engineer.

- Gas supplied?

  All of the investigators (100%) considered the presence of a gas supply/presence. One would have expected an investigator to have considered this in a residential premise and it would have been surprising if they had not.

- Electricity supplied?

  All of the investigators (100%) considered the presence of an electrical supply/presence, again demonstrating the very basic requirements for data collecting at a fire investigation.

- Oils present (e.g. wood working)?

  Only two investigators (16%) considered the potential for an oil based product causing spontaneous combustion and being a viable ignition source. The author has observed at many fire scenes, both simple and complex, investigators being ‘drawn’ to what they initially believe is the obvious conclusion. A systematic approach is a measure which will prevent assumptions to be made without all of the facts.

- Petrol/diesel present in any quantity?

  All investigators (100%) considered an ignitable liquid as being a potential cause of the fire. Again, in an accelerated fire, ignitable liquids are often used and fairly easily detected after the fire.

- Solid fuels (fuel loading of furniture, etc)

  Only one investigator (8%) did not proactively consider the fuel loading within the room of origin. Most of the investigators took their enquiries regarding solid fuels into Level 2 and a few into Level 3 and included it in their hypothesis.

- Naked flames?

  All investigators (100%) considered some type of naked flames as a potential ignition source.

- <u>Animals Present?</u>

  Not one investigator considered the fact that an animal could have been in the area of origin at the time of, or shortly before the fire and may have had an influence on the initiation of the fire. This was extremely surprising given the fact that animals were found in one of the fire scenes.

- <u>Machinery, Equipment and/or Appliances</u>

  One investigator did not ask about domestic appliances being present, but only three considered their involvement to Level 3 and either included them within a hypothesis that needed to be tested or dismissed them as being involved. The rest of the investigators considered appliances to Level 2, but failed to complete their enquiries to Level 3.

- <u>Weather/Nature?</u>

  Only two investigators (16%) considered weather or nature as being relevant to their investigation and these were both police investigators. Again, with lightning strikes and focused sun's rays, this was an elementary question to ask so as to eliminate it as a potential cause of the fire.

- <u>Role of person involved?</u>

  All investigators (100%) considered the role of the person(s) involved during their investigations but only a few of them attempted to gather more extensive information about their role and their interaction with others.

- <u>Role of any third party influences, visitors, etc?</u>

  Seven investigators (58%) did not consider the role of a third party during their investigations. It appeared that they assumed that because both premises were secure upon the arrival of the first rescuers, then third party involvement was not present.

- <u>CCTV for unknown persons</u>

  None of the investigators (0%) considered the use of CCTV to identify the movements of any unknown persons within the area of the fires. With CCTV being readily available in both the public and private sectors of our communities, the observer was surprised that this option was not explored.

- <u>Contact details for relative, friend or neighbour?</u>
  Only two investigators (16%) discussed the need to either directly contact or obtain contact information about a relative, friend or neighbour. This was critical in one of the fire scenarios, as the investigators discovered after their exercises.

The average time of **1 hour and 10½ minutes** to complete both scenarios when the FIRMs were NOT used by the investigators clearly demonstrated that even when information is immediately to hand, investigating fires requires a thorough and complete process to make an accurate conclusion. They all determined the correct conclusion using the ready availability of comprehensive data; however it was recorded in the scoring system for each of the investigators that the depth of data gathered was not sufficient to withstand challenges for alternative hypotheses to have been available.

9.4.2 The average time to conclude the investigations when actively USING FIRMs during the second exercise

By comparison to 9.4.1 above, it was evident that when the investigators used the FIRMs during their second table top exercises, their approach to the investigation was more controlled and thorough with the average time to come to a conclusion about the origin and cause of a fire being reduced to an average time of **1 hour and 2 minutes.** The observer had to interject with several investigators (police and insurance) when using their own methodologies, to remind them to refer to the FIRMs. This occurred when it was recognised that there was a lack of a structured investigation methodology. Only two investigators took longer to carry out the investigation using the FIRMs due to their diligence of referring to every FIRM to make sure nothing had been missed. These investigators were also awarded high scores by achieving the Level 3 enquiry areas of the FIRMs.

It was noted that four investigators looked at the FIRM heading 'Processes and Substances' and assumed that none were present and moved onto the next FIRM. The observer prompted all four by asking how they knew that there were no processes or substances within the premises. This guided them to ask the relevant questions and positively dismiss this particular FIRM as a potential cause of the fires; it did make them focus on the remaining FIRMs and be very thorough.

Again, using the observer's marking sheets the following data were recorded:

- Any use of chemicals or substances (paint, etc)?

  All investigators (100%) considered chemicals and/or substances, although four (33%) had to be prompted. However, only three explored their involvement to Level 3 of the FIRM.

- Any structural issues (defects, movement, etc)?

  All investigators (100%) considered structural issues without prompting but only half progressing to Level 3 and completing their enquiries to either include or dismiss structural issues as a potential cause of the fire.

- Gas supplied?

  All investigators (100%) considered the presence or supply of gas as would be expected, however, two did not progress along the FIRM to Level 3 of their enquiries.

- Electricity supplied?

  All investigators (100%) considered the supply or presence of electricity, again, as would be expected with only one investigator not progressing along the FIRM to Level 3.

- Oils present (e.g. wood working)?

  All but one of the investigators considered the presence of vegetable or drying oils, although one (8%) had to be prompted. Only five of the investigators took their enquiries to Level 3 of the FIRM.

- Petrol/diesel present in any quantity?

  All investigators (100%) considered an ignitable liquid, however two of them did not progress to Level 3.

- Solid fuels (fuel loading of furniture, etc)

  All investigators considered solid fuels and their heat release rates.

- Naked flames?

  All investigators considered all types of potentially available naked flames.
- Animals Present?

  All investigators considered the fact that an animal could have been in the area of origin at the time of, or shortly before the fire and may have had an influence on the initiation of the fire. Only five actually followed the FIRM to Level 3.
- Machinery, Equipment and/or Appliances

  All investigators asked about domestic appliances being present, with seven considered their involvement to Level 3 and either included them within a hypothesis that needed to be tested or dismissed them as being involved. The rest of the investigators considered appliances to Level 1 and 2, but failed to complete their enquiries to Level 3.
- Weather/Nature?

  All investigators considered weather or nature being a factor in their investigations with five (42%) of them commenting to the observer that they probably would not have actively considered this FIRM with the fire scenes, as presented to them.
- Role of person involved?

  All investigators actively considered the role of the person(s) involved.
- Role of any third party influences, visitors, etc?

  All investigators considered the role or influence of a third party.
- CCTV for unknown persons?

  Even though most of the investigators had been reasonably thorough in using the FIRMs, seven of them (58%) did not consider using CCTV to eliminate any unknown person(s) from the area of origin. This appeared to be based on them believing they had enough data to demonstrate no third party involvement.
- Contact details for relative, friend, or neighbour?

  All investigators considered obtaining contact details although one (8%) needed to be prompted.

