INTERNET OF THINGS (IoT) CONNECTED BUILDING SYSTEMS AND THEIR USE IN FIRE INVESTIGATIONS: A MIXED METHOD STUDY

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY

INTERNET OF THINGS (IoT) CONNECTED

BUILDING SYSTEMS AND THEIR USE IN FIRE

INVESTIGATIONS: A MIXED METHOD STUDY

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ACKNOWLEDGEMENTS

First and foremost, I would like to take a moment to reflect upon and thank my parents, Roy W. Dodsworth and Genevieve “Cookie” Dodsworth. Even though God has taken both of you from me far too soon, you are never far from my mind or my heart. You never stopped encouraging me to push myself beyond the limits, to dream big….to shoot for the seemingly impossible, and to never give up. You led me on the path of life and taught me to always reach down and pull people up alongside me during my journey. Without you, I wouldn’t be here. I love you both!

My husband, Dane Whetsel, Sr. (ATF CFI/NRT retired), was infinitely patient with the long hours of classwork and writing. He is my strength and my sounding board. Thank you for your steadfast love and encouragement.

They say it takes a village…my family have always been some of my biggest cheerleaders. Especially my brother, Roger H. Whitford, Jr., Aunt Debbi Dodsworth, Uncle David Dodsworth, Aunt Mary Dodsworth, Aunt Karen Fox, and Aunt Patty Tranchese. Thank you all for always checking in on me and providing me with that added motivation.

Dr. Scena Webb, I cannot thank you enough! Your guidance and encouragement along each step of my dissertation process and doctoral candidacy was unmatched. I can never repay you for all of the time you gave of yourself to assist, challenge, and encourage me. Not to mention being a dear and trusted mentor to me at work as well.

I am truly grateful for the rest of my Ph.D. committee as well: Dr. John Frucci, Dr. Robert Agnew, Dr. Matthew Green, and Dr. James Hess. Thank you for all of your time and effort reviewing my writing, meeting with me, and challenging me every step along the way. I'm a better student, professional, and person because of each and every one of you.

I would also like to thank Penelope Carr (former OSU Academic Coordinator, School of Forensic Sciences) and Sarah Vizza (OSU Academic Coordinator, School of Forensic Sciences) for their guidance during the length and breadth of my academic journey at Oklahoma State University. You were always only an email or phone call away to answer my questions and keep me on track.

I cannot forget my technical review panel, taking precious time out of their days to critically analyze every part of my writing to ensure it was technically and professionally sound. A very special thanks to Andrew Cox (ATF CFI/NRT), NFPA 921 Technical Committee member, M. Dixon Robin (ATF CFI/NRT Team Leader retired), Dan Heenan (ATF CFI/NRT Team Leader retired; Assistant Fire Chief – Investigations, Clark County Fire Department), IAAI Past President and NFPA 1033 Technical Committee member, and Dr. Chelsea Bullard (OSU).

I would also like to take a moment to thank the technical reviewers for all of the case studies listed within the results section of this document: Ryan O. Parker (ATF CFI/NRT), James Lord (former ATF FRL FPE; Reax Engineering), Dane Whetsel, Sr. (ATF CFI/NRT retired), Ryan Zornes (ATF CFI/NRT), Michael Keller (Former ATF FRL EE; U.S. Department of Energy), M. Dixon Robin (ATF CFI/NRT Team Leader retired), Dan Heenan (ATF CFI/NRT Team Leader retired; Assistant Fire Chief – Investigations, Clark County Fire Department), Jesse Lampf (ATF CFI/NRT), Mark Meeks (ATF CFI/NRT), Seth Graybill (ATF CFI/NRT Team Leader); Adam St. John (ATF SA and former ATF FRL FPE), Michael Abraham (ATF FRL EE); Ryan McCormick (ATF CFI/NRT), Ricky Hankins (ATF CFI/NRT), Cameron Novak (ATF FRL EE), and Gregory Lotoczky (ATF CFI/NRT).

Furthermore, a special thank you to the ATF subject matter experts who assisted with the interview template calibration via field testing: Jonathan Butta (ATF FRL FPE), Juan Rosado-Marin (ATF FRL EE), and Matt Hartnett (ATF CFI/NRT).

Last, but certainly not least, thank you to my six anonymous ATF subject matter experts who took time out of their extremely busy days to be interviewed for this research.

Acknowledgements reflect the views of the author and are not endorsed by committee members or Oklahoma State University.

Name: DAWN T. DODSWORTH

Date of Degree: DECEMBER 2021

Title of Study: INTERNET OF THINGS (IoT) CONNECTED BUILDING SYSTEMS AND THEIR USE IN FIRE INVESTIGATIONS: A MIXED METHOD STUDY

Major Field: FORENSIC SCIENCE

Abstract: In 2009 the National Academy of Sciences produced a paper entitled *Strengthening Forensic Science in the United States: A Path Forward.* The purpose was to identify significant improvements needed in forensic science. The paper provided recommendations involving policy initiatives that should be adopted by various forensic science disciplines to increase their effectiveness. One of the fields included was fire investigation. Experts, such as Professor Jonathan Koehler from Northwestern University, have inferred that forensic science fields relying heavily on subjective interpretation of data tend to be the most problematic.

John Lentini and John DeHaan, recognized fire investigation experts, have stated that the accurate interpretation of fire effects and fire patterns can lead an investigator to the proper area of origin within a fire scene. However, the accurate interpretation of these patterns can be challenging. The correct interpretation of these patterns is dependent upon numerous variables, including the knowledge, training, and experience of the investigator as well as the investigator's understanding of scientific theory related to such topics as fire science, fire chemistry, thermodynamics, and fire dynamics. Occasionally fire investigators can misinterpret observed patterns. This can result in misidentifying the area of origin.

The Internet of Things (IoT) is a system of interrelated computing devices; these can be both mechanical and digital machines embedded with sensors, software, and other technologies that connect and exchange data with other devices and systems over the internet. Several building systems potentially fall into the category of IoT due to how they typically function such as fire sprinklers, fire and smoke detection systems, and security systems. As a result, data from the IoT involving these systems can be extracted, analyzed, and subsequently employed by fire investigators to narrow down the area of fire origin within complex fire scenes.

This study focuses on the utilization of IoT data to make fire investigations more empirical by decreasing the necessity for substantial reliance on the subjective interpretation of fire patterns. The creation of hard data points in the determination of an area of origin will successfully address the issues enumerated by Lentini, DeHaan, Koehler, and the National Academy of Sciences.

Table of Contents

Chapter Page

Chapter Page

Chapter Page

Chapter Page

List of Figures

Figure Page

Figure Page

Figure Page

List of Tables

CHAPTER I

INTRODUCTION

Fire investigation is the analysis of fire-related incidents with the intent of determining where the fire began (i.e., the area of origin) and the cause of the fire, which involves (a) the ignition source; (b) the first fuel ignited; (c) the oxidizer, which is usually air; and (d) the circumstances which brought them all together. The fire investigator also examines and attempts to identify the factors which brought the ignition source and the first material ignited together. The methodology utilized by the investigator is known as the scientific method, in other words the systematic process of acquiring knowledge through observation, data collection, and analysis to arrive at a conclusion.

Fire investigation has been called an “art,” a “science,” and a combination of the two. During a scene examination, an assessment is conducted pertaining to the observations made by the investigator regarding fire-related patterns or artifacts. The investigator then considers possible casual factors (i.e., hypotheses) which led to the creation of these patterns. This inquiry ultimately concludes with the formation of opinions as a result of the investigator’s interpretation.

One of the greatest sources of criticism of the field of fire investigation is the subjective nature of the investigator's interpretation of collected data. This issue is especially pertinent concerning the fire investigator's interpretation of fire effects and fire patterns while analyzing observed damage to a structure. The United States Congress authorized a study to provide an in-depth view of the various disciplines contained within the forensic science community; this study has come to be known as the 2009 National Academy of Sciences (NAS) report. The focus of the study was to recommend improvements to these various disciplines to increase their effectiveness. One conclusion of the NAS report was that fire investigation needed to be placed on a more scientific footing. They found that there was a "paucity of research" underlying the interpretation of fire effects and fire patterns (National Research Council, 2009, p. 173). The National Institute of Standards and Technology (NIST) Office of Scientific Area Committee (OSAC) has authored a direct response to the 2009 NAS report. As of this writing, that response has not yet been published.

This chapter serves as an introduction to the current research study. A thorough background of the problem is provided as well as the purpose of the current research study. Chapter 1 establishes the significance of this study to the field of fire investigation, and presents the questions which this research study strived to answer, as well as the conceptual framework. The selected research method and design of the study are explained as well. Definitions of terms are provided to assist the reader, who may be unfamiliar with this subject. Chapter 1 concludes with the scope and limitations of the study at hand.

Background of the Problem

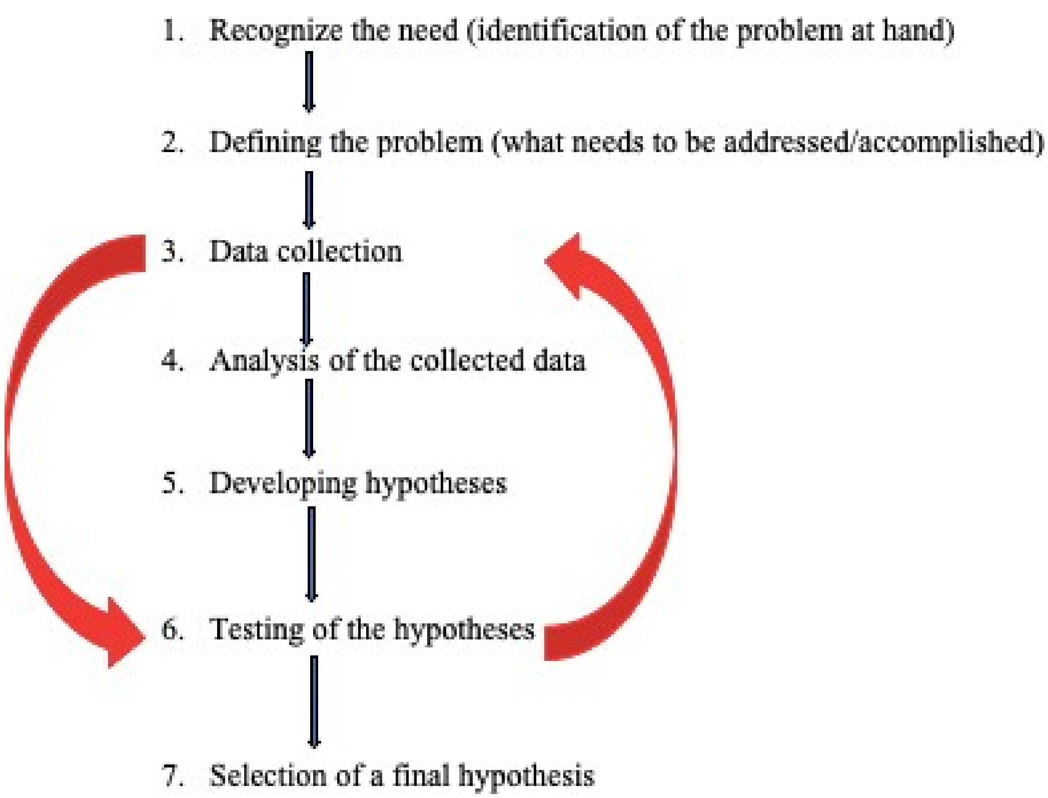
When processing fire scenes, investigators utilize the scientific method. The scientific method is described as "the systematic pursuit of knowledge involving the recognition and definition of the problem; the collection of data through observation and experimentation; analysis of the data; the formulation, evaluation and testing of hypotheses; and where possible, the selection of a final hypothesis" (National Fire Protection Association, 2020, p. 18). This method contains not only linear steps through which to progress, it also is an iterative process, as some steps are generally revisited. In the field of fire investigation, the scientific method is used for both the analysis of fire origin and the fire cause.

