# DEVELOPMENT AND ASSESSMENT OF A DECISION SUPPORT FRAMEWORK FOR ENHANCING THE FORENSIC ANALYSIS AND INTERPRETATION OF FIRE PATTERNS

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**ABSTRACT**

This paper addresses the issues with fire investigation and presents a hypothesis to standardize the analysis of fire patterns. The appropriate method of using fire patterns is to develop and implement into practice a decision support framework that will assist forensic fire investigators in assessing the efficacy of fire burn patterns as reliable indicators of the area of fire origin. This will be facilitated by the evaluation of visible and measurable fire patterns in the context of the fire environment wherein the pattern was developed. Ultimately, the framework will incorporate easy to apply tools, including checklist type forms for use on scene, supported by a software-based system that can be run in the laboratory or office to help investigators connect key observational and measured data to increase the reliability of pattern interpretation.

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## 1.0 INTRODUCTION

This plenary paper functions as a white paper that is intended to argue a potential solution to a problem. This paper identifies a research problem, the current approach to solving such a problem, and a potential process for using fundamental decision analysis coupled with fire protection engineering knowledge to solve this problem. It is not intended to specifically identify all of the variables that affect this problem or to solve the problem. Instead, this paper will suggest processes to approach this problem and to identify variables for further study.

## 2.0 RESEARCH PROBLEM

Forensic science is defined as the application of a broad spectrum of sciences to answer questions of interest to a legal system, including both criminal and civil actions (Houck & Siegel, 2006). The job of a forensic scientist is to provide scientific evidence, notably the analysis of forensic data, to the criminal justice system in order to reduce uncertainty (Taroni, et. al, 2010). However, in the real world, scientific evidence is always incomplete to some degree, which means there is a measure of uncertainty associated within each analysis. Consequently, the forensic scientist must interpret and present the significance of the evidence to the court of law. This is summarized best in the following exchange:

> Evidence does not say anything in itself; its significance needs to be elucidated in the light of competing propositions and background knowledge about the case at hand. There is a great practical necessity for forensic scientists to advise their clients, be they lawyers, prosecutors, jurors or decision makers at large, of the significance of their findings. Forensic scientists are required to qualify and, where possible, quantify their states of knowledge and to be consultants in the assessment of uncertainties associated with the inferences that may be drawn from forensic evidence (Taroni, et. al, 2006).

All forensic sciences are plagued by an inherent level of uncertainty associated with them. Fire and arson investigation is possibly one of the more complicated facets of the forensic sciences, because as a fire burns, evidence is continuously altered or destroyed.

**2.1 Fire Investigation**

Investigation of a fire incident is an integral part of the total fire safety model, including fire prevention and protection for a community. Fire investigation plays a critical role in identifying potentially faulty or improperly designed and installed products that may have played a role in the fire, and in identifying persons that deliberately started a fire with malicious intent. In the end, proper fire investigation should determine the fire cause, the cause of the resulting property damage, and most importantly, the cause of bodily injury or loss of life to civilians and firefighters. To meet this objective, an accurate cause assessment is essential, and an accurate cause assessment depends on a correct origin determination. Therefore, correct identification of the origin of the fire is the scene investigator's most important hypothesis.

***2.1.1 Use of Fire Burn Pattern Data to Identify Area of Fire Origin: Current Practice***

Since the beginning of organized fire investigation in the late 1940's, fire investigators have relied on fire burn patterns as their basis for determining the fire origin (Rethoret, 1945). Fire patterns are defined as the "visible or measurable physical changes, or identifiable shapes, formed by a fire effect or group of fire effects" (NFPA 921, 2008, p. 12). Absent the testimony of reliable eyewitnesses to the fire's inception, the investigator is required to determine the origin by observation and expert interpretation of the physical evidence (fire patterns) in an attempt to reconstruct the fire. As such, fire origin determination is largely a matter of fire pattern recognition and analysis (NFPA 921, 2008).

Currently, fire investigators identify fire patterns by visible observation or through depth measurements of materials affected by fire. This analysis demands the coupling of the physical laws of fire dynamics with the investigator's inference regarding the damage. The pattern data is collected and then analyzed by the investigator and is assigned some weight or meaning comparative to all of the remaining damage within the compartment. The investigator attempts to identify the area(s) of damage that can best explain the collected data to arrive at a decision regarding the area of origin. In other words, the analysis of fire patterns involves identifying damage and then performing a comparative analysis to other materials and damage observed.

Presently, much of this analysis is implicit and subject to investigator bias, with assignment of weights to patterns being largely dependent on the investigator's knowledge, experience, education, training, and skill, without the benefit of a structured framework to help guide the investigator through the process. This is of particular concern with respect to the importance of being able to identify and properly weigh potentially subtle differences from one fire scene to the next, some of which could have significant bearing on the interpretation of the evidence. The analysis is also limited to the investigator's personal knowledge and limitations.

In part, this is due to the nature of fire itself. Fire is defined as "a rapid oxidation process, which is a chemical reaction resulting in the evolution of heat and light in varying intensities" (NFPA 921, 2008).

To be able to discern the subtleties of one situation to the next; of small differences in fuel package or location, compartment geometry, or ventilation openings, the investigator must have a solid foundation of the physical laws that govern fire behavior, and how the factors interrelate, in order to make the best decision possible. The most effective fire investigators will compare the observed damage to attributes associated with the physics and thermal sciences of enclosure fire dynamics.