There were limitations with the second exercises, those where the FIRMs could be applied. This was identified approximately one-third of the way through the validation process. The fact that the two cases were similar in their origins and causes was a predetermined decision by the observer to enable better comparison of the FIRMs' effectiveness and to allow them to be completed within a three hour time-frame per investigator, thereby completing two fire investigators in the same day from the same organisation. This was designed to prevent any discussion between the two investigators. However, the cases were reported as not being challenging enough by four (33%) of the investigators during the second exercise when they were applying the FIRMs. The feedback detailed a preference to a more complex fire investigation to enable them to use the FIRMs to their maximum potential.

It was also apparent that the reduction in time to complete the second exercises when the FIRMs were used may, in part, be due to the investigator having become accustomed to the 'table-top exercise' situation and naturally progressing quicker than the first. Due to the case similarity, data that had been obtained from the first case without the use of FIRMs was subsequently asked for in a more structured way during the second case when the FIRMs were used.

The comparison between the times taken to complete the fire investigations during the first and second exercises, when the investigator could use the FIRMs during the second exercise, has been identified as not being important to the outcomes of the investigations. The most important comparison has been the accuracy and depth of the data gathered and the way that data was considered holistically during the investigations.

It was evident to the observer that the more experienced investigators would use their own or their organisations' methodologies up until they needed to check to see if they had missed any important data. It was also evident that there was no clear methodology used that was common to all of the fire investigators. However, when all of the investigators referred to the FIRMs, it clearly structured the remainder of their investigations. Most fires are relatively small and the FIRMs, when applied to these fires are useful for verifying the methodical approach. FIRMs are clearly more usefully applied to complex and difficult fire investigations.

9.4.3 The total scores attributed by the investigators out of a potential 600 maximum points

The scoring system was developed to allow the investigators to express their views on the effectiveness and positive use of the FIRMs. The investigators awarded ‘1’ point for ‘Strongly Disagree’ and ‘5’ points for ‘Strongly Agree’. Therefore a maximum of 50 points could be awarded by an investigator as to the positive use of the FIRMs with an overall maximum from the 12 investigators of 600.

The total score of 489/600 given by the 12 investigators from the six agencies derived from individual questionnaires and is summarised in Table 9.10 below.

*(Blue numbers **(n)** are combined scores of (n) number of fire investigators)*

Name:		**Strongly Disagree**	**Disagree**	**No Opinion**	**Agree**	**Strongly Agree**
Q	**Question details**	**1**	**2**	**3**	**4**	**5**
1	Using FIRMs helped structure my investigation.	**0**	**0**	**3** (1)	**20** (5)	**30** (6)
2	FIRMs were easy to understand and apply to the investigation process.	**0**	**2** (1)	**6** (2)	**24** (6)	**15** (3)
3	FIRMs were an asset to the natural flow of my own methodology.	**0**	**0**	**3** (1)	**32** (8)	**15** (3)
4	Studying the FIRMs for only 15 minutes allowed me to understand their methodology	**0**	**4** (2)	**3** (1)	**28** (7)	**10** (2)
5	Regular application of the FIRMs would enable me to apply them more effectively.	**0**	**0**	**0**	**12** (3)	**45** (9)
6	I may not have considered all available data without the use of FIRMs	**0**	**2** (1)	**9** (3)	**16** (4)	**20** (4)
7	The associated guidance notes were useful at certain decision points when I needed further guidance.	**0**	**0**	**3** (1)	**28** (7)	**20** (4)
8	I would use the FIRMs as a field reference document at future investigations.	**0**	**0**	**9** (3)	**16** (4)	**25** (5)
9	I have never used anything like the FIRMs before.	**0**	**10** (5)	**3** (1)	**16** (4)	**10** (2)
10	I would recommend their use in my organisation's training plan.	**0**	**2** (1)	**3** (1)	**20** (5)	**25** (5)
	Total Scores:		**20**	**42**	**212**	**215**
	Additional Comments:					
	This space was for the investigators to write any additional comments, which have been summarised in Section 9.5 below.					

Table 9.10 – Combined Scores from 12 Fire Investigators

9.5 Analysis of qualitative (anecdotal) data

Following the validation process, when the observer asked the investigators to complete and score the questionnaire, they were also asked to make personal comments in a space provided at the bottom of the marking sheets.

Seven of the 10 Fire and Rescue Service fire investigators (FRS #1, FRS #2, FRS #4, FRS # 6, FRS #7, FRS #9 and FRS #10) suggested that the overview of the FIRMs, which is on Page 2 of the FIRMs book, could be laminated and detachable so it can be viewed without having to turn back pages. This recommendation was also carried out for the remainder of the validation process.

Most commented on the thoroughness of the investigation when the FIRMs were used and evidence showed that the second exercise, whichever scene it was and using the FIRMs, was completed quicker than the first exercise by almost all of the investigators. The observer noted that the FIRMs certainly assisted in structuring their investigations by using an efficient and non-repetitive methodology, however, as previously stated, there was also an element of familiarisation with the process once they had completed the first exercise without the FIRMs and progressed with the second exercise using the FIRMs.

9.5.1 Free text comments by fire investigators (bullets grouped by individuals):

- Some of the terminology was not clear
- Difficult to follow some of the road maps
- I'll order the book now!

➢ I needed guidance on how to interpret some of the charts
➢ Need to be an experienced fire investigator to use them so would only use them on case review
➢ I would use FIRMs more if they were simpler

❖ I feel that the FIRMs are far more advanced and useful than a basic aide memoire
❖ They can be an asset for a fire investigator

o Their use will help to ensure the methodology and process they (the fire investigators) will apply to their fire investigations is full and complete
o The ability to access reference data and material over such a wide range of subjects in a simple format must add confidence to the process

▪ A useful tool to assist in a thorough fire investigation
▪ Would not use FIRMs on all investigations

- ➢ Very interesting development which I would use as a simple aide memoire to my exam but which would also allow me to document the fact that I had considered all options and ideas
- ➢ I certainly think it is a good idea
- FIRMs are an advance in 'best practice' and methodology in dealing with fire scenes, which are often the most difficult type of scene to deal with
- They enable management and vetting of CSI (Crime Scene Investigation) staff methodology
- ❖ They give confidence that all (or most) options have been considered
- o I would need to study the whole document and keep for reference.
- o Maps are easy to understand and quick to process
- o Needs a compressed format (for field use)
- o I have used process diagrams before but not for fire investigation

The role and remit of fire investigators from different agencies had to be considered during the first exercise when FIRMs were not used. Another factor to be considered was the experience of the investigators used; this ranged from those with less than three years experience to those with more than 30 years experience. It was interesting to observe how the fire service fire investigators conducted their investigation directed at dealing with the origin, cause and development of the fires, whereas the police and forensic scientist focused on origin and cause to ascertain whether a crime had been committed (they also addressed the development of the fire, but it was not their main focus). The insurance investigators were very interested in any electrical or gas appliances within the area of origin and therefore product liability, whereas the fire scientists were focused on fire development after they had identified the origin and cause.

The validation process identified the practical and forensic benefits for using the FIRMs and demonstrated that all agencies would be able to use them irrespective of their organisation's remit. It suggested that the time to conduct the investigations varied between agencies, with the police completing the investigations quicker than any other agency. This was most probably due to the two investigators that took part being the most experienced from all the investigators used. Their investigative skills appeared to be focused on scene preservation and any criminal activities which led to them processing the scene in a very structured and efficient manner.