Below is a basic outline of the scientific method. The reader can observe that there is a linear progression of steps that the investigator must take, beginning with identifying the problem, and ultimately moving to the selection of a final hypothesis. There is also an occasional reevaluation that occurs involving data collection and analysis, as well as the development and testing of hypotheses. As hypotheses are generated, they are tested in order to ascertain if they can be disproven. When hypotheses are disproven, the investigator must continue to collect and analyze data. The testing of hypotheses involves a mental evaluation. Here the investigator considers the hypothesis in conjunction with what they know to be accurate, via the investigator's knowledge, training, and experience, as well as the fire scene particulars. Physical testing produces additional data for the investigator to cognitively evaluate with respect to hypotheses. Field testing occurs by conducting simple physical testing at the scene. An example of field testing would be testing the flammability of material at the scene. Field tests generally result in a simple “yes” or “no” answer for the investigator. Hypotheses can also be tested at a laboratory to obtain measurable results, such as heat release rates (HRR) of a material or a fuel package configuration.

Figure 1 shows the general order of the steps taken in the scientific method. The red arrows indicate that steps three through six are constantly being revisited and reanalyzed during the process, as the investigators progress towards the selection of a final hypothesis. Figure 2 further refines this process and provides a visual picture of how the scientific method flows during a fire investigation.

Figure 1

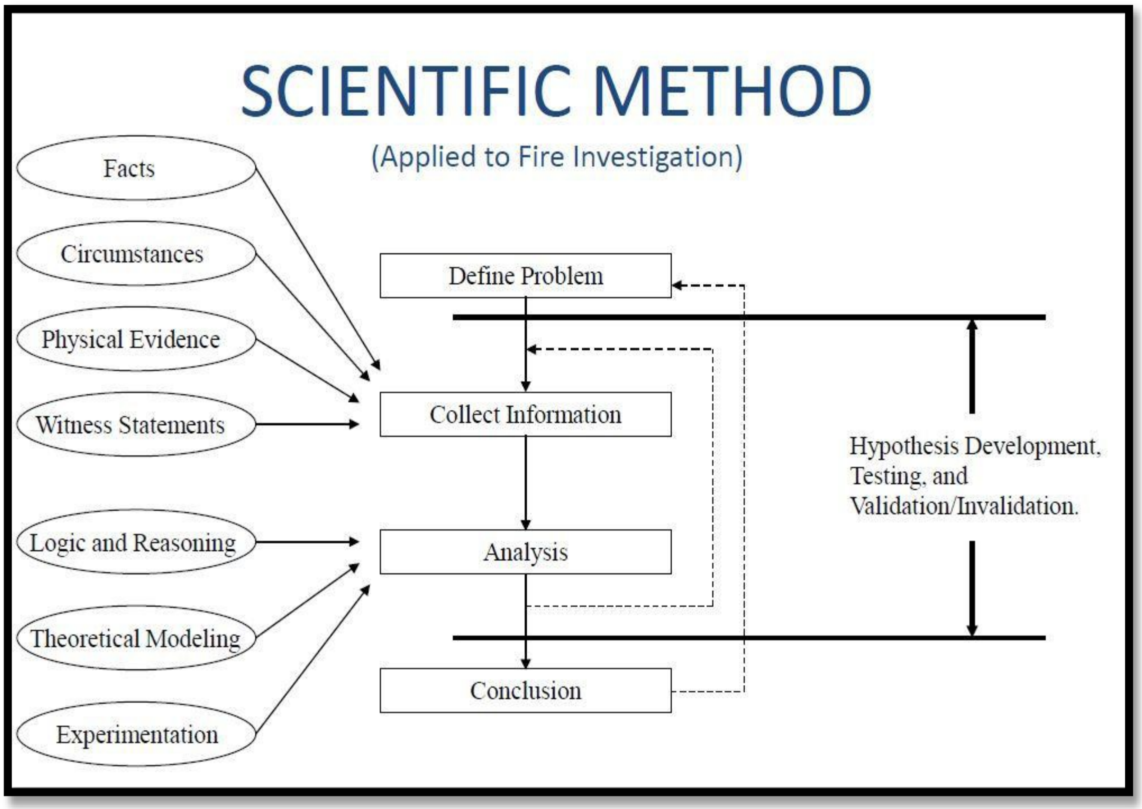
Steps of the Scientific Method



Note. Adapted from National Fire Protection Association, 2020, p. 20.

Figure 2

Scientific Method Applied to Fire Investigation



Note. Source: Cox, 2013.

effects. Observable fire patterns are subsequently examined, documented, and interpreted by the investigator by applying contextual data to gain an understanding of the life of the fire, and more importantly, to trace the life cycle of the fire back to its area of origin.

Lentini (2013) explained that the accurate interpretation of fire patterns can lead an investigator to the proper area of origin, but further emphasizes that accurate interpretation of these patterns can be elusive (p. 396). The correct interpretation of these patterns is dependent upon numerous variables, including the knowledge, training, and experience of the investigator, as well as the investigator's understanding of such topics as fire science, fire chemistry, thermodynamics, and fire dynamics.

Observed fire patterns must be interpreted in their proper context, including a consideration of all available information about the fire scene. Fire investigation is not a process of merely following predefined rigid steps to arrive at an answer. It is a process that involves critical thinking by the investigator and the utilization of problem-solving skills. One fire pattern on its own is rarely sufficient for proper interpretation pertaining to the totality of the incident. Essentially, the interpretation of fire patterns can be compared to a student reading a novel. The individual words taken by themselves may make very little sense to the reader. As these words are strung together into sentences their syntax begins to be meaningful. Once the sentences are strung together to form a paragraph, the reader can more clearly understand the concepts being written about. Finally, when all of the paragraphs are placed together, forming a cohesive and comprehensive framework, the reader can understand the complete storyline.

Because the cause of any fire is contained within the area of origin, one very crucial point must be realized: if the area of origin of a fire is not correctly identified, then ultimately the cause of the fire will also not be correct (National Fire Protection Association, 2020, p. 220). An example of this begins with an investigator failing to understand specific phenomena regarding the life cycle of a fire, such as under ventilated fires. As a result, the area of origin could be potentially misinterpreted as the most heavily damaged portion of the affected structure, because under ventilated fires seek fenestrations to access oxygen (Lentini, 2013, p. 396).

For years, arguments have been promulgated focusing on the subjective nature of the investigator's interpretation of fire patterns. These arguments have continued to persist despite the proper knowledge, training, and experience of the investigator working the fire scene. When considering what the term "subjective" means, these concerns are valid. Subjectivity involves the understanding and interpretation of something via the subject's own mind (Soukhanov & Ellis, 1988, p. 1153). Professor Jonathan Koehler, from Northwestern University's Pritzker School of Law, added that the forensic science fields, which rely heavily on subjective interpretation of data, tend to be highly problematic (Scherb, 2019, p. 1). Subjective interpretation is often incapable of external verification. Subjectivity has the potential to become the "it is because I say it is" approach.

The National Research Council (2009) concluded that many former rules of thumb for fire investigators have been shown to be inaccurate (p. 173). Such fire investigation myths came from a 1977 booklet published by the Law Enforcement Assistance Administration (LEAA), entitled *Arson and Arson Investigation: Survey and Assessment* (Lentini, 2006, p. 435). These misconceptions included crazing of glass, alligatoring, annealing of springs, and spalling (Lentini, 2006, p. 436). As the knowledge of fire and its investigation improved, these false indicators of incendiary fires were challenged and eventually debunked by the publications of the National Fire Protection Association (Lentini, 2006, p. 435).

In recognizing that the field of forensic science needed significant improvements, a study was authorized by Congress which resulted in a paper being produced by the National Academy of Sciences, entitled *Strengthening Forensic Science in the United States: A Path Forward* (National Research Council, 2009, p. xix). The paper focused on recommendations involving policy initiatives that should be adopted to improve various forensic science disciplines, thus making them more effective. One of the fields included within the realm of this paper was fire investigation. The National Research Council concluded that "experiments should be designed to put arson investigations on a more solid scientific footing" (p. 173).

In 2016, the President's Council of Advisors of Science and Technology (PCAST) created a report entitled, *Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods.* They concluded that there were two important gaps in the field of forensic science which must be addressed. The first is that clarity is needed regarding the scientific standards employed involving validity and reliability; second, that specific forensic methods must be evaluated to ascertain if they have been concluded to be scientifically proven to be valid and reliable (President's Council of Advisors of Science and Technology, 2016, p. x).

PCAST was able to establish two types of scientific validity for forensic methodologies. Foundational validity required "that it be shown, based on empirical studies, to be repeatable, reproducible, and accurate, at levels that have been measured and are appropriate to the intended application” (President’s Council of Advisors of Science and Technology, 2016, p. 4). PCAST also defined validity as applied to be the proper application of the method in practice. These concepts are what is considered within the Federal Rule of Evidence (FRE) 702. FRE 702 specifically states that the trial judge shall conduct 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 in issue” (Daubert v. Merrell Dow Pharmaceuticals, 1993, pp. 592-593).

Statement of the Problem

Fire investigators are continuously searching for techniques to utilize to bolster their effectiveness and accuracy when processing fire scenes. The methodology and techniques employed during a fire scene examination must be reliable and valid. Occasionally, the conclusions of an investigator come under scrutiny by opposing experts who raise potential issues of cognitive errors and bias. The current study explores the utilization of empirical data extracted from the Internet of Things (IoT) building management systems, and related devices located at the fire scene to assist in the identification of fire origin.

Purpose of the Study

The purpose of this qualitative study is to explore the utilization of IoT data by fire investigators to assist with determining the area of fire origin. This technique involves the proper collection and analysis of IoT data from building management systems that are connected to the internet. These data are then applied to the fire scene and subsequently utilized to assist investigators in determining the area of origin within a burned structure. This technique will address the aforementioned issues raised by the National Research Council, thus providing a mechanism to place fire investigation on a more solid scientific footing. It will also address concerns regarding the subjective interpretation of fire patterns, by providing a procedure to obtain and utilize hard data points, which can be relied upon in determining the area of origin. The information gleaned from the IoT-connected systems and devices will then empirically support the determination of the area of origin. The data obtained from these IoT-connected systems and devices can also be utilized to formulate a timeline related to fire progression throughout the structure.