However, not all fire investigators have the same level of education and training, or appreciation for the interaction of the fire in its environment. Historically, fire investigators have been individuals without any formal education or training in scientific methodology. In a recent survey of 422 fire investigators by the National Center for Forensic Sciences, findings revealed that only 33% held a college degree, of which only 10% were related to science or engineering (Minnich, n.d.). This survey also related that the average fire investigator has only received 60 hours of training, indicating a one-to-two week course. This suggests that many investigators have received the majority of their training through informal on-the-job training. More experienced fire investigators would mentor less experienced fire investigators, unfortunately in some cases, passing on what has since become realized as a collection of myths (NFPA 921, 2008). This occurred because many investigators, particularly those who obtained their "basic training" before 1992, were trained with misinformation and misconceptions, as they lacked the fire science understanding to help them make better interpretations of the information available to them (Lentini, 2006). A number of those investigators have taken very little additional training since then, and of those, some do not recognize how flawed their early training was or the impact of how the lack of training regarding current techniques affect the assessments that they make. The most recent example of this failure being the execution of Cameron Todd Willingham by the State of Texas on the basis of an investigation that relied on "poor understandings of fire science and investigators that failed to acknowledge or apply the contemporaneous understanding of the limitations of fire indicators" (Beyler, 2009).

The standard of care in the fire investigation profession is the 2008 edition of the National Fire Code NFPA 921 *Guide for Fire and Explosion Investigations*, as espoused by the National Fire Protection Association (NFPA). Since its inception in 1992, NFPA 921 represents the industry "standard of care" for fire and explosion investigations. With the introduction of NFPA 921, the fire investigation profession began a movement toward the implementation of science-based principles in fire investigation. Although a good step forward, this change has sometimes been met with fierce resistance, and only since 2000 has the scientific method become "generally accepted" by the relevant community. This text reaffirms the importance of fire patterns and their analysis as the means to determine an area of origin. A process to help step fire investigators through their analysis in a scientific manner remains unaddressed.

Even though historic and current treatises espouse the use of fire patterns for fire investigations, only limited research has been conducted to study the scientific foundation of fire patterns. The National Institute of Standards and Technology (NIST), National Institute of Justice (NIJ), and the United States Fire Administration (USFA) have completed full-scale fire research specifically to address fire patterns (McGarry, 1997; Gottuk, 2009; Shanley, 1997). Due to the numerous parameters associated with full-scale fire tests and the limited number of studies conducted, there are still many questions unanswered.

The legal and science professions are currently scrutinizing forensic science, which is forcing the nation to question the discipline's scientific foundation (NIJ, 2009). Recently, the National Academy of Sciences released a cautionary report regarding this type of analysis (2009). In this document, the authors outlined the need to improve the scientific foundations of the forensic disciplines, particularly those that are dependent on qualitative analyses and expert interpretation of observed patterns, including fire investigations (NIJ, 2009).

When lacking a systematic approach to solving complex problems, many professions have turned to decision support frameworks, tools or methods, the intent of which are to guide the decision by asking questions and helping to assess the weight or importance of variables. It is evident that with the education and training for the average fire investigator often lacking helpful scientific and engineering knowledge, coupled with the lack of a systematic procedure for the analysis of fire patterns, a major gap exists within the fire investigation profession. A science-based decision framework is proposed to fill this gap within the profession. From a scientific basis, an investigator who includes attributes of fire dynamics in the evaluation of fire patterns is more likely to reach a technically valid determination of the origin and cause of a fire. It is recognized, however, that not all fire investigators in the near future will receive the necessary training and education to address their knowledge gaps, and even if they do, without guidelines they can use in the field to help them do a better job, it will be difficult to apply newfound knowledge.

### 2.2 Use of Decision-Support Frameworks to Enhance Decision-Making under Uncertainty

In the face of non-systematized approaches to solving complex problems, many professions have turned to decision support frameworks, tools or methods. As used here, decision frameworks, tools or methods encompass any mechanism used to support the systematic identification and assessment of information deemed important to a decision, ranging from checklists, to structured problem-diagnostic tools such as fault trees, event trees or decision trees, to computationally supported decision analysis tools. Decision support frameworks are derived from the field of decision analysis, as well as from uncertainty analysis and risk analysis.

Decision analysis has its roots in operations research, where it emerged from a desire to better understand and address decision-making under uncertainty, becoming viewed as a unique area of study in the 1960s (Howard, 1966; Raiffa, 1968). A fundamental principle of decision analysis is that people do not always have all the data or information needed to make a good decision, and sometimes do not know where to go to obtain the information, or how to judge the value of the information to the overall decision. As these areas began to be studied, approaches began to be developed to help individuals and organizations identify the components of a good decision, how to structure the decision problem, and how to treat the associated uncertainty (e.g., Kahneman and Tversky, 1974; Von Winterfeldt and Edwards, 1986; Morgan and Henrion, 1990; Kleindorfer et al., 1993; Clemen and Reilly, 2001; Donegan, 2008).

Key aspects of a decision support framework include identification of decision objectives (e.g., identify the most likely factors leading to presence of a particular burn pattern), attributes (criteria) which are important to the decision problem (e.g., fuel type and location, compartment geometry, ventilation openings, etc), and the weighting (importance) of the attributes to the decision given the uncertainty and variability in the data and relationship between attributes. Once these parameters are identified and agreed, various techniques can be applied to facilitate collection of critical information, analysis of the data, and facilitation of a decision.

This type of structured approach to reaching better decisions has been applied in various fields, from business and economic decisions (e.g, Clemon and Reilly, 2001), to building and fire safety analysis and regulation (Meacham, 2000; Donegan, 2008), diagnostic support within the psychological, psychiatric, and medical professions (Boorse, 1976; DSM-IV-TR, 2000), failure analysis (Benner, 1975; Ericson, 1999; Vesely, 1981) and forensic analysis (Taroni, et. al, 2005; 2010; Morvan, 2007; Jarman et al., 2008), including with respect to fire investigation (Biedermann, A., et. al, 2004).