This style of scene processing reflected on the agencies that would attend a fire scene as a first responder or first responder support, such as the fire service and forensic science service providers. Other agencies who attend after the scene has possibly been disturbed, such as insurance investigators and fire scientists appeared to be more cautious but neither were more or less thorough. The training providers were experienced police and fire investigators prior to becoming trainers, but it was interesting to note that they presented more structure with their approach to processing the scene, as if at a training session.

The use of FIRMs encouraged all of the agencies to adopt a common approach to processing fire scenes and enabled all potential hypotheses to be developed and tested. This was the most important gain for the investigators when using the FIRMs.

9.6 Application of FIRMs using a complex fire investigation case study

A complex fire investigation case study was selected to rigorously test the application of the FIRMs. The case study involved a timber framed building under construction, approximately 20 metres by 100 metres and four storeys high, being totally destroyed by fire in south London and required 30 pumping appliances to extinguish it. The fire occurred in the early hours of the morning and during very high wind conditions coming from the south-east. The fire was so ferocious that it ignited residential houses, flats and a public house on the opposite side of the road. There was no loss of life nor any serious injuries. The fire was investigated by a senior Fire Investigation Officer of the London Fire Brigade over a five week period and the observer had no involvement with the investigation. The methodology used for this exercise involved the same scoring system as detailed above.

The first stage of the exercise was to allow the investigator to explain in detail his own investigation methodology (without the use of FIRMs) using his contemporaneous notes and final report. The observer asked the investigator to detail his investigation thoroughly, from when he was first ordered to the scene up to his final conclusions as to the origin and cause of the fire. The observer documented the investigator’s methodology and awarded points using the same criteria for Level 1, 2 and 3 as detailed in 9.3.1 above.

a) During the first stage of this exercise, the investigator explained in detail to the observer (the author of this thesis) his approach to the investigation from the moment he was ordered to investigate the origin, cause and development of the fire up to his final conclusions. He was extremely thorough and meticulous with his approach, applying a personal methodology using the scientific method.

b) It took approximately 10 days before the scene was declared safe for the fire investigator to be able to enter due to distorted and unsafe scaffolding following the fire. The scaffolding had to be cut away and removed by workers in a hydraulic platform cage in order to preserve the scene as much as possible. When considering the origin of the fire and with no other data than witness testimony available during the early phase of the investigation, the investigator gathered those testimonies and associated telephone logs to plot the witnesses' location and view point during the early stages of the fire's development. He concluded that an area of approximately 5 metres by 20 metres was to be the first 'Area of Origin'.

c) During the account of how he applied his fire investigation methodology to this fire, the observer recorded that although he was very thorough in everything that he had explored, there were several aspects of the investigation that he had not explored. The investigator had 'assumed' and had not gathered sufficient data to positively eliminate those aspects as the cause of the fire. An example of this relates to FIRM #2: 'Structure'.

   The investigator assumed that because the 110v electrical system had reportedly been isolated at the end of the working day and therefore considerably before the fire was believed to have started, there was no electrical power anywhere on the site. The un-clad timber frame building, which was four storeys high, would certainly have been subject to structural movement during the extremely windy conditions that prevailed that night. It was almost two weeks before the investigator could positively eliminate an electrical ignition in the defined area of origin, however, he assumed that any structural issues would not be relevant.

d) When considering other potential causes of the fire such as substances, oils, animal involvement or the role of any persons related to the site, he did not go into the depth of inquiry that the FIRMs would have encouraged him to do. During the early stages of the investigation he was drawn to, and became focused on, the only obvious potential ignition source being hot works carried out by a roofing contractor during the afternoon of the day prior to the fire but concluded the fire was started by human agency involvement with no accidental ignition sources.

e) He did go into great depth of enquiry when considering most of the energy sources and when trying to identify unknown persons using CCTV.

f) Below in Table 9.11 are the actual results of the observer's allocated scores to the fire investigation when the investigator did not use the FIRMs. It can be seen that a complex investigation requires a rigorous methodology; however, the experience of this investigator also reflected the depth of inquiry that was applied.

30 Pump Fire – Timber Framed Building Used FIRMs/ Did not use FIRMs	**Each key item missed = 0; L1=1; L2=2; L3=3**		
	Data Requested/Identified		
Details Relating to FIRMs	**Level 1**	**Level 2**	**Level 3**
Any use of chemicals or substances (paint, etc)	1	2	-
Any structural issues (defects, movement, etc)	0	-	-
Electricity supplied	1	2	3
Gas supplied	1	2	3
Oils present (e.g. wood working)	1	-	-
Petrol/diesel present in any quantity	1	2	3
Solid fuels (fuel loading of furniture, etc)	1	2	3
Naked flames	1	2	3
Animals present	1	-	-
Machinery, Equipment and/or Appliances	1	2	3
Weather/ Nature	1	-	-
Role of person involved	1	2	-
Systematic consideration for each role identified	1	-	-
CCTV for unknown persons	1	2	3
Contact details for relative, friend, neighbour	1	2	3
Total score out of 45	**4**	**+ 4**	**+24=32**
Percentage of expected information requested	**71.1%**		

Table 9.11 Non-use of FIRMs in Complex Fire Investigation Case

It can also be seen that although the investigator scored a high percentage of expected data gathering and hypotheses testing, there was still almost 29% of data that should have been considered to either include or dismiss as the cause of the fire.

g) During the second stage of this exercise, the observer explained the FIRMs design, use and application and encouraged the investigator to revisit his investigation applying the FIRMs as he proceeds.

h) He had already concluded that an area of approximately 5 metres by 20 metres was to be the first 'Area of Origin' and the observer informed him that he did not need to explain that methodology again.

i) The investigator used the FIRMs very methodically, cross-linking them to each other where necessary or when the FIRM guided him to do so. It took longer for the investigator to go through this process than it did during the first stage of the exercise, but due to the lack of familiarisation with the FIRMs, this was anticipated.

j) As with several of the previous fire investigators, when completing the second of the table top exercises and using the FIRMs as detailed above, this investigator also tested the alternative routes along the FIRM to confirm that the original path positively worked when applied to his complex case. He wanted to explore whether an alternative path would lead to a different but possible solution. The observer noted that when he did this, he was almost surprised to learn that the FIRMs supported his investigation by creating a more robust structure to his own methodology and an alternative path away from his investigation did not yield accurate data gathering.

k) Below in Table 9.12 are the actual results of the observer's allocated scores to the fire investigation when the investigator actively used the FIRMs. When used thoroughly, this complex investigation not only accrued maximum points, but the investigator conceded to the observer that, had he applied the FIRMs during his original investigation, his lines of inquiry would have been more thorough in certain areas of the investigation. Although his conclusions were the same as his original investigation, that this was a fire involving human agency with no accidental ignition identified, his methodology when using the FIRMs would have been more robust against any cross-examination during criminal proceedings had any person(s) been prosecuted for arson.