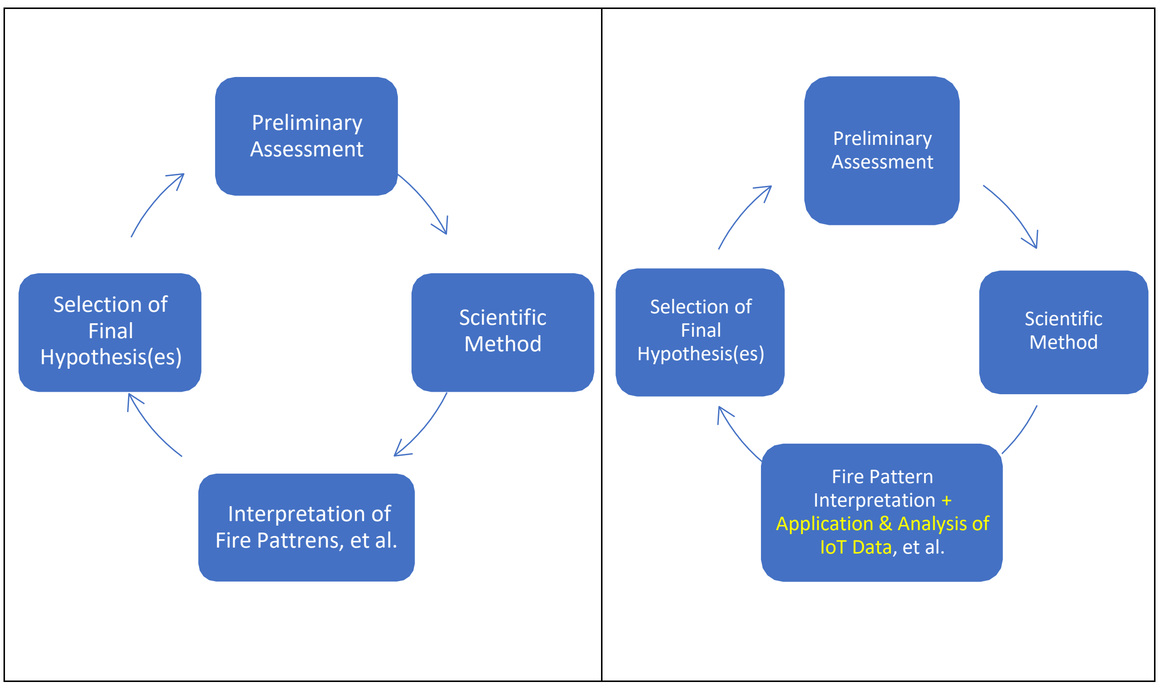
The practical implications of this project are the introduction of an additional tool for fire investigators to employ during an origin and cause investigation. The use of IoT data can provide empirical data upon which to build a hypothesis as to the area of origin. As a result, investigators should become cognizant of the potential presence of IoT building management systems and devices during the data collection phase of fire scene processing.

Significance of the Study

By providing expert insights on the effectiveness of using IoT data as a fire investigation tool, the proposed research improves the current procedures used in fire investigations seeking to find the origin of fires. Current practices use the coordination of information derived from one or more of the following: (a) witness information and/or electronic data; (b) fire patterns; and (c) fire dynamics to determine the area of origin (National Fire Protection Association, 2020, p. 220). Fire investigation is often criticized as overly subjective, especially concerning the interpretation of fire patterns within a scene. The application of IoT data has the potential to increase scientific merit by introducing empirical hard data which significantly improves current practices. Such empirical data can first be utilized to assist the investigator in determining the area of origin. Secondly, it can be used by the investigator to test his or her final hypothesis as to the area of origin. This technique will address concerns reported by the National Research Council which concluded that fire investigation needs to be placed on a more solid scientific footing (National Research Council, 2009, p. 173). Figure 3 shows the general process now, alongside the process proposed by this study.

Figure 3

Current Process of Fire Investigation Versus Proposed Process



Nature of the Study

A qualitative research method was determined to be optimal for this particular study. Qualitative methods tend to be exploratory and oriented toward the understanding of the phenomena and processes investigated. As for the research design methodology of this study, a mixed-method approach integrating both qualitative and quantitative data was determined to be optimal.

The particular approach to mixed methods utilized within this study is what is known as Sequential Explanatory Design. This particular design involves two distinct phases. First quantitative or numeric data are collected and analyzed (Ivankova et al., 2006, p. 5; Schoonenboom & Johnson, 2017, p. 117). Afterward, the qualitative or text data are collected and analyzed (Ivankova et al., 2006, p. 5; Schoonenboom & Johnson, 2017, p. 117). This allows the qualitative data to provide insight into the story of the quantitative data. During this stage, there is a comprehensive exploration of the participants' views.

As a result, it was determined that priority would be given to the qualitative data stage despite it being the second phase of the process. Thus, it is a quan → QUAL theoretical drive (Schoonenboom & Johnson, 2017, p. 112; Terrell, 2012, p. 261). This decision was arrived at due to several factors. First, while the quantitative phase occurred first in the research process, the data collection was limited to one source. The purpose of the quantitative phase was to identify relevant subject matter experts (SMEs) and specific case examples for exploration. The qualitative phase of this research was in-depth and extensive, focusing on the creation of themes and categories. The qualitative data also was derived from numerous different sources.

This research was implemented in a process in which the quantitative and qualitative data were collected sequentially, meaning they were collected one after the other. The qualitative data were collected as a result of the outcomes from the quantitative phase of the process (Ivankova et al., 2006, p. 10). The quantitative phase was conducted to identify and permit the purposeful sampling of SME participants. The result was an integration of the quantitative and qualitative data of the research process.

A preliminary review of the literature occurred before the start of the research to identify pertinent research questions and areas from which data can be extracted for analysis (Almarzooqi et al., 2016, p. 84; Thai et al., 2012, p. 4). The literature review was conducted to provide a solid foundation upon which to build this study. The current research was led by research questions that assisted in focusing efforts of data collection to streamline the process.

Due to their renowned expertise in the field of fire investigation, SMEs from the Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF) were queried. These SMEs included Certified Fire Investigators (CFIs) as well as Fire Protection Engineers (FPEs) and Electrical Engineers (EEs) employed at the ATF Fire Research Laboratory (FRL). SMEs who have utilized IoT data to determine an area of origin were subsequently identified via self-reporting.

Audio-recorded telephonic interviews of each SME were subsequently scheduled and conducted. The interviews involved open-ended questions to elicit each SME’s particular experience related to utilizing IoT data in fire scene examination, their thoughts, and resulting opinions (Creswell & Creswell, 2018, p.187). Documents relevant to SME cases, which involved IoT system utilization during the fire scene examination, were also examined. The manner in which SMEs performed data extraction, analysis, and their subsequent application of the data to the scene was critical to this research.

Following the completion of each interview, the recordings were then outsourced for transcription by a neutral third party.

Once the transcriptions were returned, the review and coding of keywords into categories occurred. Coding refers to the “analytical processes through which data are fractured, conceptualized, and integrated” (Almarzooqi et al., 2016, p. 87). The coding progression proceeded from simple concepts towards the complex although the process was also cyclical. Memoing, the act of keeping reflective notes throughout the research, was utilized to assist with the coding process. Ultimately, the complied data tells the story from the participants’ points of view.

Research Questions

In early iterations of NFPA 921 (National Fire Protection Association, 1997), fire investigation was alluded to as an art. The *New Riverside University Dictionary* defines art as a trade or craft with “a system of principles and methods used in the performance of activities”; it further adds that it is “a specific skill in adept performance, held to require the exercise of intuitive faculties that cannot be learned solely by study” (Soukhanov & Ellis, 1988, p. 127). Essentially, new fire investigators were taught their trade from older, more seasoned fire investigators through a mentoring process. While mentoring is an effective way to pass on knowledge to trainees, it can inadvertently create a mechanism through which bad habits, misinformation, and inaccurate practices are transferred between generations of employees. This is especially an issue if mentoring is not accompanied by formal professional training.

Within later editions of NFPA 921 (National Fire Protection Association, 2020), fire investigation has been elevated to a science. Science is defined as “the observation, identification, description, experimental investigation, and theoretical explanation of natural phenomena. A methodological activity, discipline, or study" (Soukhanov & Ellis, 1988, p. 1045). Methodology, discipline, and study are the key words here. To increase validity, reliability, and repeatability there must be a consistent process for accomplishing a task. The methodology ensures that each fire scene is approached similarly. No fire scene is precisely the same, as each presents its own unique challenges and issues. But, what can stay the same across the multitude of fire scenes is application of the proper and consistent methodology to ultimately reach a conclusion. NFPA 921 (National Fire Protection Association, 2020) refers to this as a systematic approach and defines it as a method that "provides an organizational and analytic process that is desirable and necessary in a successful fire investigation" (p. 20).

Science tends to be a self-correcting process. It adapts and changes as new, more reliable methodologies progress to the forefront. Even so, it is important to be cognizant of the fact that scientific activity is ultimately conducted and controlled by humans. As such, it can be inherently fallible, because humans are flawed. This is not to mean that humans deliberately miscalculate or misinterpret data. Errors in scientific interpretation and application can be unconscious and accidental. As a result, the people involved must strive to consciously improve the enterprise of science whenever and wherever possible. The primary focus of this study is to improve the accuracy of origin determination in the field of fire investigation employing the use of technology.

The research questions for the proposed study are as follows:

RQ1: How can IoT data extracted from building management systems and devices be successfully utilized to assist in determining the area of origin during a fire scene examination? This study is focusing upon the overall result in the utilization of the IoT data during fire scene processing and the resultant origin determination.

RQ2: How do these IoT building management systems operate? For this study to be able to understand what information would be available to the fire investigators for analysis, it is critical to understand the basic operations of these systems.

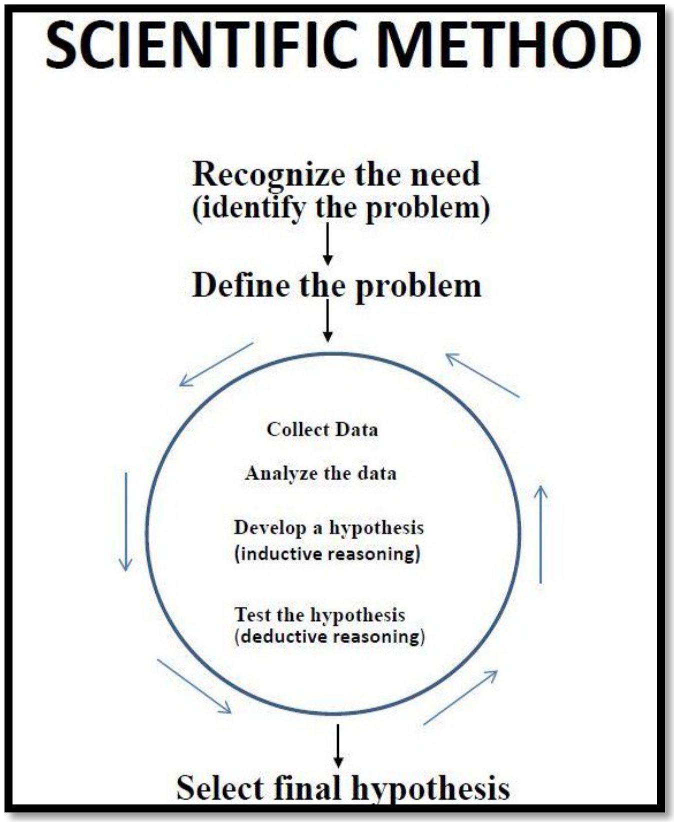
RQ3: How is the extracted IoT data interpreted and subsequently applied to the scene? Ultimately, each IoT system provides slightly different data related to a fire event. For example, smoke alarms are triggered by smoke movement while sprinkler systems are activated by heat. This question will lead to a consideration of how the extracted data are correctly applied to origin determination.

Conceptual Framework

Fire investigators use the scientific method when conducting a fire scene examination. The scientific method is defined as "the systematic pursuit of knowledge involving the recognition and definition of a problem; the collection of data through observation and experimentation; analysis of the data; the formulation, evaluation and testing of hypothesis; and, where possible, the selection of a final hypothesis" (National Fire Protection Association, 2020, p. 19). It is an iterative process where many of the steps are revisited by investigators when evaluating the area of origin as well as the cause of a fire. Figure 4 shows the process of the scientific method in a slightly different way than Figure 1. Here can be seen the continuous flow of data collection and analysis in conjunction with the development and testing of hypotheses.