### 2.3 Decision-Support Framework to Increase Reliability of Burn Pattern Interpretation

It is evident that with the education and training for the average fire investigator often lacking helpful scientific and engineering knowledge, coupled with the lack of a systematic procedure for the analysis of fire patterns, a major gap exists within the fire investigation profession. A science-based decision framework is needed to fill this gap within the profession. From a scientific basis, an investigator who includes attributes of compartment fire dynamics in the evaluation of fire patterns is more likely to reach a technically valid determination of the origin and cause of a fire. It is recognized, however, that not all fire investigators in the near future will receive the necessary training and education to address their knowledge gaps, and even if they do, without guidelines they can use in the field to help them do a better job, it will be difficult to consistently apply newfound knowledge. As an additional benefit, the decision support data can be updated from time-to-time so that even knowledgeable investigators can be brought up-to-date with the most current research.

## 2.4 Goals and Objectives

The goal of this research is to develop and implement into practice a decision support framework that will assist forensic fire investigators in assessing the efficacy of fire burn patterns as reliable indicators of the area of fire origin. The framework will be based on identifying, relating and weighting key attributes of the fire environment, observed and measured, from a compartment fire dynamics and related fire physics and chemistry basis, with the aim to facilitate more reliable evaluation of visible and measurable fire patterns given the influence of the fire dynamics attributes. Ultimately this framework will guide the investigator in gathering on-scene evidence that can better assist in the scientific analysis of the area of origin hypothesis, and will allow the user to identify and evaluate the most common attributes that affect the pattern reliability based on information and research studies that are currently available.

Procedurally, the proposed framework will first provide the investigator with a series of research-based evidentiary attributes, which have been shown to affect the reliability of that pattern, about which data will be collected at the scene. The framework will then provide the investigator with the basis for a qualitative assessment of the reliability of that pattern, given the strength of the attributes, and help the investigator assign a more appropriate confidence weighting to the specific pattern. The decision support framework will also help to assess the scientific probability of each pattern occurring, given the evidentiary data, providing quantifiable measures of the reliability as well. Ultimately, the combination of pattern evidence, given the identified attributes, their reliability measure and respective weighting will provide a more objective and technically valid means to arrive at an area of origin.

This framework will also assist with the evaluation of multiple origin hypotheses by analyzing each fire pattern in support and in opposition to the various hypothetical area(s) of origin. Consequently, this framework would also identify areas that require further study that would allow the framework to be compressible and/or expandable based on the findings of each research study. As the state of the art develops, this framework will also identify other tools (e.g., computer fire models) that can be used within the framework to better assess the area of origin objective.

## 3.0 Literature Review

The following literature review has been divided into two sections, (1) studies that have been conducted to help identify fire patterns in compartment fires, and (2) studies that provide evidence of the effectiveness of decision support frameworks in other professions.

## 3.1 Fire Pattern Studies

As early as 1945 Rethoret in his text *Fire Investigations* explained: “In which direction is the wood carbonized? Study closely the depth of carbonization at various places. Bear in mind that superheated gases spread upwards. This again will assist you in getting back to the point of origin.” (p 36)

The Law Enforcement Assistance Administration collected some of the myths about fire investigation in a 1977 study entitled “Arson and Arson Investigation: Survey and Assessment” (Boudreau, Kwan, Faragher & Denault). The arson investigators surveyed cited interpretation of “burn indicators” as the most common method of establishing arson. Some of the burn indicators used were alligatoring, crazing of glass, depth of char, lines of demarcation, sagged furniture springs and spalled concrete. The LEAA report, after listing the indicators, provided the following caution:

> "It is recommended that a program…be conducted to establish the reliability of currently used burn indicators. Of particular importance is the discovery of any circumstances, which cause them to give false indications (of, say, a fire accelerant). A primary objective of this testing would be to avert the formidable repercussions of court ruling on the inadmissibility of burn indicators on the grounds that their scientific validity had not been established. In addition, the research might well uncover new methods of value to fire and arson investigators" (Boudreau, Kwan, Faragher & Denault, 1977).

Given the history of using fire spread and fire pattern analysis, it was reasonable that the system would also be included in the first edition (1992), and all subsequent editions of NFPA 921 *Guide for Fire and Explosion Investigations.* In the 2008 edition of NFPA 921 the importance of fire patterns is clearly reiterated by stating that "the major objective of any fire scene examination is to collect data as required by the scientific method (*see 4.3.3*). Such data include the patterns produced by the fire" (Section 6.1.1).

In 1994/1995 The United States Fire Administration, in conjunction with the National Institute of Science and Technology, Building and Fire Research Laboratory (NIST-BFRL) launched the fire pattern research committee and produced the USFA Fire Pattern Test report, authored by Shanley, July 1997. This project consisted of 10 separate full-scale burns to produce the first scientifically controlled and recorded research into the formation, growth, and investigation of patterns produced in fires. These tests produced the first data that supported fire patterns as being useful in fire investigation. However, this report also demonstrated that in two tests, "distinctive patterns were produced which without careful study and a full understanding of *all factors* which influenced the progress and growth of the fire, could easily be interpreted to indicate incorrect or multiple origins" (p. 56). This study also noted that ventilation was one of the most misunderstood variables, having the influence to alter "normal" fire pattern production.

In March of 1997, McGarry and Hill, in conjunction with the University of Maryland, continued the full-scale room experiments. Four full-size furnished bedrooms were burned at the University of Maryland Fire Rescue Institute Facilities. The burns were intended to be identical to determine if differences would be discovered with a close analysis of the results. In both cases, ignition of a gasoline spill next to an upholstered chair was used to initiate the fire. The researchers noted differences, and attributed these to small variations in the inflow of air.