30 Pump Fire – Timber Framed Building **Used FIRMs/ Did not use FIRMs**	**Each key item missed = 0; L1=1; L2=2; L3=3**		
	Data Requested/Identified		
Details Relating to FIRMs	**Level 1**	**Level 2**	**Level 3**
Any use of chemicals or substances (paint, etc)	1	2	3
Any structural issues (defects, movement, etc)	1	2	3
Electricity supplied	1	2	3
Gas supplied	1	2	3
Oils present (e.g. wood working)	1	2	3
Petrol/diesel present in any quantity	1	2	3
Solid fuels (fuel loading of furniture, etc)	1	2	3
Naked flames	1	2	3
Animals present	1	2	3
Machinery, Equipment and/or Appliances	1	2	3
Weather/ Nature	1	2	3
Role of person involved	1	2	3
Systematic consideration for each role identified	1	3	3
CCTV for unknown persons	1	2	3
Contact details for relative, friend, neighbour	1	2	3
Total score out of 45			**45**
Percentage of expected information requested	**100%**		

Table 9.12 Using FIRMs in Complex Fire Investigation Case

l) The investigator was given the same questionnaire using the same scoring system as the previous investigators, so that he could provide anecdotal data based on his opinions regarding his use of the FIRMs. The results of those scores are detailed in Table 9.13 below:

Name: Senior Fire Investigator – 30 Pump Fire (Complex Fire)		Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
Q	**Question details**	**1**	**2**	**3**	**4**	**5**
1	Using FIRMs helped structure my investigation.	0	0	0	0	5
2	FIRMs were easy to understand and apply to the investigation process.	0	0	0	4	0
3	FIRMs were an asset to the natural flow of my own methodology.	0	0	0	4	0
4	Studying the FIRMs for only 15 minutes allowed me to understand their methodology	0	0	0	4	0
5	Regular application of the FIRMs would enable me to apply them more effectively.	0	0	0	0	5
6	I may not have considered all available data without the use of FIRMs	0	0	0	0	5
7	The associated guidance notes were useful at certain decision points when I needed further guidance.	0	0	0	0	5
8	I would use the FIRMs as a field reference document at future investigations.	0	0	0	4	0
9	I have never used anything like the FIRMs before.	0	0	0	4	0
10	I would recommend their use in my organisation's training plan.	0	0	0	0	5
	Total Scores:				20	25
	Additional Comments:	45/50 = 90%				
	Solid fuels terminology: Coal; Coke? *Need more time to familiarise myself with the structure of the FIRMs*					

Table 9.13 Fire Investigator's Scores regarding the positive use of FIRMs in a complex fire investigation case

From these exercises, it can be seen that the application of FIRMs during an investigation will result in a more robust, thorough and rigorous fire investigation, which would be beneficial to the judicial system, whether during a criminal or civil inquiry.

Chapter 10
Discussion

10.1 Introduction

Fire investigations have historically been described as a mixture between 'art' and science. This thesis clearly identifies that all fire investigations are based on scientific and engineering principles. There is a lack of understanding by many practitioners that a comprehensive scientific methodology will contribute to improving the accuracy of fire investigations, however no such comprehensive methodology had been developed. Several publications (DeHaan and Icove, 2011b) (NFPA, 2011c) promote the scientific method (see Figure 1.4), but none give the investigator a robust tool by which to apply it. At the beginning of this research project, the principal aim was to develop a methodology that would increase the prosecution rate for arson (see section 1). It was believed that this would mainly involve dealing with human behaviour, actions, inter-actions and motivations. During the initial stages it became apparent that unless all possible causes of a fire were scientifically eliminated, the potential for a successful prosecution of a deliberate fire diminished. The focus became the identification of the cause of a fire (see section 1.8); that being the ignition source, the first combustible material to become ignited and the mechanism that brought the two together. The 'mechanism' may be failure, fault, accidental or deliberate action. Until that mechanism can be demonstrated, a deliberate act cannot be proven.

10.2 Benefits of accurate fire investigations

A fire investigation is conducted to enable the governing investigative body to understand where the fire started, what caused it and why it developed the way it did (see section 1.2). These findings may prevent similar events happening again if the outcome of the investigation is appropriately acted upon. The Kings Cross fire (see section 2.6.1) is a good example of such lessons preventing similar fires whereby London Underground replaced every timber constructed escalator within its stations' network. In all cases, fire prevention is better than cure, however accurate data can only be obtained by accurate investigations. Although it is incumbent upon the investigating body to share information they have gained with others in the interest of public safety, some organisations fear a breach of client confidentiality and are often reluctant to do so. For example, when a defect has been identified within a fridge/freezer (see section 2.6.2.1) that could lead to a fire hazard, a risk assessment is often taken to identify the associated risk level and the defect information may then not be shared to prevent negative commercial impact. However low the risks statistically, information about any defect which could result in a fire within such a high fuel load as fridge/freezers should not be withheld. It is paramount that safety issues learnt from fire investigations are disseminated at the earliest opportunity.

10.2.1 Organisations

Statutory bodies such as the fire and rescue services, the police and the Health and Safety Executive need to know how to prevent fires, both accidental and deliberate, to meet their duty of care and make communities a safer place to live and work. Community safety initiatives may be misguided and public money therefore misspent if accurate patterns and trends of fires are not clearly identified during fire investigations. Other organisations, such as the insurance industry, need to protect their policy holders by reducing the cost of claims made against them. This can be done by the insurers stipulating fire prevention measures (based on the outcomes of accurate fire investigations) within their policy or by identifying fraudulent claims and reducing unjustified pay-outs. Fire investigation is critically at the fore-front of regulatory and community fire safety; if the problem is not clearly identified, public safety initiatives may be inappropriate and misdirected. Consistency in fire investigation methodology is needed between all agencies to ensure the accuracy of their investigations.

10.2.2 Society

Everyone will benefit if fires can be prevented by reducing the related economic costs, fear of fire and arson, and fire injuries and deaths (see section 1.3.1). Society relies upon professional investigators from various organisations (as outlined in 10.2.1 above) to carry out their work in a thorough and rigorous manner to determine the cause of an incident. Air travel is claimed to be the safest form of travel; it can be no coincidence that air crash investigators are extremely good at determining the cause of most accidents and ensuring the findings are circulated back into air safety, thereby achieving the safest form of travel. The methodology that they use is overseen by the UK Air Accidents Investigation Branch (AAIB), which is part of the Department for Transport and is responsible for the investigation of civil aircraft accidents and serious incidents within the UK. The purpose of the AAIB, according to their Chief Inspector, is to improve aviation safety by determining the causes of air accidents and serious incidents and making safety recommendations intended to prevent recurrence. It is not to apportion blame or liability.

The same must apply to fire investigators, ensuring that society is made ever safer from the effects of fire. If blame is not the driver behind such investigations, it may need to rest with the UK Fire and Rescue Services to lead on all fire investigations, working in partnership with other agencies when others are investigating the liability issues of the fire; i.e. police and insurance investigators.

10.3 The causes of fires

The presence of an ignition source and a combustible material is not enough for an investigator to have claimed to identify the cause of a fire (see section 1.4).