Figure 4

Scientific Method with Continuous Flow

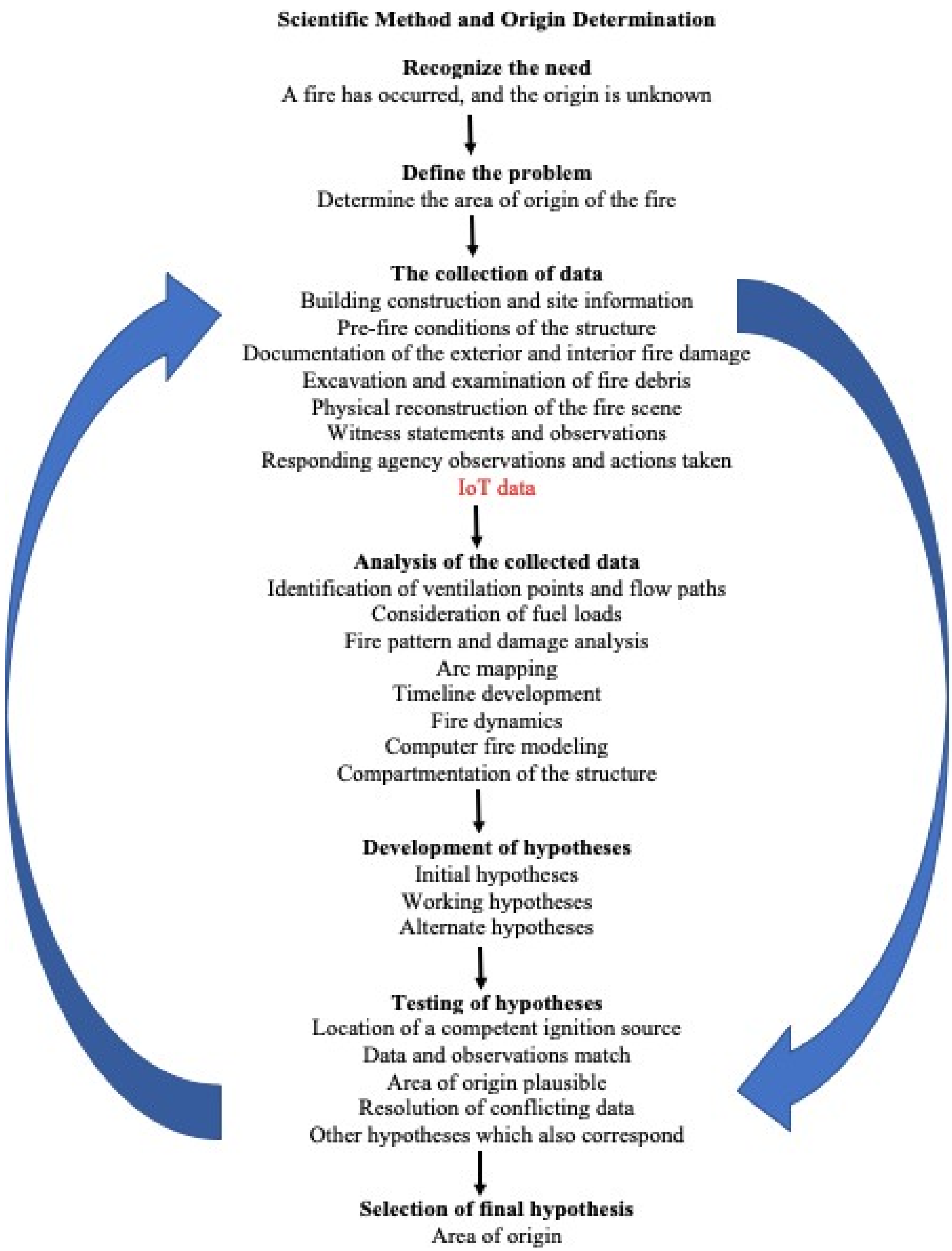


Note. Source: Cox, 2013, pp. 1-16.

Figure 5 presents a visual of the application of the scientific method to a fire scene examination, more specifically to the process of analysis involving the determination of an area of origin. The items listed below each step are not exhaustive, but merely there to provide typical examples of facts and circumstances considered during the various phases of the process.

Figure 5

Scientific Method in a Fire Scene Examination



Note. Adapted from National Fire Protection Association, 2020, p. 221.

Currently, the National Fire Protection Association (2020) states that "determination of the origin of the fire involves coordination of information derived from one or more of the following: (1) witness information and/ or electronic data; (2) fire patterns; and (3) fire dynamics" (p. 220). As a result, the investigator essentially reconstructs the fire sequence backward toward the area of origin by the interpretation of the aforementioned data points. Fire patterns change continuously throughout a fire event and are influenced by ventilation and available fuels (Icove & Haynes, 2018, pp. 249-250). Origin determination within a fire scene is a complex process. This complexity increases with additional variables such as structure size, fuel load, manner the fire was extinguished, and length of burn.

Due to the potential issues previously identified concerning the proper interpretation of the observed damage at a fire scene, effort must be taken to either reduce error altogether or at the very least attempt to limit the potential for error. One of the principal ways to achieve this is by increasing reliance on empirical data that have been collected. IoT information falls under the purview of empirical data.

Fire investigators must be familiar with the various types of IoT systems that may be operational within the structure. They also must opine about the potential data that may exist on each type of system and device present at the scene. The pertinent portions of the systems and devices must be recovered, and the data properly extracted. Following the extraction of the data, they must be properly applied to the context of the fire scene. The result is the recovery and application of hard empirical facts which can then be interpreted. This interpretation can involve identifying locations and times of system activation, or location and time of circuit impingement by the fire which caused a cessation of operation. These resulting interpretations must then be applied within the context of the investigation, and combined with other known facts to ascertain and ultimately support an area of origin.

This information may also be utilized to trace fire progression from the area of origin throughout the structure to other affected areas. Therefore, instead of fire investigators tracing observed fire damage back towards the area of origin through fire pattern interpretation (i.e., looking for the earliest area of fire damage), investigators are identifying the area of origin and then tracing the sequence of fire spread outward from that location. A timeline of events related to the fire event can then be developed and applied. This research looks to provide a framework for the use of IoT information in fire investigations. It further intends to explain how this information can then be synthesized into the data points, resulting in a factually substantiated conclusion as to the area(s) of origin.

Definitions

Alligatoring is a formerly utilized indicator of an intentionally set fire that has since been declared inaccurate by the scientific community. Alligatoring occurs as the result of the evaporation of water in the surface material as a result of heat application. It is characterized by large rolling blisters of char which are often shiny in appearance (DeHaan & Icove, 2012, pp. 281-298; Redsicker & O'Connor, 1997, p. 100). The International Fire Service Training Association stated in their 1982 manual that large, deep, and shiny blisters should be considered by the investigator as indicative of the presence of an accelerant in the vicinity (Lentini, 2013, p. 474). The most recent edition of NFPA 921 (National Fire Protection Association, 2020) clearly states that there is no justification to indicate that large curved blisters of char indicate an accelerant was used (pp. 54-55). Figure 6 provides a visual depiction of this particular type of charring.

Figure 6

Alligatoring

Annealing of springs refers to an indicator that has been utilized by fire investigators during their origin and cause investigation. The primary items where annealed springs were observed included: mattresses, couches, and chairs. This indicator was often used to suggest that a fire had initiated in a piece of furniture as a result of a long burning heat source (e.g., a smoldering cigarette). It has also been used to opine that a fire originated on the outside of a piece of furniture as a result of an ignitable liquid (Smith, 1995, p. 1). Science has since proven that the collapse of furniture springs has to do with several factors: the prefire condition of the furniture as well as the temperature, length of heat exposure, and loading (National Fire Protection Association, 2020, p. 58). Figure 7 depicts an example of this.

Figure 7

Annealing of Springs

Arc mapping has also been referred to as an arc survey. This methodical process includes the systematic evaluation of electrical circuitry to include their configuration, spatial relationship, and the identification of electrical arc sites involving the conductors (Lentini, 2013, p. 107; National Fire Protection Association, 2020, p. 13). It was frequently used to analyze the area of fire origin as well as fire progression within the structure.

Area of origin refers to the general location where a fire originated. The area of origin can be identified within a three-dimensional area; it does not have to be located on a two-dimensional plane. It is the place where a competent heat source interacts with a fuel source that results in a fire or explosion (National Fire Protection Association, 2020, p. 220).

Certified Fire Investigator (CFI) refers to a fire investigator who becomes certified through their training, education, and experience. There are many levels of CFIs throughout the world, for example, an ATF CFI. A CFI for ATF is the field division's expert on fire-related incidents. During training, each ATF CFI is required to process a minimum total of 100 fire scenes. They also must author a minimum of 80 origin and cause reports which then are submitted to a technical review process by a senior CFI. The trainees are also required to take five graduate-level college courses in fire and explosion investigation. Additionally, they are required to attend several multiweek in-person training courses. They are certified through not only ATF, but also are required to take and pass the International Association of Arson Investigators written exam. Thus, the program involves dual certification.

Charring is the fire effect that will likely be found in most fires. It is the result of the chemical decomposition—also known as pyrolysis—of wood as a result of heat exposure. During this process, gases, water vapor, and pyrolysis products (such as smoke) are produced. The solid material remaining because of this process mainly consists of carbon (DeHaan & Icove, 2012, p. 745; Lentini, 2013, p. 57; National Fire Protection Association, 2020, p. 53; Redsicker & O'Connor, 1997, p. 99).

Coding refers to a process utilized in research that aids in the development of categories or themes to be analyzed (Creswell & Creswell, 2018, pp. 194-195). These codes can include those which are expected, unanticipated, or of conceptual interest.

Consumption is pervasive char which is observable throughout the material or the actual destruction of the material as a result of fire (DeHaan, 2007, p. 220). This is also often referred to as mass loss by investigators. Figure 8 depicts this phenomenon; the yellow arrow indicates the consumption of both wood and polyurethane as it decreases in severity towards the reader's right.

Figure 8

Consumption

Crazing of glass is a complicated pattern of short cracks found in glass. The presence of this damage had previously been utilized by investigators to indicate that the glass was exposed to rapid heating. The cracks can be straight or crescent-shaped. They may or may not extend through the thickness of the glass (Lentini, 2013, pp. 480-481; National Fire Protection Association, 2020, p. 67). It has since been proven scientifically that glass is crazed as a result of rapid cooling (e.g., the application of a hose stream onto the hot surface).

Electrical engineer (EE) refers to an individual whose primary focus of study pertains to equipment, devices, and systems that utilize electricity or electromagnetism.

An ATF EE is employed at the Fire Research Laboratory (FRL) in Ammendale, Maryland.

Empirical data refers to information that is capable of proof or verification as a result of experiment or observation.

Fire cause refers to the set of circumstances, conditions, or agencies which resulted in a fuel, ignition source, and oxidizer being brought together, resulting in the fire incident (National Fire Protection Association, 2020, p. 16).

Fire chemistry is the study of the chemical processes that occur during the lifetime of a fire. This includes such topics as changes in the state of the materials, decomposition of the materials, and combustion (National Fire Protection Association, 2020, p. 16; Sesniak & Wendt, 2018, p. 41).

Fire dynamics refers to how fire interacts with its surroundings. It involves the study of how chemistry, fire science, and engineering principles concerning fluid mechanics and heat transfer interact together to influence the behavior of fire (Brogan & Wendt, 2018, p. 34; National Fire Protection Association, 2020, p. 16).

Fire effect is any observable or measurable change either in or on a material as a result of fire (National Fire Protection Association, 2020 p. 16).

Fire pattern is any visible or measurable physical change or identifiable shape that is formed by a fire effect or group thereof (Lentini, 2013, p. 396; National Fire Protection Association, 2020, p. 16).