Another series of full-scale fire tests was conducted with funding provided by the National Institute of Justice, resulting in a report "Full Scale Room Burn Pattern Study," released in December 1997 (Putorti). Putorti reports that "comparisons of the conditions of the rooms and furnishings after the experiments resulted in the determination of several similarities, as well as many differences, between experiments with the same method of ignition" (p. 26). He attributes the differences to the "ventilation effects" (p. 26).

In 2002, fire pattern analysis was identified as an essential area of research by the National Fire Protection Association's Fire Protection Research Foundation. In their report, authored by its "Research Council on Post-Fire Investigation", they recommended that "if patterns are to be used for origin and cause determination, forensic methods to identify the specific source of a pattern need to be developed and rigorously vetted" (p.5).

Beginning in March of 2005, a series of twenty full-scale fire pattern studies were conducted by Eastern Kentucky University and the National Association of Fire Investigators (Gorbett, et al., 2006; Hopkins, 2007; Hopkins, 2008; Gorbett, 2010). These studies were completed using the EKU's Fire and Safety Engineering Technology burn facility. The test fires were conducted in identically constructed, finished, and furnished living room and bedroom compartments. These studies focused on fire patterns reproducibility, patterns persistence through flashover, the use of fire patterns in origin determination, and the influence on fire patterns produced by an initial, low heat release rate fuel. The most important finding from these tests is that "the interpretation of *all* fire effects provides substantial evidence for the investigator to identify the correct area of origin" (Gorbett, 2010).

Between 2006 and 2008 (Hicks, et al.), a fire pattern reproducibility study using single fuel items was completed at Eastern Kentucky University. Forty-eight tests were conducted with a standardized ANSI/UL wood crib and ten additional tests were conducted with commercially available polyurethane foam recliners. These two studies resulted in fifty eight single fuel items burned and fire patterns documented. The studies demonstrated that class-A fuel items and composite materials would reliably reproduce similar fire patterns from a single fuel burning.

In 2005 and 2008 (Carman, 2009), three studies were completed in conjunction with a training seminar to analyze burn pattern development in post-flashover fires. This study focused on the impact of ventilation on fire patterns and the ability of fire investigators to use fire patterns to determine the origin area. Carman (2008 & 2009) divided the room into four quadrants and performed a survey of the attendees in an attempt to derive an error rate study of investigators. He reports a 5.7% success rate of determining the correct quadrant where the fire was started. Neither study provided the demographics of the attendees, nor could it provide any statistical rigor. Nevertheless, Carman attributed the failure to the lack of understanding by the investigation profession of the differences between pre- and post-flashover fire behavior.

In 2009 (Wolfe, Mealy, and Gottuk), through the funding of NIJ, fifteen full-scale fires were conducted with varying ventilation conditions and fuels. They focused on unventilated fires, the fire growth associated with these types of fires, and their forensic analysis. While much of the research was based more on the tenability limits and associated dynamics in unventilated fires, they reported on a few forensic-based conclusions. These included that soot deposition can be used to aid in the area of origin determination and that the clean burn area size is proportional to the fire size (2009).

### 3.2 Decision Support Frameworks, Tools and Methods

As introduced earlier, decision frameworks have been applied to a diverse set of decision problems across a wide range of professional disciplines to help facilitate better decisions under uncertainty. The first major application of decision analysis to complex problems was the development of military strategies during World War II, known as operations research (Clemen and Reilly, 2001), emerging as a recognized discipline in the 1960's (e.g., Howard, 1966; Raiffa, 1968), and in combination with related tools, such as uncertainty analysis, risk analysis and failure analysis, soon found application in areas related to forensic investigation.

As early as the mid 1960s, the application of decision analytic techniques, coupled with structured diagnostic techniques, such as fault tree analysis (FTA), event tree analysis (ETA), and failure modes and effects analysis (FMEA) began to be applied in the investigation of aircraft and nuclear power plant accidents (Rassmussen, 1975; Benner, 1975; Vesely, 1981; Ericson, 1999). Over time, these tools became embedded in the pre-construction risk analysis of aircraft, nuclear power plants, and other facilities (e.g., chemical and petroleum processing facilities (CCPS, 2002), buildings (e.g., Meacham and Johann, 2004; Watts, 2008; Meacham et al., 2008), critical infrastructure (Fenelon et al., 1994), as well as in failure analysis of systems and facilities (e.g., CCPS, 2002), and work to integrate these tools with decision analysis approaches continues (Puente et al., 2002).

In much the same way, decision analysis tools began to be used as diagnostic support tools within the psychological, psychiatric, and medical professions starting in the 1970s (Boorse, 1976; DSM-IV-TR, 2000). Over time, decision analysis tools have been applied to a wide range of diagnostic, failure and forensic analysis in the medical profession, including development of decision support tools for assessing heart failure (Hossen and Al-Ghunami, 2006; Colantonio et al., 2008), microbial forensics (Jarman et al., 2008), and forensic entomology (Morvan et al., 2006), and within forensic science in general (Taroni, et. al, 2005).

This trend continues, with newer decision support tools, such as Bayesian networks and probabilistic inference, being applied to forensic sciences (Taroni et al.; 2010), and even to fire investigation, where the application of this logic towards ignitable liquid residue has been investigated (Biedermann, A., et. al, 2004). These examples provide a glimpse of the breadth of successful application of these decision making techniques in diverse fields.

**4.0 Research Design and Methods**

Development of the decision framework will consist of three operations: system design, professional judgment review and critique, and systems testing.

**4.1 System Design**

The system design will consist of the following:

1. Analysis of the requirements of fire investigation standards and related authoritative treatises,
2. Analysis of the relevant literature regarding compartment fires, fire pattern studies, and decision analysis,
3. Organization of the results of this analysis into a decision support framework format that is suitable for identifying critical attributes, including fire scene data and information (observed and measured) and critical post-scene data or information (from testing, analysis or other), the relationships between attributes, and the weighting of the attributes based on relative importance to the decision given the data and associated uncertainty,
4. Elicitation of professional judgments on the weighting of the fundamental attributes relative to the area of origin determination objective (decision objective), and
5. Iterative incorporation of system changes resulting from the professional judgment review and system tests.