10.3.1 Accidental fires

The purest forms of accidental fire, where no human has had any inter-related activity with the scene are lightning strikes and volcanic eruptions, which may initiate the combustion process of flammable materials. Accidental fires will always occur; however as discussed in section (10.2.2) above, by identifying the cause of an accidental fire, measures may be taken through education or design to prevent future similar events occurring. Component failures in appliances, equipment and machinery, the sun's rays through a discarded bottle in dry grass, self-heating of unmonitored haystacks are all examples of human activity which could be described as careless or even reckless in some cases. In the latter examples however, the intent of any person connected directly or indirectly with these types of fires was not to deliberately start a fire. It is paramount that the fire investigator can accurately identify the mechanism which brought the ignition source and combustible material together to cause the fire, or the accuracy of any fire's causation could be challenged (see section 1.2).

A recent example of this (June 2011) is a component failure in the defrost switch of a fridge/freezer, which causes the outer casing of the switch to ignite and spread to the extremely flammable foam insulation around the body of the fridge/freezer. The duty of the London Fire Brigade, whose investigators discovered the problem when conducting several of their fire investigations, was to bring this identified component failure to the manufacturer’s and public attention alike, so that modified replacements of the faulty part could be expedited at the earliest opportunity.

10.3.2 Deliberate fires

It was the enormous proportion of deliberate fires (see section 1), over 60% of all fires in 2001, which initiated this research. With approximately 3% resulting in a successful prosecution, it was debated whether this low statistic was due to the fact that fire is difficult to investigate or the way fires are investigated is not sufficient to secure enough evidence for a prosecution.

The answer is that both of these factors contribute to a low prosecution rate for arsons. When a crime is committed, there is always a victim and an offender. However, when arson has been committed, there is always a victim, but until the fire has been thoroughly investigated, it may not be apparent that an offender has been responsible for the fire. The ‘offender’ may not be a person who intended setting a fire (see 10.3 above) and the fire may indeed have been accidental in its causation.

To ensure that prosecutions of arsonists are successful, all other potential causes of a fire must be eliminated by testing all available hypotheses relating to the fire’s cause.

10.4 Fire statistics

The need for regional statistical monitoring (see section 1.6.1) being necessary to identify patterns and trends of both accidental and deliberate fires has been shown within this project. Accurate fire investigations are the foundation for effective databases; problems can only be quantified if they can be identified. Incident Commanders of Fire and Rescue Services complete a national data base with what in many cases can be regarded as their ‘best guesses’. Fire investigation awareness and associated training for these data collectors must be increased. The same applies to some officers charged with the duty of being the organisational ‘fire investigator’. Unless they are 'competent’ fire investigators (see section 2.10.1) it is difficult to ensure the best data is collected.

10.5 Existing fire investigation methodologies

Highlighted during this research project has been the way fire investigators from different organisations apply their methodologies depending upon their terms of reference for investigating fires. Insurance companies formed the original fire brigades to mitigate their financial losses. However, fire investigations have been conducted by a range of professionals (see section 2.1) all requiring information relative to their own roles associated with the property affected by fire. Lessons should be learnt from all fires that are investigated (see section 2.6.1 and section 2.6.2) but focus has tended to be on the spread of fire and any corrective measures to prevent or compartmentise that spread. Identifying the cause of a fire has always been one of the most difficult investigations to conduct.

Police investigators need to know if a crime has been committed and some have demonstrated a tendency to develop a hypothesis early in the investigation, finding facts that fit it; insurance investigators need to know who is liable and in one case in particular, commented that the insured was over insured but failed to mention that he had been over insured for 20 years; fire service need to identify fire safety issues, however personal bias may still impinge on the expected impartiality of a thorough investigation. That said the methodology used during the investigation of fires should be similar with similar outcomes. If the scientific method (see Figure 1.4) was followed rigorously, then all available data would have been gathered and considered when formulating all potential hypotheses.

It has been identified throughout this research project, that many investigators make assumptions and may also be prone to finding available facts to meet their expectations or developed hypothesis (see section 9.4.1). It was clear that fire investigators' hypotheses should be changing and developing based on the latest data obtained at, or related to a fire scene. The 'problem' was discussed and the need for this research identified (see section 1.7). A new methodology was needed to enforce the scientific method, making sure fire investigators obtained all the available data and to prevent assumptions being made without having considered the data.

10.6 Fire Investigation Road Maps (FIRMs)

Fire Investigation Road Maps, also known as FIRMs, have been developed, tested and applied at real fire investigations to assist all fire investigators, from all organisations, to conduct a thoroughly rigorous investigation of an incident. As discussed in (10.1) above, it was considered at the beginning of this research project that the most important aspect to increasing the prosecution rate for arson, thereby helping to reduce the number of deliberately set fires in society, is to focus on the 'person'. Whilst the initial research focused on the causes of fires that did not directly involve human agency actions, the latter work inter-linked any human agency involvement (see section 6.2.1) with the scene of the fire and aimed to identify the mechanism which led to the ignition of the first combustible material involved.

10.6.1 Non-human agency

The initial difficulties associated with this research project involved categorising the FIRMs into subject groups (see section 3.2). It was considered from the viewpoint of a practicing fire investigator, therefore terminology was adopted that all practitioners could relate to. The more obvious categories included processes and substances (see section 3.2.1), fuel and energy sources (see section 3.2.3), equipment and appliances (see section 3.2.5), weather and nature (see section 3.2.6). Due to several well documented cases, for example:

- a British Science Weather Station in Antarctica which burnt to the ground following a fire attributed to un-grometted cables passing through the side of a sandwich panel structure in high winds;
- a double-decker bus fire caused by a high tension, un-protected cable running through the vehicles chassis;
- a halogen cooker switched on by a large dog trying to retrieve food from the work surface adjacent to the on/off switches and igniting combustibles left on the hob surface;
- a family of squirrels chewing through electrical cables in a loft area igniting surrounding nesting materials and subsequently the entire roof;

other categories were introduced, those being structures (see section 3.2.2) and animals (see section 3.2.4). 'Animals', as a cause of fires, may not be obvious to a lay person, however to experienced fire investigators, the interaction of an animal with an ignition source is well known. 'Structures' presented some difficulty in relation to ignition sources. In the context of the FIRMs, it is the defect(s) within a structure that has allowed an ignition source to come into contact with an ignitable material. It was felt that if this category was not included, then valuable data may be lost during an investigation of it were not positively addressed.

As with FIRM #2: 'Structures', difficulty was experienced with the involvement of solid fuels in FIRM #3.19. It was difficult to restrict these categories to the contributory causes of a fire rather than the fire's development. Taken in context of the 'Fire Triangle' (see Figure 1.1) or 'Fire Tetrahedron' (see Figure 1.2) these certainly are an integral part of the fire's causation. The investigation of a fire's development would be suitable for future work (see Chapter 12 below) with the potential for an array of FIRMs relating to structural components, fire stopping, ventilation, suppression, etc. Another difficulty experienced when developing the FIRMs was the inter-linking to all other relevant FIRMs. However, when the 'Person' FIRMs were developed (see section 6.2) it became much more logical to work through them in their entirety.