Fire Protection Engineer (FPE) is an individual whose main focus of study pertains to applying science and engineering principles to protect people and property and related environments from the effects of fire and smoke. Their areas of focus can include topics such as fire protection systems, building design, and fire dynamics. An ATF FPE is employed at the Fire Research Laboratory (FRL) in Ammendale, Maryland.

Fire science is the body of knowledge involving the study of fire and its related subjects (examples include such topics as combustion, flame, products of combustion, heat release, thermodynamics, kinetics, and fluid mechanics) and their interaction with people, structures, and the environment (National Fire Protection Association, 2020, p. 16; Sesniak & Wendt, 2018, p. 40).

Flashover is considered to be a transition phase during the life span of a fire within a compartment (room, building, or space), in which all surfaces reach their ignition temperature nearly simultaneously, causing rapid fire spread throughout the space and resulting in full room involvement (DeHaan & Icove, 2012, p. 56; Lentini, 2013, p. 77; National Fire Protection Association, 2020, p. 16). A rule of thumb measurement for flashover occurring is that the radiant heat flux measures 20 kW/m2 at floor level, and approximately 600° C (Lentini, 2013, p. 29).

Fuel item is any article that is capable of burning (National Fire Protection Association, 2020, p. 30).

Fuel load is the total quantity of all combustible material within a building, room, or space (National Fire Protection Association, 2020, p. 16).

Fuel package is a collection of fuel items in close proximity with one another, which can result in flame spread throughout the array of items (National Fire Protection Association, 2020, p. 30).

Heat Release Rate (HRR) is the rate at which heat energy is released through burning a fuel item, fuel package, or fuel load (National Fire Protection Association, 2020, p. 17). HRR is measured in watts (W), kilowatts (kW), or megawatts (MW) and can be considered by a layperson as the size of a fire (DeHaan & Icove, 2012, p. 43; Lentini, 2013, p. 24). HRR is considered to be the most important property of fire as it allows a prediction to be made concerning the fire's behavior (DeHaan & Icove, 2012, p. 44; Lentini, 2013, p. 24). Table 1 provides examples of approximate heat release rates for some commonly encountered fires.

Table 1

Heat Release Rates for Commonly Encountered Fires

Object(s) on Fire	Estimated Heat Release Rate
Smoldering cigarette	5 W
Flame from a wooden kitchen match or cigarette lighter	50 W
Candle flame	50-80 W
Office wastebasket containing paper	50-150 kW
Small padded chair	150-250 kW
Armchair	350-750 kW (can be as high as 1.2 MW
Recliner	500-1000 kW (1 MW)
Sofa	1-3 MW
Pool of gasoline (apx 1 quart on concrete pad)	1 MW
Dry Christmas tree	1-2 MW (can be as high as 5 MW)
Living room or bedroom	3-10 MW (depends on ventilation sources)

Note. Adapted from DeHaan & Icove, 2012, p. 44.

Hypothesis is a scenario or supposition formulated by an investigator through their knowledge, education, and experience which can explain a situation or event by considering the fact pattern and circumstances surrounding the occurrence, and can ultimately be proven or disproven (DeHaan & Icove, 2012, p. 14; Lentini, 2013, p. 150).

Internet of Things (IoT) refers to a system of interrelated computing devices; these can be both mechanical and digital machines, embedded with sensors, software, and other technologies to connect and exchange data with other devices and systems over the internet ("What is the internet of things?," 2021).

Memoing is a process of notetaking by the researcher throughout their research, which reflects upon the process as a whole and can also assist with the formation and development of codes and themes within the study (Creswell & Creswell, 2018, p. 184; Tie et al., 2019, p. 6).

Penetration refers to char that is observable beneath the surface of a material (DeHaan, 2007, p. 220).

Radiant heat flux: The measurement of the rate of heat transfer to a surface, area, or object. It is typically measured in kilowatts per meter squared (kW/m2; DeHaan & Icove, 2012, p. 45; Lentini, 2013, pp. 25-26; National Fire Protection Association, 2020, p. 18). A general rule of thumb for the layperson is that the radiant heat flux produced by the sun is approximately 1 kW/m2. Radiant heat travels in a line-of-sight fashion. It can either be absorbed or blocked by objects. Table 2 shows some common radiant heat flux measurements for familiarization and comparison purposes.

Table 2

Common Radiant Heat Flux Measurements

Approximate Radiant Heat Flux	Notes
170 kW/m2	Maximum heat flux which has currently been measured in a postflashover compartment fire
29 kW/m2	Spontaneous ignition of wood after a long duration heat exposure
20 kW/m2	Heat flux at floor level in a compartment at the beginning of flashover
16 kW/m2	Human skin exhibits blistering following a 5 second exposure resulting in a 2^{nd} degree burn
12.5 kW/m2	Ignition of wood from direct flame exposure
10.4 kW/m2	Human skin exhibits blisters following a 9 second exposure resulting in a 2^{nd} degree burn
6.4 kW/m2	Human skin exhibits blistering following an 18 second exposure resulting in a 2^{nd} degree burn
4.5 kW/m2	Human skin exhibits blistering following a 30 second exposure resulting in a 2^{nd} degree burn
1.4 kW/m2	Thermal radiation from sunlight

Note. Adapted from Lentini, 2013, p. 29.

Reliability is the degree to which a measurement, calculation, or specification results in accuracy, yielding the same results during repeated trials (Soukhanov & Ellis, 1988, p. 992).

Scientific method is a systematic approach taken in the pursuit of knowledge involving several steps: recognition and definition of the problem; collection of data and analysis of that data; formulation, evaluation, and testing of hypotheses; and, if possible, the selection of a final hypothesis (DeHaan & Icove, 2012, p. 11; National Fire Protection Association, 2020, p. 19). This process is not merely linear in progression, it is iterative as well.

Spalling is the loss of surface material of concrete, masonry, rock, or brick which results in cracking, breaking, chipping, or cratering observed on the surface of the material (DeHaan & Icove, 2012, p. 283; National Fire Protection Association, 2020, p. 64; Redsicker & O'Connor, 1997, p. 103). Originally this damage was considered to be an indicator of the presence of ignitable liquids (Lentini, 2013, p. 490). It has since been proven that this damage is often caused by the rapid cooling of the heated material. Spalling occurs as a result of different rates of expansion and contraction of the material. "Spalling may be more readily induced in poorly formulated or finished materials" (Lentini, 2013, p. 493; National Fire Protection Association, 2020, p. 64). Figure 9 depicts an example of spalling, outlined in red, on a concrete floor.

Figure 9

Spalling on Concrete Floor

Surface deposits are fire-related deposits, such as soot deposition or smoke staining, upon the surface of a material which subsequently causes no irreversible effects to it (DeHaan, 2007, p. 220).

Surface thermal effects refers to the irreversible melting, scorching, or discoloration of the surface of a material as a result of heat exposure (DeHaan, 2007, p. 220).

Theoretical drive refers to which approach, quantitative or qualitative (or both), a researcher gives more weight or attention to throughout the data collection and analysis part of the study (Ivankova et al., 2006, p. 9; Schoonenboom & Johnson, 2017, p. 112).

Thermodynamics is the study of how heat produces work. This section of physics is concerned with the relationship between heat and other forms of energy (National Fire Protection Association, 2020, p. 19; Sesniak & Wendt, 2018, p. 41).

Validity is the extent to which a concept, conclusion, or measurement is well-founded and likely corresponds accurately to the real world (Soukhanov & Ellis, 1988, p. 1274). Validity of a result often leads to an increase in an investigator's confidence in that result.

Assumptions

This research project will operate under several assumptions. An assumption can be defined as a temporary statement for a specific purpose that is presumed to be true (Wargo, 2015, p. 1). It will be assumed that all participants will be truthful and candid throughout the project. It will also be assumed that the selection criteria utilized to determine the participating SMEs is appropriate and results in an adequate sample with the requisite knowledge and experience. Furthermore, it is assumed that all participants in the study have an intrinsic motivation to be part of the research.

The information developed by this research study will have a profound impact on how future fire scenes are processed. The researcher has been involved with the fire service for 30 years, initially serving as a structural and wildland firefighter. Currently, the researcher is employed by ATF as a CFI and has served in that role for the past 7 years. As a member of the ATF's National Response Team (NRT), the researcher has had the opportunity to investigate large, complex fire scenes nationwide. The NRT consists of a hand-selected cadre of CFIs and Certified Explosives Specialists (CES) who respond to major fire and explosives incidents nationwide within 24 hours.

Scope and Limitations

There have been potential limitations identified involving this research. Research limitations can be understood as areas of the study over which the researcher has no control (Wargo, 2015, p. 1). First and foremost, the population of this study was limited to SMEs from the ATF. This study gathered data from interviews and reports from a sample of 20 SMEs. It could be argued that a larger sample size would be preferable, as the sample of 20 represents only a limited portion of the entire population of fire investigators worldwide. As a result, it can potentially raise concerns of internal validity within the study. Being that the population was limited to ATF SMEs, the study could potentially be incestuous because all of the ATF SMEs have received the same training and follow the same protocols. Whereas fire investigators from outside this subgroup may have different training, experience, and education, the SMEs selected are considered by many to be some of the best in the country (Lentini, 2020, p. 5). As a result, the techniques utilized by this particular sampling of SMEs are on the cutting edge of fire investigation methodology, and will no doubt offset the smaller sample size.

The initial self-reporting request of SMEs was conducted via email. There is a possibility that individuals either did not receive the email, or that they chose not to respond to the request. Those respondents who had the requisite experience to take part in this research have been identified. This research has further been limited by the use of telephonic interviews instead of an in-person interview process. This is due to the combination of several facts, such as COVID-19 restrictions limiting the ability to travel, and as well as the financial aspect of multiple out-of-state trips. The six SMEs who were interviewed during this study resided in separate geographic locations and different time zones. As a result, the scheduling of interviews had to be clear and coordinated, taking into account the different time zones.

The fact that the researcher is also an ATF CFI introduced personal knowledge, experience, and expertise into the fold. Due to this fact, the utilization of data validation processes was intended to reduce or eliminate any potential bias brought into the research.

Summary

The focal points of Chapter 1 include the background of the problem, which is the discussion by experts in the field of fire investigation on the subjectivity of fire pattern interpretation. Mirroring this concern, Professor Jonathan Koehler from Northwestern University's Pritzker School of Law added that the forensic science fields, which rely heavily on subjective interpretation of data, tend to be problematic (Scherb, 2019, p. 1). Further complicating this issue is a study conducted by the National Research Council, in

2009, which concluded that many prior rules of thumb for fire investigators have also been shown to be inaccurate (National Research Council, 2009, p. 173). Additionally, the Council specified that "experiments should be designed to put arson investigations on a more solid scientific footing" (National Research Council, 2009, p.173).

Due to these aforementioned issues, a mixed-methods study was designed to consider additional steps that could be taken by fire investigators to reduce weaknesses related to subjectivity, as well as addressing the concerns voiced by the National Research Council. The study involved audio-recorded telephonic interviews of participants to glean not only the types of IoT data obtained, but also the interpretation and synthesis of that information into an area of origin determination, the intent of which was to provide a methodology for the use of IoT-based empirical data points to be utilized by fire investigators in identifying areas of origin.