It is currently envisioned that the decision support framework will consist of two primary components: a simple to use data collection tool, which could be in checklist, tabular or similar format (field use), and a computational analysis tool, which takes input from the data collected and helps lead the user through a structured process of reaching a decision relative to the reliability of fire patterns as indicators of area of fire origin (office use). Research from this effort will underpin the analysis tool, including attributes, relationships and weighting, meaning that for the investigator, data collection and input into the tool will be their primary responsibilities.

**4.2 Professional Judgment Review**

Initially, a decision support framework will be developed based on the available literature and research studies, as well as the experience and professional judgment of the principal investigators and research assistant, as outlined above. Subsequently, a group of experts will be consulted, through the mechanism of a “Delphi” exercise, to test such factors as attribute relationship and weighting. The Delphi group will consist of practitioners/experts within the fire investigation profession. Various approaches to obtaining relevant information through a “Delphi” process will be explored. In-person and web-based approaches will be considered.

Delphi is a procedure for obtaining the most reliable consensus of opinion of a group recognized as experts on a technical question for which no “true” answer is within the state of current knowledge (Dalley, N, Helmer, D, 1963). The core of the process is that the question is considered independently by members of the group prior to committee work.  The responses are tabulated and circulated to group members who revise their "answers" based on further thought and consideration of the collective response.  Additional rounds of response possibly involving direct contact and discussion among the group members can ensue.  In its classic form, Delphi incorporates various statistical measures of the "convergence" to consensus, which are circulated with the group along with the responses (Tesfamariam, S., Sadiq, R., Najjaran, H., 2010).  In this proposal, a questionnaire provided to the group will focus on obtaining expert interpretation of the weighting associated with a given pattern based on the fire dynamics attributes.

**4.3 System Testing**

The testing will involve a series of exercises to determine the validity of the framework. The testing will assess: how users apply the framework based on what is postulated in this proposal; how well the framework operates in guiding decisions of practitioners and students during practical field exercises; and, the consistency of application and outcomes.  These exercises will include:

(1) Examinations of previously published fire pattern studies with the framework;
(2) The framework will be tested via integration with practitioners in the field.
(3) Two phases of workshops (alpha and beta) with fire science students and fire investigation experts will be employed throughout the duration of the project.

**4.4 Proposed Objectives and Attributes (Higher level Framework)**

Although research as outlined above is needed to complete development and assessment of the framework, some preliminary research has already been conducted to demonstrate how the approach is anticipated to develop. To date, effort has focused on the 'higher-level' issues that influence fire patterns. The following is a working list of the higher-level objectives and attributes that influence fire pattern identification and analysis.  The lower-level, more specific attributes will be identified as part of this study through research and the "Delphi" group.

**4.4.1 Fire Effects**

The analyst observes damage in or on surface materials after a fire.  The damage is commonly referred to as a fire effect by the fire investigation profession.  Fire effects are defined as "the observable or measurable changes in or on a material as a result of exposure to the fire" (NFPA 921, 2008, p. 39). There are a total of 15 effects listed in NFPA 921 (2008) and will be the base list of observations (Table 1).

The damage can be visible and/or measurable.  The extent of this damage and type of damage will be dependent on the type of material and its associated factors (Figure 1).  Each fire effect will be processed through steps 4.4.1-4.4.4 to properly assign the factors that created the effect.

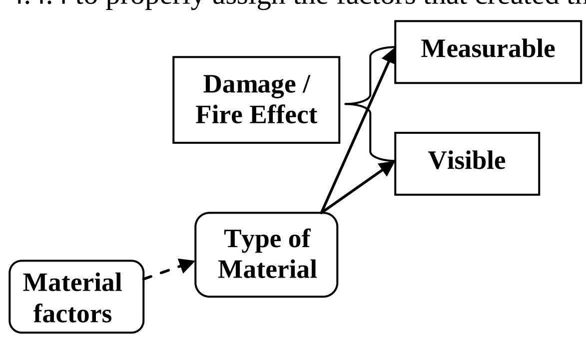


**Figure 1: Initial Observations**

**Table 1: Base List of Fire Effects and Observations identified in NFPA 921 (2008)**

| FIRE EFFECT | OBSERVATION(S) | |
|---|---|---|
| | Visible | Measurable |
| Temperature Estimation | X | |
| Mass Loss | X | X |
| Char | X | X |
| Spalling | X | |
| Color Changes | X | |
| Melting of Materials | X | |
| Thermal Expansion and Deformation | X | X |
| Oxidation | X | |
| Deposition | X | |
| Clean Burn | X | |
| Calcination | X | X |
| Window Glass | X | |
| Furniture Springs | X | |
| Victim Injuries | X | |
| Light Bulbs | X | |

### *4.4.1 (a) Material Factors*

There are numerous factors that may influence how a material is affected by heat and exposure to incomplete combustion products (i.e. smoke, aerosols). The loss of mass from a material may also have several variables that are typically dependent on the material and the exposure to heating. A short list of material properties that may influence the effects of exposure of a material exposed to a fire environment, include: moisture content, thermal conductivity, density, specific heat, critical heat flux, ignition and flame spread propensity, and heat of gasification/vaporization.

### 4.4.2 Visible and/or Measurable Damage

The visible and/or measurable damage in or on a material is caused by one or a combination of the following: heat, deposition, and/or consumption (NFPA 921, 2008). The investigator may use this effect as an indicator to initially classify the cause of the observed damage (i.e. clean burn=heat). Next, the analysis of the following factors and their involvement into the cause of the damage must be considered: fire environment, compartment, fuel(s), and suppression (Figure 2).