It was also deemed necessary to break down the fuel/energy sources in FIRM #3 into sub-categories for example electrical (see section 3.2.3.1), petrol (see section 3.2.3.4) and naked flame (see section 3.2.3.6). This FIRM was therefore divided into six sub-categories, with the electrical FIRM being very time consuming to develop as it high-lighted one of most investigators' weaknesses when investigating fires. Understanding the involvement of electricity at fire scenes needed more explanation than most of the other FIRMs. It was important that all the FIRMs could be referred to at a fire scene, be understood and practically applied so if extra explanations were needed to ensure a principle could be understood, then they were included.

10.6.2 Human agency

When the 'Person' FIRMs were designed (see section 6), it involved some debating as to how they were to be categorised. Some researchers categorise the person by their motive for setting a fire, others by certain psychological categorisations, but both of those examples relate to deliberate fire setting. It was decided in this research project to use the person's role in society (see section 6.2) as the main frame for this series of FIRMs as it was important to capture accident, deliberate, design or a failure which leads to the ignition of a combustible material. If any person was to be identified by their role with relevance to a fire, it first needs to be established whether anyone was in or near the area of origin at the time of, or shortly before the fire. This FIRM #7: ‘Person’ was then divided into 10 sub-categories. During the designing of the ‘Person’ FIRMs, it became evident that most of the decision points within each of the sub-categories of persons were the same. It was predominantly the ‘gain’ that each person may have had following or during the fire that differentiated them from each other. Any person involved with a fire is either the victim through an accidental cause by themselves or another or that person could have been instrumental in the cause of the fire, either by accident or intent. The ‘Person’ FIRMs are related to the ignition caused by a person and does not focus on any victim(s) of a fire (see section 1.4.10.1) unless they were instrumental in the cause.

In one way or another, human agency involvement has almost always had some influence on the cause of a fire. Whether it was the inadequate design feature of a defrost switch on a fridge/freezer or the careless positioning of an electric heater too close to combustible materials, most of the FIRMs #1 to #6 will interlink with the sub-FIRMs in #7, the ‘Person’.

10.7 Practical application of the FIRMs

It was fortunate that the author was able to apply the FIRMs at real fire scenes throughout their development and was able to make adjustments as necessary before getting to the validation stage of the research project. During this development period, it was evident that many assumptions were being made by investigators during their enquiries. It was also evident that although many of the investigators that had been trained, developed and deemed competent by their organisations, did not take their enquiries to the depths required to achieve a full and thorough fire investigation (see section 9.3.1). An example of the latter is when it was established that an appliance was unplugged during the fire’s development and could therefore not have been a cause of the fire. The investigator failed to ask the occupier whether they had unplugged it at the beginning of the fire or consider examining the appliance for any electrical activity to show it had been energised during the fire’s development. It would initially appear that some of these investigators were being very thorough with their fire investigation methodology, however, when the FIRMs were applied it could be seen that it was the ‘depth’ of their enquiry which demonstrated some short-falls.

10.7.1 Depth of enquiry

During the validation of the FIRMs, each FIRM was divided into three levels (see Figure 9.1); the first would demonstrate that the investigator had considered that category as a potential cause of the fire; the second level demonstrated that the investigator had considered many of the facts and evidential data that could identify the category as being possible responsibly for the fire; the third level however, demonstrated that the fire investigator had not only considered this category as a potential cause of the fire and gathered all available data but also had considered that data and actively included or dismissed it as a possible cause of the fire. This is what the FIRMs enable a fire investigator to do successfully and it is this methodology that will be able to withstand scrutiny by others who may not have been able to conduct the same fire investigation at the same time.

10.8 Assisting the Courts

Most competent fire investigators would be considered to be an expert in the field of fire investigation. The duty of an expert witness is to the court. The expert will assist a court in coming to conclusions based on the facts of the case in hand. The expert can give his or her opinion based on the data they have collected and considered.

It would be unprofessional and immoral for any fire investigator that has had an opportunity to conduct a full and thorough investigation not to have done so and subsequently give evidence in a court of law. Every fire investigation has the potential to end up in a court; civil, criminal or coroners. From the outset of the investigation the FIRMs must be rigorously applied so that all available evidential data is gathered and all possible hypotheses are developed and tested.

Following this discussion, the conclusions of this research project can be found in the next chapter, Chapter 11.

Chapter 11
Conclusions

The identification of how a fire started is usually quite complex, despite the basic requirements of the accurate identification of the ignition source, the first material ignited and the mechanism which brought the two together. However, without this fundamental identification, it is not possible to make an accurate conclusion whether the fire was initiated by accident or design.

To some extent, the complexity is responsible for the prosecution rate for arson being one of the lowest prosecuted crimes in western civilisation, approximately 3%. A number of individuals/organisations stress the need for the adoption of a scientific method when investigating fires, but there is little guidance above a page of prose to illustrate the meaning of the term. This thesis addressed this short-fall in approach and provides a series of inter-linked road maps to aide those investigating fire, irrespective of their specific interests e.g. investigators from the police force may wish to assess whether a crime has been committed. Different professional groups will have different priorities. A robust and thorough methodology needed to be developed to assist the fire investigator and ultimately the Court, in determining the accurate outcome of a fire's causation. Such a robust methodology will also assist any subsequent inquiry following a fire.

11.1 Development of a systematic methodology

There are a number of techniques to identify hazards, for example 'Hazard and Operability Analysis – HAZOP' (PQRI, 2008) and the 'Successful Health and Safety Management' book produced by the Health and Safety Executive (HSE, 1998) and also to analyse incidents (e.g. root cause analysis) in many industries. Another technique is the use of road maps, which combine decision trees with detailed texts, which help in deciding the route to take. A road map technique has been applied to investigate fires, with the emphasis on the origin and cause (i.e. the ignition source and first fuel to be ignited in each event) with a brief description of the fire spread mechanism, which may have led to financial loss, injuries or fatalities.

11.1.1 Fire Investigation Road Maps (FIRMs)

23 specialist Fire Investigation Road Maps (FIRMs) have been devised to address *inter alia* the environment, presence of all potential viable ignition sources, flammable materials, people and their actions. The aim was to reach a complete understanding of conditions, immediately before the fire and at the moment of initiation of the fire as well as any subsequent effects/events caused by the ignition and/or any persons or fire protection systems present.

11.1.2 Levels of Investigation

The road maps are designed to take the fire investigator through a logical sequence of increasingly relevant decisions leading to final conclusions on the potential involvement or interaction of key elements in the ignition process. The decision boxes within the maps may lead to the use of inter-related road maps.

If a specific topic is irrelevant to the investigation of the event, then interest in that topic road map ceases at the first level. The deeper the level reached within the road map and the possible involvement of other road maps suggests the greater potential for the specific topic being a possible cause of ignition.

11.1.3 Supporting information

Within the FIRMs, the road maps/decision trees are supported by a knowledge base founded on fire-fighting experience, previous fire investigations and the increasing understanding of fire safety science and engineering undertaken in research establishments.

The knowledge base is appropriately numbered, so that support for the fire investigator in making decisions is readily available during map usage.

11.1.4 Advantages/Disadvantages

11.1.4.1 Reliability

Fire investigators from various organisations have expressed their opinions during the table top exercises when using the FIRMs that the practical application of the road maps assisted with the structure of their case study investigations. Several stated that they were forced to consider data that they would have previously made assumptions about without fully considering all of the available data; for example, although a television may be seen to be unplugged following fire, the investigator could not assume that it was not plugged in and energised prior to the fire. The investigator would be guided to confirm or discount electrical activity with the television at the time of the fire.