CHAPTER II

REVIEW OF THE LITERATURE

The mixed-method approach permits the researcher to conduct a preliminary study of the literature on the topic of interest. In the current study, a literature review was first conducted to identify trends as well as to obtain background information regarding several associated topics. The literature rendered within this chapter provided a glimpse into the background of the issue upon which this research focuses, which is the use of Internet of Things (IoT) connected building systems and their use in fire investigation. The literature review was critical, not only to develop the basic platform for the study but also for the reader's holistic understanding of the issue at hand. A basic understanding of fire science and fire behavior, as well as scene processing methodology and related issues, is necessary in order to build the foundation of the problem being addressed by this study. A review of the literature before beginning the study also assisted the researcher in developing a solid perspective upon which to build the parameters of the study and interpret the results.

The literature was compiled as a result of numerous searches which included textbooks, technical manuals, international guidelines, and standards. Peer reviewed journals were obtained through searches of the Eastern Kentucky University website, the International Association of Arson Investigators website, the National Fire Protection Association, SpringerOpen, EBSCOhost, ProQuest, and Google. The exploration and compilation of literature culminated with an additional search conducted by the librarian of the ATF FRL.

Searches included keywords that included fire pattern analysis, cognition, bias sources of error, fire scene processing methodology, basic fire behavior, fire dynamics, forensic science, digital forensics, IoT, IoT and fire, and IoT and building systems. A review of the literature was conducted to identify trends as well as provide a foundation regarding several associated topics which are critical to the reader's holistic understanding of the research. The literature review also assisted in the formation of the research questions enumerated in Chapter I of this study. An attempt was made to ensure that the flow of information was sensible and coherent. The literature review began with an examination of basic fire science and fire behavior. It then continued by considering recognized issues regarding cognition, bias, and error. Because cognition, potential bias, subjectivity, and the resultant potential for error are current hot button issues, having a base of knowledge regarding these matters is essential. Once the basic building blocks for understanding bias, cognition, and error were achieved, the applicability of these factors to fire scene processing was then considered. The literature review progressed through fire pattern analysis and the determination of an area of fire origin. The IoT and specific

IoT building systems which could be encountered in a fire scene were next reviewed. Finally, case specific examples of the use of IoT data in determining the area of origin were examined.

Various ATF origin and cause reports, and engineering reports about multiple case specific examples germane to this current study, were also compiled and reviewed. Table 3 constitutes a display of the theoretical concepts and areas which were reviewed within the totality of the current research. It should be noted that occasionally the material reviewed covered multiple topics about this study.

Table 3

Theoretical Concepts and Areas Reviewed within the Totality of the Current Research

Reviewed Topics	Textbooks and books	Peer reviewed journal articles	Official reports	Lectures and training material	Total
Research method and design	3	28		16	47
Government studies – forensic science			2		2
Basic fire science and behavior	16	2		15	33
Cognition, bias, and error	4	11			15
Bias and error in fire scene processing	1	7			8
Fire pattern analysis	12	14		4	30
IoT		17		2	9
IoT building systems	4	13		16	33
Case-specific examples			20		20

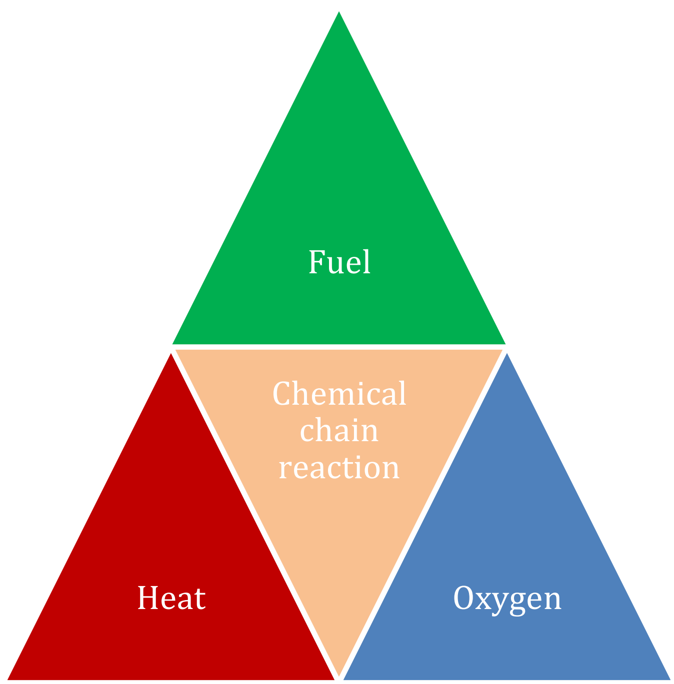
Examination of Literature by Topic

Basic Fire Science and Behavior

Fire is scientifically defined as a process of rapid oxidation producing heat and light of varying intensities (DeHaan, 2007, p. 23; DeHaan & Icove, 2012, p. 2; Icove et al., 2013, p. 2; International Fire Service Training Association, 2013, p. 2008; National Fire Protection Association, 2020, p. 16). Fire is a type of process known as combustion. Combustion is a self-sustained chemical reaction that yields energy and other products, which then cause further reactions (Icove et al., 2013, p. 56; International Fire Service Training Association, 2013, p. 28). The fire tetrahedron in Figure 10 is a wonderful illustration of the four components which must interact for a fire to occur.

Figure 10

The Fire Tetrahedron



Note. Adapted from International Fire Service Training Association, 2013.

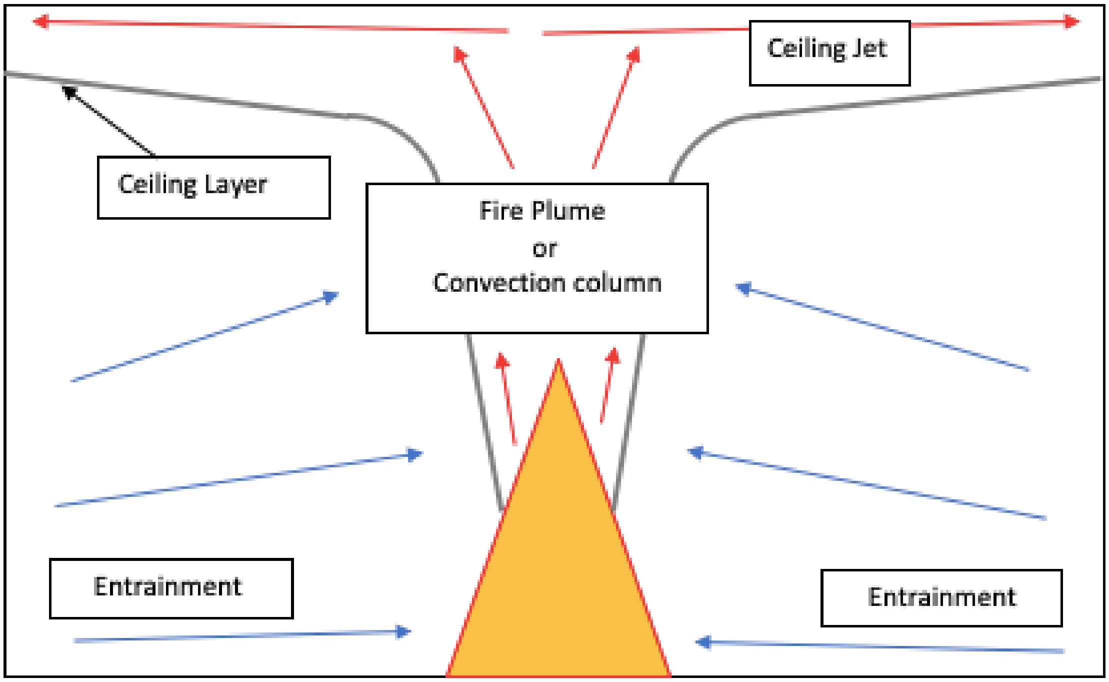
Fuel is any substance that can undergo combustion (National Fire Protection Association, 2020, p. 23). When considering the “fuel” portion of the tetrahedron, it is important to be aware that there are three main states of matter: solids, liquids, and gases. Solids have a definite shape and a definite volume. Liquids have a definite volume, but not a definite shape. Gases have neither a definite shape nor a definite volume. For solids and liquids to become potential fuels for flaming combustion, they must be transformed into a gaseous state. This transformation process is referred to as pyrolysis.

As a fire burns it requires a continuous supply of oxygen to grow. Sources of oxygen can be the remaining air within the compartment, and air from ventilation sources such as broken or open windows and broken or open doors. Air is subsequently drawn into the base of the fire. This process is more specifically referred to as entrainment (DeHaan, 2007; p. 25; Icove et al., 2013, p. 98; National Fire Protection Association, 2008, 2020).

Heat and combustion products, such as gases and smoke, are buoyant and flow upwards in what is referred to as a fire plume, also known as a convective column. If the convection column becomes confined by a surface, for example a ceiling, it will then spread outward in all directions until it meets additional obstacles (such as walls). This phenomenon is known as a ceiling jet (DeHaan, 2007, p. 56; National Fire Protection Association, 2008, pp. 2-53). The collection of unconsumed combustion products, which is subsequently formed in the ceiling layer, becomes increasingly lower as more combustion products are added. Figure 11 depicts a labeled diagram of these processes.

Figure 11

Fire Plume Interactions with Ceiling



Note. Adapted from DeHaan, 2007; Icove et al., 2013; National Fire Protection Association, 2008.

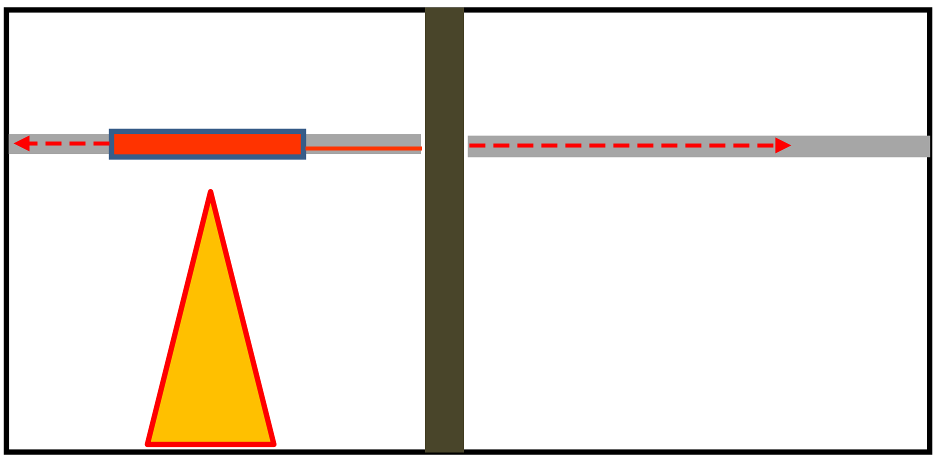
Another critical element that must be understood about fires is the different mechanisms of heat transfer. The three basic mechanisms of heat transfer are known as conduction, convection, and radiation. Regardless of the mechanism of heat transfer, heat always transfers from objects with warmer temperatures to objects with colder temperatures.

Conduction involves the transfer of heat through and in between solid object as a result of molecular action (DeHaan, 2007, p. 36; Icove et al., 2013, p. 58; International Fire Service Training Association, 2013, p. 220; National Fire Protection Association, 2008, pp. 2-6; Redsicker & O'Connor, 1997, p. 58). Conduction is a localized mechanism of heat transfer because it is limited to molecular movement within a solid object

(National Fire Protection Association, 2020, pp. 26-27). An example would be a metal pipe exposed to flame on one side of a wall, and a person touching the pipe and potentially being burned on the opposite side of the wall. Figure 12 shows the aforementioned example of conductive heat transfer.