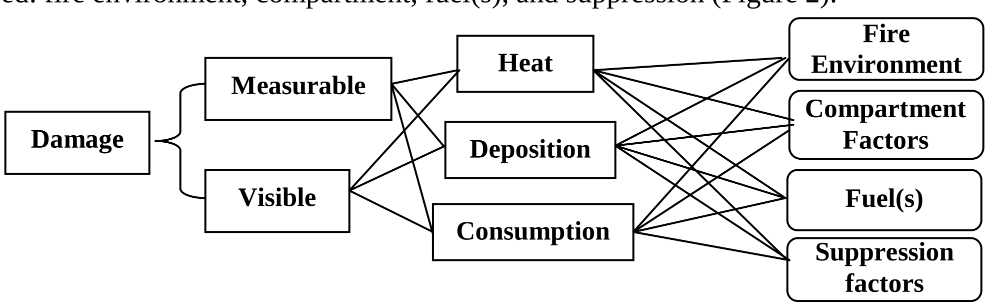


**Figure 2: Attributes that influence visible and measurable damage**

### 4.4.3 Heat, Consumption, and Deposition

The visible and measurable fire patterns are listed in NFPA 921 to be caused by one or a combination of the following physical effects to the material: heat, deposition, and/or consumption (2008, p.48). Heat, consumption, and deposition will be separated into local or global effects that will assist analysts in better identifying the cause of the resulting damage. These physical effects will be broken into more specific attributes as part of this study, however, a brief listing has been provided below.

- *Heat* - heat transfer is driven by fundamental physical principles, including: temperature difference, view factor (radiant heat transfer), turbulent/laminar flows (convective heat transfer), thermal inertia (conductive heat transfer).
- *Consumption* – the loss of mass from a material when exposed to heat is considered consumption of the fuel or material. This is based on heat exposure and material properties.
- *Deposition* – Smoke contains particulates, liquid aerosols, and gases (NFPA 921, 2008). As smoke decreases in temperature and/or collides with cooler surfaces, deposition of the smoke occurs. Locations of protected areas, areas of greater and lesser soot deposition, and the effects of thermophoretic forces (temperature difference and velocity between hot gas layer and cooler wall surfaces) will be assessed. The differences between horizontal and vertical surfaces will also be noted and referenced as to their relative importance.

**4.4.4 Fire Dynamics Attributes**

A fire can develop in many different ways, which may significantly influence the resulting damage. The major attributes that influence fire behavior have initially been divided into 4 categories based on their relative importance to the developing fire and the resulting impact on the location and degree of damage. The initial portion of this proposal will focus specifically on breaking these categories into detailed attributes, however, a brief listing is provided below.

***4.4.4 (a) Fire Environment***

The first priority is to determine what environment existed during the fire. This will be accomplished by analyzing the resulting damage to determine if the fire was ventilation-controlled or fuel-controlled. Additionally, this analysis would take into consideration if the compartment reached full room involvement or not.

***4.4.4 (b) Fuel (Location, Heat release rate, number of fuel items)***

Secondly, the fuel items will need to be identified, including the heat release rate(s), the location of the fuel in proximity to other fuel items, the presence of multiple fuels, and the configuration and orientation of the fuel items. Finally, a comparative analysis will be undertaken between each fuel item to identify their relative involvement in the damage.

***4.4.4 (c) Compartment Factors***

Basic compartment factors may influence the development of a fire, therefore, the area, volume, configuration, and ceiling heights of compartments will need to be assessed as to their relative importance to the damage observed. Additionally, the location of damage in the compartment may provide the investigator with valuable data regarding the fire environment. One of the most important factors that will be assessed under compartment factors is the location, number, and position of the ventilation openings for the compartment. Finally, the adjoining space or compartment volume will be assessed to determine the availability of "fresh" air and the presence/lack of wind.

***4.4.4 (d) Suppression Factors***

The suppression factors that will be assessed as to their impact on visible and measurable damage includes the location of water application, duration of fire burning prior to arrival, duration required to extinguish the fire, location of fire department entry, method of extinguishment, use of positive pressure ventilation (i.e. forced convection, mechanical movement of smoke (deposition of products) or spreading of contaminants), and the change of ventilation upon arrival (breaking windows, opening doors, cutting holes in ceiling).

**4.4.5 Grouping of Fire Effects**

Each effect will be processed through the analysis of the fire dynamics attributes from above in an attempt to group like effects. Once groups of effects have been identified with similar causes, then a decision can be made regarding the basis for pattern generation. NFPA 921 (2008) provides the following classifications for the generation of fire patterns: ventilation, plume, suppression, upper layer, full room involvement (Figure 3).

Comparative analysis of the damage (greater/lesser) may provide the analyst with data that provide indicators (fire patterns) of intensity, fire travel, and/or geometry. However, if the damage cannot be determined conclusively, then a determination of insufficient data is appropriate.