Using the FIRMs during a fire investigation enables the logical gathering of data at the scene and ensures a greater level of reliability; however the FIRMs must be considered in their entirety to ensure that the depth of their investigation is thorough and complete.

11.1.4.2 Up-dating

The FIRMs will be updated to include new social trends, e.g. barbeques, candles, plasma televisions and Chinese lanterns. Feed-back from fire investigators will enable ease of inclusion for the periodic updating of the FIRMs to maintain their currency, as does NFPA 921 and Kirk's Fire Investigation.

11.2 Current Fire Investigation Methodology

The application of the FIRMs, although primarily designed to be used at the scene, can also be used in other situations.

11.2.1 In-situ investigations

FIRMs are a valuable tool to be taken to every scene and referred to at least once before leaving the scene. This will ensure the investigator has considered all available data at the scene before it may become lost.

11.2.2 Report preparation

When the investigator is preparing his/her report, the FIRMs will offer a reminder of the logical structure applied during the investigation. It will also allow any reviewer, for example a line manager, to be able to check through departmental procedures and cross-check the data gathered and considered in the conclusions.

11.2.3 Cold case reviews

FIRMs have been applied to cold case reviews and offer a rigorous and structured methodology for an investigator that has to consider data that is either very old or non-existent. This allows hypotheses to be developed and tested accordingly based on sound opinions.

11.3 Application of individual FIRMs

The application of the FIRMs will assist the investigator in identifying whether the fire was started deliberately or accidentally. Without this accurate identification, incorrect data will be recorded within statistical databases reducing the focus of future fire prevention initiatives.

11.3.1 Ignition sources

The FIRMs and their supporting guidance will assist in identifying all the ignition sources that had enough energy to be transferred into a material or materials to initiate combustion.

11.3.2 Items/materials first ignited

Once a viable ignition source(s) has been identified, the FIRMs assist the investigator into considering all the available materials that the identified source(s) could have ignited, discounting those that could not have, e.g. a large section of wood adjacent to an electrical conductor that has arc damage.

11.3.3 Involvement of people

Most of the non-human agency FIRMs will cross-reference to the FIRMs dealing with human agency involvement, again assisting the fire investigator to actively consider all human inter-action with the fire scene either at the time of or shortly before the fire.

11.4 FIRMs for use by the professions

Although each of the professions that investigate fire has an individual role in society, the outcomes of their fire investigations should be the same, i.e. their conclusions should not differ between organisations.

11.4.1 Fire and Rescue Service Investigators

This group investigate ‘the most probable cause’ of a fire so that fire safety campaigns or measures may be implemented to prevent similar events. However, individual bias may be demonstrated based upon the investigators competencies, strengths, weaknesses and social views.

11.4.2 Police and forensic service providers

This group are identifying whether a crime has been committed or not; if it has not, then they normally cease their investigation as their ‘duty’ has been fulfilled. Their bias is to sometimes find the facts to fit their early formed hypothesis at the expense of gathering all available data for the fire scene. By applying the FIRMs, this bias can be prevented and would make any potential prosecutions more likely to succeed, as all accidental causes would have been considered.

11.4.3 Insurance investigators

This group, who work for loss adjusters, often look for a breach in the insured’s policy before investigating the fire. The bias that is sometimes demonstrated is towards the ‘best interest’ of their client, the insurance company. If these investigators used the FIRMs, they could openly demonstrate they have done a thorough fire investigation on behalf of their clients and their clients’ clients.

11.4.4 Fire scientists and engineers

This group are predominantly interested in fire development and its spread beyond the compartment of origin once a fire has started. There is a potential for bias to be demonstrated towards their focus on structural and installed fire safety systems. For this group to use the FIRMs would encourage a more holistic investigation which would benefit their professional remit.

11.4.5 Health and Safety Executive (HSE)

The HSE are responsible for investigating fires and various other incidents in work-places under the HSE Work etc Act 1974 (HASAW) and enforcing the Act, which is the primary piece of legislation covering occupational health and safety in the United Kingdom.

11.5 FIRMs used as teaching aides

FIRMs will be used to aid the training and development of, not only fire investigators, but others who interact with fire scenes.

11.5.1 Fire-fighting operations

Many high profile cases involving the serious injury or death of fire fighters has resulted in fire investigation data being fed back into fire fighter training programmes and operational procedural measures being improved. FIRMs ensure the outcomes of a fire investigation will be accurate and of significant value to the authorities following a high profile or sensitive fire.

11.5.2 Fire investigations

FIRMs will become part of fire investigation foundation training courses so that investigators from all organisations can begin applying a structured and repeatable methodology throughout their careers and continual professional development.

11.5.3 Health and safety considerations

A thorough fire investigation that has been completed using FIRMs will, in many cases, highlight health and safety deficiencies relating to all of the FIRMs subject areas, both human agency and non-human agency. The deficiencies will be recognised by the investigator rigorously applying the FIRMs, ensuring such actions involving processes, machinery, equipment, human agency interactions, etc are performed correctly. These deficiencies may or may not directly relate to the cause of the fire but may be of great value to those responsible for the health and safety of that scene/organisation.

11.6 Consequences

The penalty for not conducting a robust and auditable fire investigation may be severe, especially for the 'expert witness' either imposed by the court or by his or her client. Decision makers are more frequently asking what methodology was used to investigate a fire; FIRMs can clearly demonstrate to a coroner, judge or jury that a suitable and sufficient methodology was applied to a fire investigation.

11.6.1 Use of FIRMs in legal procedures

FIRMs will assist the court in making decisions based on the findings of a fire investigator, who would be considered by most judges and Coroners to be an expert. The duty of the expert, whoever their employer is, is to the court.

11.6.1.1 Criminal Courts and the Criminal Damage Act 1971

Criminal damage by fire as described by Sections 1, 2 and 3 of the Criminal Damage Act 1971 is arson and carries a maximum punishment of life in prison. Needless to say that such a serious crime warrants a thorough investigation. FIRMs will assist criminal courts by removing any ambiguity of the investigation by demonstrating facts obtained by a logical and auditable investigation methodology.

11.6.1.2 Coroner's Court

Coroners look to fire investigators for their expertise to assist them when dealing with a sudden death by fire. Often the family is present at the inquest and are seeking truthful answers to often complex questions. FIRMs will allow the investigator to structure their evidence whilst in the witness stand, instilling confidence in both the Coroner and the families that the investigation into their loss has been conducted thoroughly and professionally, resulting in an accurate and true conclusion.

11.6.1.3 Civil Courts

It is in the civil courts that the fire investigator as an expert witness is most vulnerable. Large sums of money can be lost or won in court due to, for example, a personal injury claim following an appliance fire. If that injury claim is proven to be due to defective equipment rather than misuse of that equipment, the fire investigator that ‘got it wrong’ may be subject to litigation by their client as they are no longer exempt from prosecution. FIRMs will protect the investigator by ensuring that an accurate methodology has been applied during the investigation of the case in hand. The investigator will have the confidence to present evidence in court having considered all available data in depth and being able to demonstrate the methodology used.