Figure 12

Conductive Heat Transfer through Metal Pipe



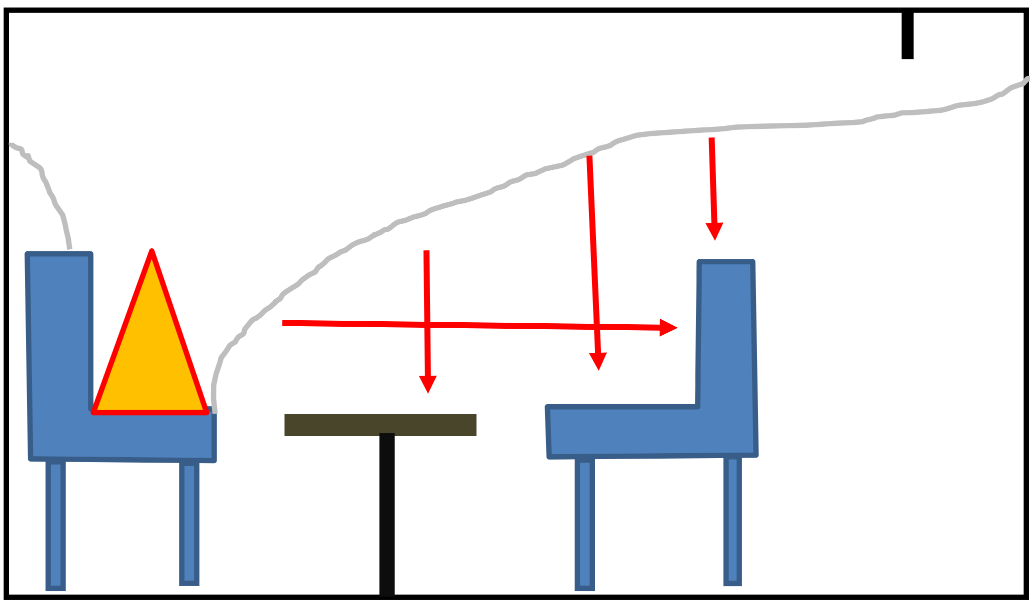
Convective heat transfer can be understood as the distribution of heat within a circulating medium (DeHaan & Icove, 2012, p. 46; Karlsson & Quintiere, 2000, p. 143; National Fire Protection Association, 2008, 2020; Quintiere, 1998, p. 50). This particular type of heat transfer will not occur within solids, only within liquids and gases. Convective heat transfer is the predominant form of heat transfer during the early stages of fire development, as the heating of surfaces occurs through the circulation of heat and products of combustion. Convection can occur in any direction, but most of the heat is transferred upward and outward due to the buoyancy within the convective column. An everyday example of this is a convection oven being used for cooking.

Finally, radiation must be considered. This method of heat transfer occurs via straight line electromagnetic waves and, as such, it is transferred only via line of sight

(Drysdale, 2011, p. 59; Icove et al., 2013, p. 61; International Fire Service Training Association, 2013, p. 222; Karlsson & Quintiere, 2000, p. 143; National Fire Protection Association, 2008, pp. 2-9; Redsicker & O'Connor, 1997, p. 59). During the later stages of fire development, radiant heat becomes the primary mechanism of heat transfer. Once all items within a compartment are heated to their ignition temperature via radiant heat transfer, they will burst into flame. The result is known as flashover. Figure 13 depicts radiant heat transfer (denoted by red arrows) within a compartment fire.

Figure 13

Radiant Heat Transfer within Compartment Fire



Note. Adapted from National Fire Protection Association, 2020.

Occasionally investigators will observe what is known as "heat shadowing." This phenomenon occurs as a result of an object (i.e. an iron) blocking another object (i.e. a wall) from the radiant heat transfer. The result is a protected area, where burning or charring did not occur, that appears to be in a shape similar to the protecting object (DeHaan, 2007, p. 41). These protected areas can often assist investigators with scene reconstruction. They can indicate where objects had been situated at the time of the fire, which had then subsequently been moved.

Several distinct stages typically occur during the lifecycle of a fire. Fire growth is determined by a multitude of conditions. For purposes of the current research, the focus will specifically be on the stages of fire development.

The incipient stage of fire begins immediately following ignition. During this stage, the fire is relatively small and is confined to the first material which has ignited (DeHaan, 2007, p. 46; Icove et al., 2013, p. 71; International Fire Service Training Association, 2013, p. 241). The room exhibits low heat and a small amount of smoke. This phase is also referred to as fuel-controlled burning (National Fire Protection Association, 2020, p. 46), meaning that the fire can only grow as large as the available fuel will permit.

Next is the growth or free-burning stage. As more fuel becomes involved, the fire grows in its intensity. Convection is the dominating form of heat transfer throughout the compartment, but radiant heat transfer is also present (DeHaan, 2007, p. 46; Icove et al., 2013, p. 74; International Fire Service Training Association, 2013, p. 243; National Fire Protection Association, 2020, p. 46;). As additional fuel ignites, it adds to the overall heat level within the room. A buildup of smoke within the room is present, as well as flame spread. Radiant heat transfer evolves to become the primary mechanism of heat transfer within the compartment (National Fire Protection Association, 2020, p. 46).

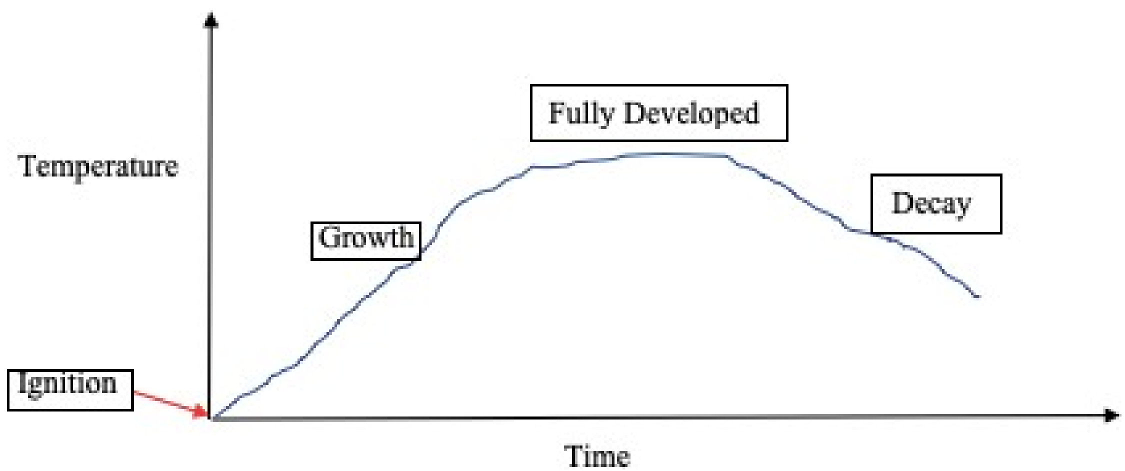
A rapid transition then occurs, which is known as flashover. A general observable rule of thumb is that the fire in a room appears to turn into a room on fire. It is often recognized that radiant heat flux during this transition measures 20 kW/m2 at floor level

(Lentini, 2013, p. 29). Once there is a fully developed fire, a copious amount of smoke can potentially be produced. Furthermore, there is a large amount of heat output from the fire. This is also known as the steady-state or the fully-developed stage (Icove et al., 2013, p. 79; International Fire Service Training Association, 2013, p. 246). The mixture of hot gases and smoke, which have built up across the ceiling, slowly begin to descend downward. Depending on the availability of oxygen, the fire can either remain as a fuel-controlled fire or it can become a ventilation-controlled fire (Icove et al., 2013, p. 79). Generally, when considering a compartment fire, this phase is often ventilation-controlled. If there are limited sources of ventilation (such as windows or doorways) within the area of the fire it will quickly progress into the decay phase. This is because the fire and its ability to grow is controlled by the amount of air available to it (National Fire Protection Association, 2020, p. 20). The remaining fire will rapidly migrate to a ventilation point and situate itself there, burning at an intense rate due to the unfettered access of air. Also, depending on the momentum of the entraining air, flaming combustion can occur within the stream of ventilation into the compartment at varying depths (National Fire Protection Association, 2020, p. 48).

The decay stage occurs once the fire has consumed all the available fuel within the compartment, or if the available oxygen within the room has dropped to a point where flaming combustion can no longer be sustained. The oxygen concentration in the breathable air is approximately 21%. The oxygen level below which flaming combustion generally begins to cease is approximately 16% (DeHaan, 2007, p. 54; Icove et al., 2013, p, 79; International Fire Service Training Association, 2013, p. 246). At that point, flaming combustion is only observed at or near ventilation openings, where fresh oxygen is present. Figure 14 depicts the idealized curve involving the relationship between temperature and time in the fire behavior of a traditional fuel-controlled fire.

Figure 14

Idealized Curve Involving Relationship between Temperature and Time in the Fire Behavior of a Traditional Fuel-Controlled Fire



Note. Adapted from National Fire Protection Association, 2020, p. 31.

Figures 15, 16, 17, and 18 (adapted from National Fire Protection Association, 2008, 2020) serve as visual references regarding the stages of fire development.

Figure 15

Incipient Stage of Fire Development

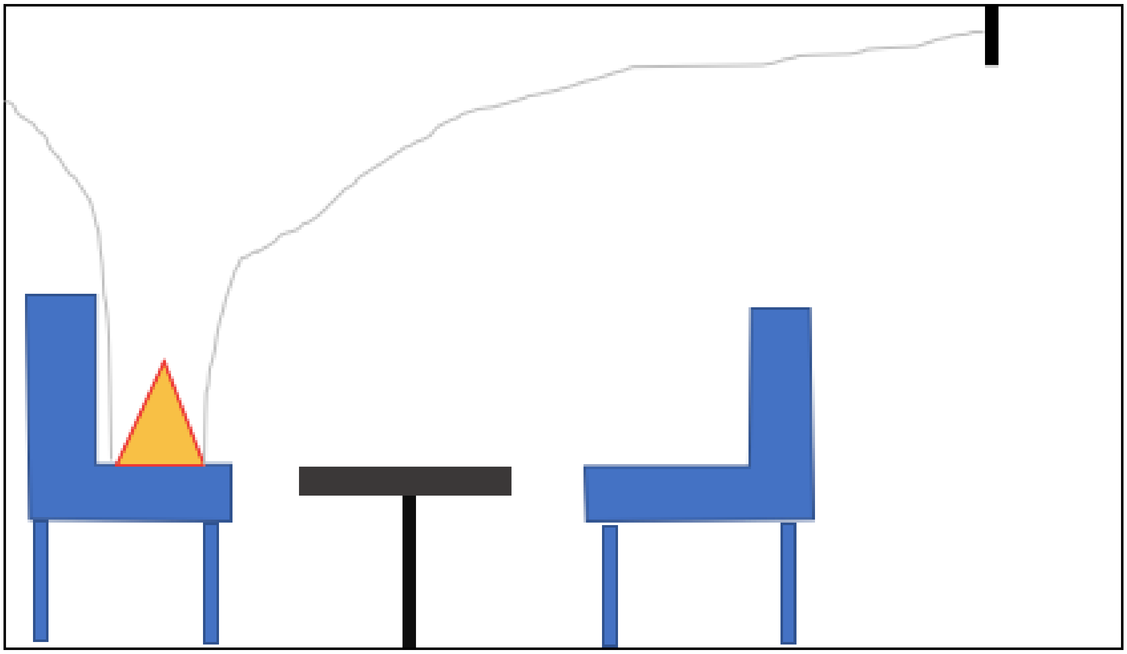


Figure 16

Growth Stage (Free-Burning)