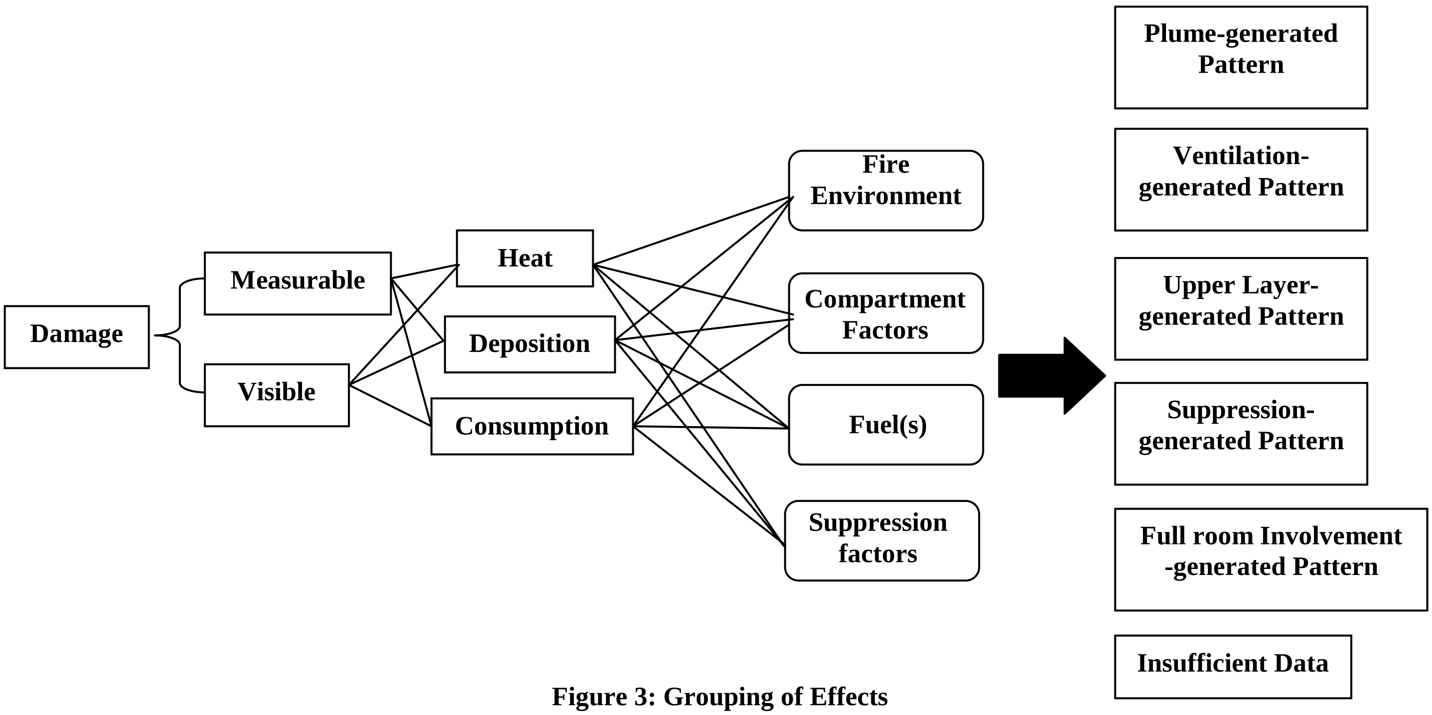


**Figure 3: Grouping of Effects**

### 4.4.6 Analyze all Collected Fire Effects Data: Fire Pattern Analysis

When the cause of the damage has been established, then the fire effect may provide the analyst a direction of fire travel or a location of more intense burning/longer burning duration (Figure 4). Analysis of fire patterns involves the processing all of the collected data and determining if there is a preponderance of the patterns/damage in an area or areas.

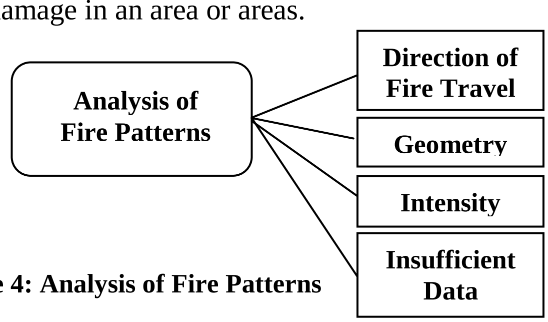


**Figure 4: Analysis of Fire Patterns**

### 4.4.7 Determining the Area of Origin

Arrival at a hypothetical area of origin requires the analyst to test the hypothesis by asking several questions: (1) is an ignition source present or not present? (2) Was a fuel package present or not? (3) Is the actual damage observed consistent with expected damage based on first fuel ignited and fire growth? (4) Is the ignition source competent compared to the first fuel ignited? (5) Can the first fuel ignited result in the fire spread scenario that resulted in the damage observed? (6) Are there more than one hypothetical areas of origin? Ideally, the investigator would strive to use this system to arrive at an area of origin of a practicable size, which will be defined here as the first fuel ignited (Figure 5).

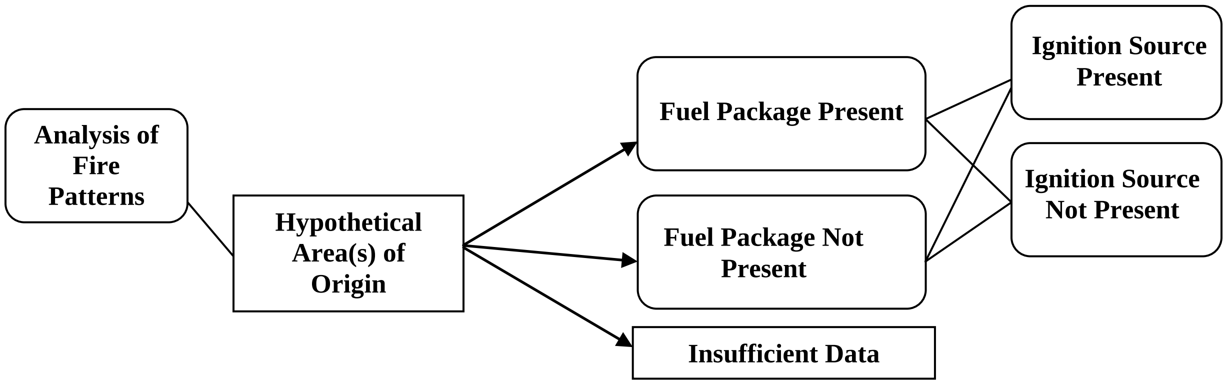


**Figure 5: Area of Origin Hypothesis**

### 4.4.8 Insufficient Data

Insufficient data requires the analyst to collect more data, reanalyze the data, retest, and rework the process. However, if insufficient data still exists, then the area of origin is undetermined.