Chapter 12

Future work

The active application of the 23 Fire Investigation Road Maps to all fire and explosion investigations allows a methodology to be used by any competent fire investigator from any organisation. This will enable all available hypotheses to be created, tested, eliminated, proved or concluded as undetermined due to multiple hypotheses being proved as possibly being responsible for starting the fire.

12.1 Fire Development Road Maps

Future work is required to develop a series of additional road maps that apply the same principles of the Fire Investigation Road Maps to help determine how a fire developed beyond the point of origin and possibly beyond the compartment of origin. The road maps may also assist in ascertaining how a fire became suppressed by guiding the investigator through the identification of all available data that allowed the fire to develop and/or how it was eventually extinguished. The development of a fire is often the most complex part of a fire investigation, frequently demanding the use of real fire tests, full scale reconstruction fire testing and/or computer-based fire modelling. This has been the situation in many high profile fire investigations that have resulted in multiple loss of life, including fire fighter fatalities. The organisation that was responsible for the safety of victims of fire may be subjected to prosecution for failing to meet those responsibilities, but it is the families of the victims, normally through the Coroner, that demand to know the truth.

A rigorous and thorough fire investigation not only addresses the origin and cause of a fire, but also the fire's development. Presenting such complex investigations in a manner and format that can be clearly understood by a layperson is of great importance, for example when the verdict of an inquiry is to be made by a jury in a court. An investigation carried out using road map methodologies offers a structured and auditable process to assist in compiling a report or presenting the investigation in a court or other arenas.

The scope of the additional road maps addressing a fire's development should include additional fire dynamics and factors such as changes in ventilation (structural failures, opening of apertures, etc) or suppression activities (water application from fire fighting, fixed systems, fuel starvation, etc). These road maps will address fire safety and fire engineering principles and any solutions that may have been incorporated into the design of a structure, allowing the investigator to measure the effectiveness of those applied principles (or not) and solutions, based on the outcomes after the fire.

12.1.1 Assessment of fire fighting activities

Combining the use of Fire Investigation Road Maps and Fire Development Road Maps would enable an analysis of all fire fighting tactics and methodologies used at a particular fire. It would allow the investigator to determine if an appropriate weight of attack upon the fire was executed and if that attack was timely in its execution when compared to the time line of the fire's development. Data obtained during the fire investigation may support an accident investigation if any fire fighter injuries occur and also address whether best practice was being applied by operational crews at the fire scene. This information could subsequently be available for fire safety/fire engineering teams and also fire fighting operational training teams.

12.1.2 Fire deaths and injuries

As discussed in (12.1.1) above, the combined use of all road maps would assist a fire investigation in determining how any fire deaths and/or injuries have occurred and would enable an accurate database to be compiled from the results of the investigation. This database could be periodically reviewed to identify any patterns or trends that may arise allowing corrective fire prevention actions to be applied.

12.2 Training in the use of Fire Investigation Road Maps

There is a need for training of fire investigators for the correct application of the Fire Investigation Road Maps and a method to feed back into further development of the road maps following their practical application at real fire scenes. Feed back is an important element of the continual cycle of development of the road maps, which is carried out by publications such as NFPA 921 and Kirk's Fire Investigation.

12.3 Software version of Fire Investigation Road Maps

It is recommended that future work should include the development of the Fire Investigation Road Maps into a computer software package to enable the investigator to work from a computer tablet or other computerised device whilst at the scene. This could include the potential to transmit the results of the data collection and analysis back to an office environment via an internet link. An advantage of computerised data capture is that is can be analysed quickly, backed up for security immediately and transmitted to any part of the world almost instantly.

12.4 Monitoring arson prosecution rates

As discussed in (12.1.2) above, accurate fire investigations will result in accurate data bases being populated. Success or failure of an arson prosecution will depend upon the quality of the data (evidence) and the accuracy of the investigation brought against a suspect. If fire investigators were to adopt and actively apply the Fire Investigation Road Map methodology to all of their fire investigations, society should see an increase in successful arson prosecutions.

12.5 Arson in relation to other crimes

By utilising Fire Investigation Road Maps at fire scenes, increasing prosecution rates for arson patterns or trends may emerge (12.4 above) that connect a group of fires to other crimes, such as vehicle theft or burglary. If fires can be referenced or connected to a crime type, there may be more evidence available at the crime scenes to identify the arsonist, such as shoe prints, DNA, fingerprints, etc.

> Terrorists use fire as a weapon; such terrorist related fires have been experienced by people around the world for many years. Fire may be used due to the ease of obtaining combustible materials and its effectiveness to terrorise, cause injuries and death without a terrorist having to use explosives or chemicals, which could be more easily detected. Small deliberately set fires in public places that are not identified as such may develop into more serious fires. These small ‘public’ fires may be the work of terrorist organisations and therefore all available data obtained at fire scenes, no matter how small, assisted by the use of Fire Investigation Road Maps, should be analysed periodically to identify such patterns and trends so that early intervention can be effected.

APPENDIX ONE

LONDON FIRE BRIGADE & METROPOLITAN POLICE SERVICE
DELIBERATE FIRE REPORTING AND RECORDING LIAISON FORM

To be completed in ALL cases when a fire involves:
Serious Injury
Fatality
Suspicious
Tick Relevant Box

CIRCULATION
Page 1 (White): Police
Page 2 (Green): Scene Examiner
Page 3 (Blue) : LFB Fire Investigator
Page 4 (Pink) : LFB Officer In Charge

LONDON FIRE BRIGADE
Officer in Charge:
Name:
…………………………
Date:
…………………………

PROPERTY DETAILS

Owner Name: Contact No:

Enclosed Structure
Exterior
Vehicle
Tick Relevant Box

Residential	Place of Education	Public Place
Commercial	Place of Entertainment	
Industrial	Hospital/Medical Treatment	
Place of Worship	Public Gathering	

Address: ………………………………
………………………………
………………………………
Post Code: ……………………………
Geo Code: ……………………………

Date of Call: Time of Call:

Vehicle Make:
…………………………………..
Model:

FIRE BRIGADE OBSERVATIONS & ACTIONS
(Including Police Actions)

Suspected Area of Origin:
(provide plan if necessary)

Reason for Suspicious Fire:

Did any LONDON FIRE BRIGADE Officer bleed at the scene? YES /NO
Name:

Photos or Video available? YES / NO

Other forensic evidence observed/ noted and actions to preserve:

H&S Risk Assessment

Security Details
Was alarm sounding on arrival? YES / NO
If 'Yes', what type? **FIRE/ INTRUDER**
(Delete as appropriate)
Other relevant security observations:
……………………………………………..
Actions to gain access and/or ventilate:
……………………………………………..

Did a LONDON FIRE BRIGADE FIU attend? YES / NO
Name of Fire Investigator: ……………………

Police Contact Name:
Contact No: CAD No:
Borough: Station:

Services on arrival *(Delete as appropriate)*
Electricity: ON OFF N/A Unknown
Gas: ON OFF N/A Unknown
Brigade switched: Gas ON OFF N/A
Electricity: ON OFF N/A

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