### 4.4.9 Total Process

At this point, the resultant fire patterns and the corresponding fire dynamics attributes will be assessed with one of the statistical methods (Figure 6). This will provide the investigator with a probability for each fire pattern and its resultant reliability, as well as a quantifiable measure of reliability for the process. The specific statistical method will be determined throughout the implementation of this study.

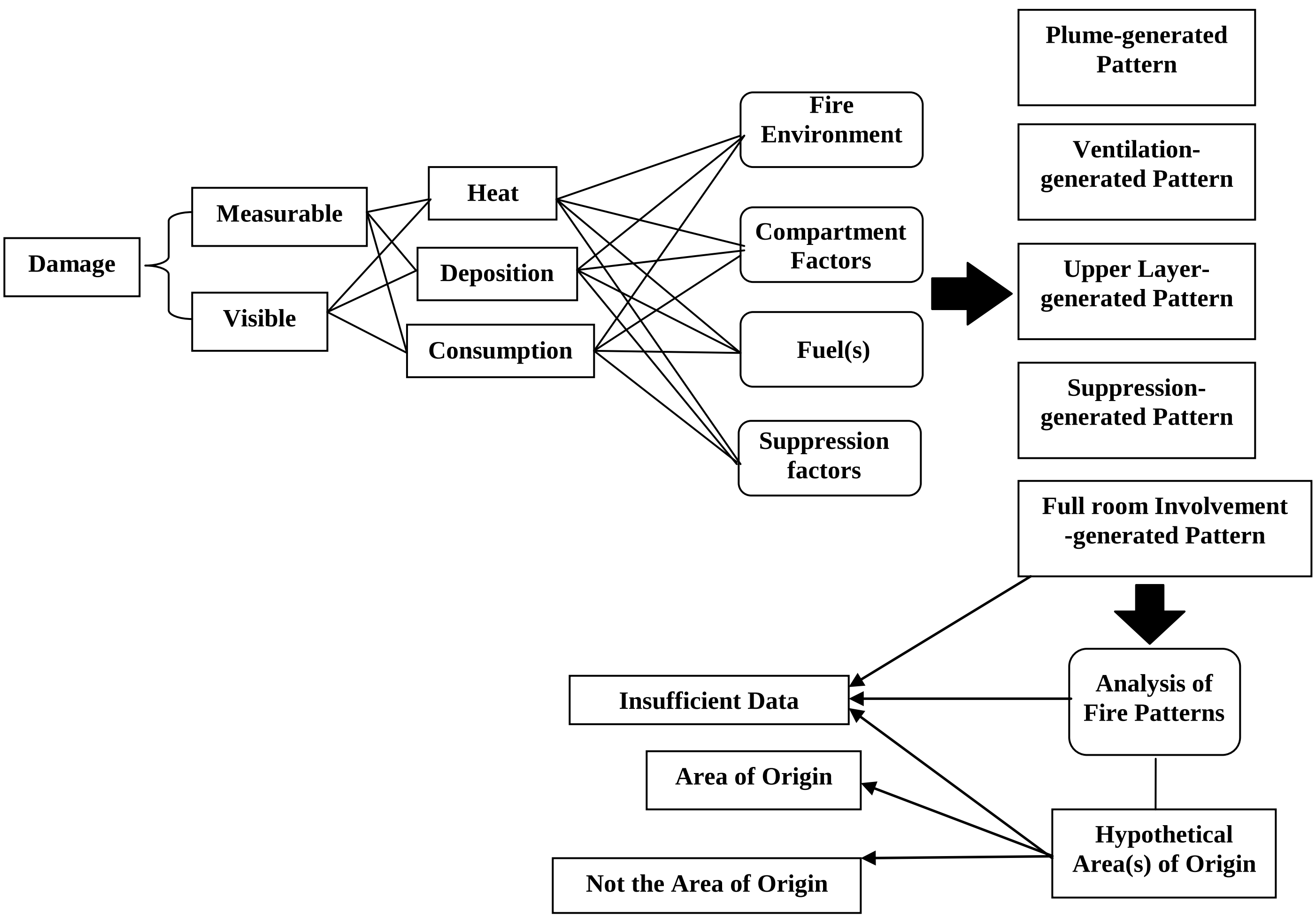


**Figure 6: Total Process**

At the culmination of the project, a computer system based on the decision framework will be developed that allows investigators to make a better origin decision. An investigative form will be developed to assist with on-scene data collection, similar to a checklist, which will assist the investigator in considering the appropriate attributes and resultant effects.

## 5.0 Conclusions

As fire patterns are the cornerstone of origin determination, and fire investigation altogether, it is necessary to equip investigators with tools to help them conduct better and more scientifically-supported investigations. This is especially important where there are a range of visual and measurable data that interrelate in different ways to impact the reliability of fire patterns as indicators of the origin area. To help advance fire investigation and the integration of science and the scientific method into the process, a better, more systematic, research-based decision support framework for determining an area of origin based on fire patterns will be developed. The proposed research will enhance the current methodologies prescribed and utilized in the fire investigation community. The natural variability of fire patterns and damage characteristics will be determined and disseminated to the fire investigation and legal communities. The scientific underpinnings for these fire patterns will be determined to assist fire investigators in correctly interpreting fire damage and assigning more appropriate weighting to fire patterns based on the fire dynamics attributes.

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