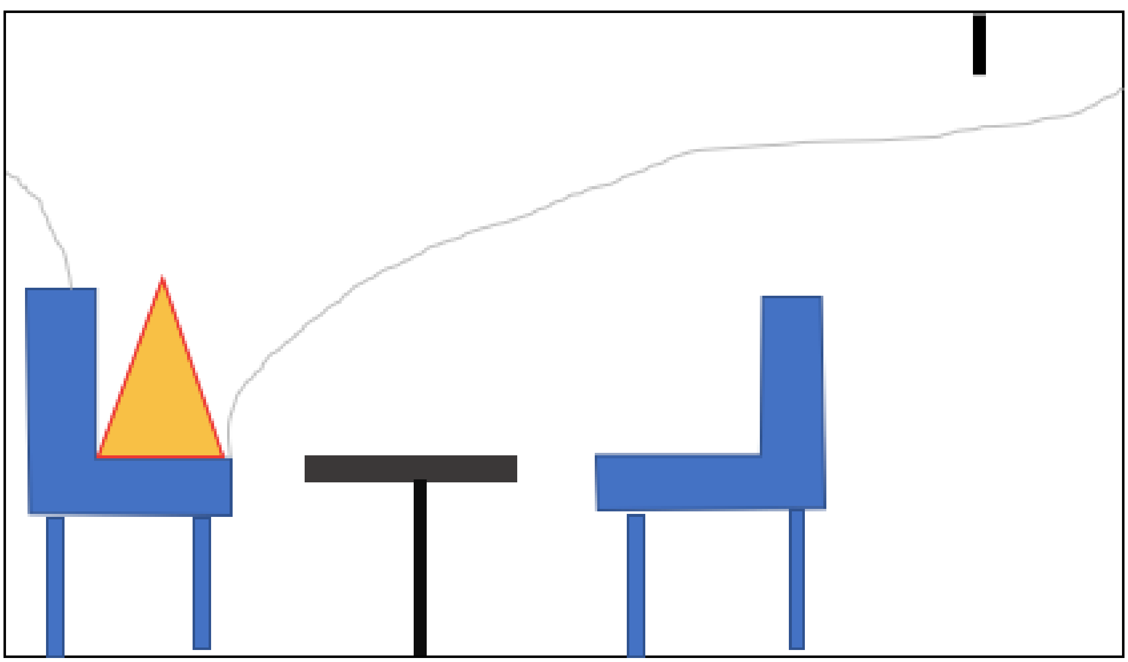


Figure 17

Fully Developed Stage (Steady State/Full Room Involvement)

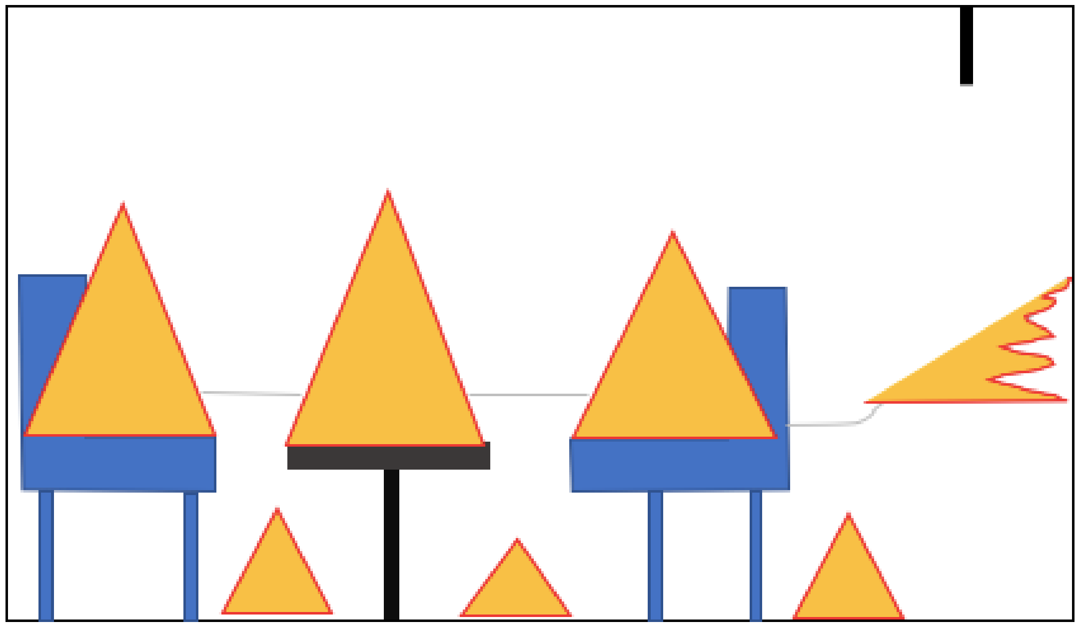
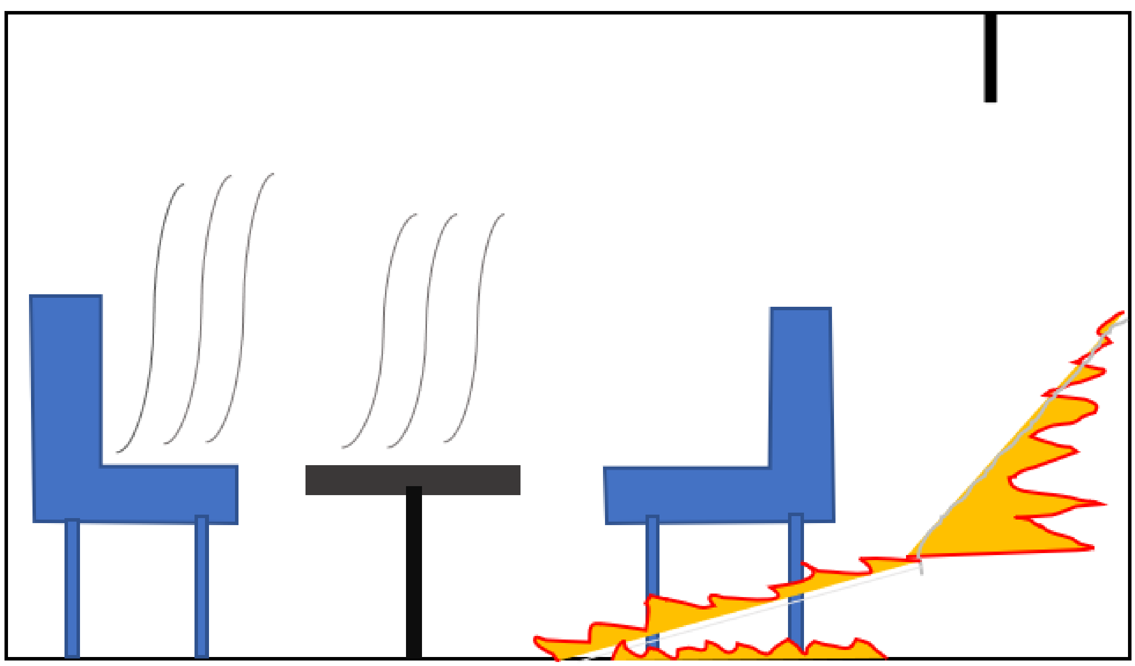


Figure 18

Decay Stage

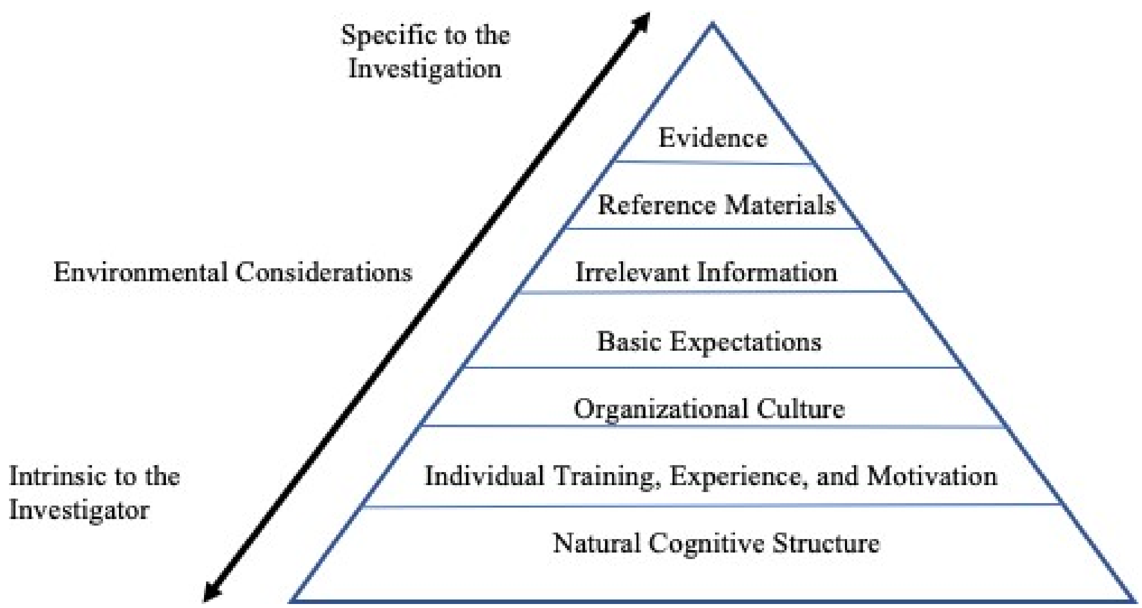


Cognition, Bias, and Error

Sources of bias affecting one's observations and conclusions can be placed on a continuum that progresses from the general to the specific. Human beings are fallible and, as such, can be prone to cognitive errors. While progressing through these issues within a continuum, additional complications can compound this, such as personal experience, education, and training (Dror, 2009, p. 99; Dror, 2011, p. 180; OSAC Task Group, 2019, p. 3). Figure 19 provides a visual representation of this continuum.

Figure 19

Continuum of Bias Affecting One's Observations and Conclusions



Note. Adapted from Dror et al., 2017.

According to Francis Bacon, all of humanity views the world selectively and, because of this, a person's understanding of what they see is partial and distorted (Bacon, 1620/2019, p. 10; Dror, 2009, p. 96; Risinger et al., 2002, p. 14). This phenomenon is known as selective attention. It was deemed a significant problem by Bacon, who in his 1620 work, *Novum Organum,* termed this issue "Idola Tribus." The modern interpretation of this terminology is "Idols of the Tribe," or what is considered today as perception being derived from human nature. "Human understanding is like a false mirror, which, receiving rays irregularly, distorts and discolours the nature of things by mingling its own nature with it" (Bacon, 1620/2019, p. 10; Dror, 2009, p. 96).

An interesting point is made by Tversky and Kahneman (1974) while discussing representativeness when forming a conclusion. Their research states that when an individual considers probabilities concerning representativeness, prior probabilities are often neglected (Tversky & Kahneman, 1974, p. 1124). This approach can lead to serious errors in a person's interpretation of the data. They found that if people are provided no specific evidence regarding a matter then prior probabilities are considered, but if they are provided valueless evidence regarding something, prior probabilities tend to be disregarded (Tversky & Kahneman, 1974, p. 1125). As a result, if investigators approach an issue with a clear mind generally, they tend to gravitate to previous similar examples. If they are provided misinformation regarding the issue, they will ultimately use that information when forming their conclusions.

Research has shown that people generally predict an outcome based on the level of representativeness of the input (Tversky & Kahneman, 1974, p. 1126). The issue at hand is that this approach causes overconfidence in a conclusion because the individual is envisioning how the outcome fits within the information they are processing, also known as "the illusion of validity" (Dror et al., 2017, p. 1; Risinger et al., 2002, p. 26; Tversky & Kahneman, 1974, p. 1126). Bacon (1620/2019) wrote of this phenomenon in his work *Novum Organum*, originally published in 1620, by stating that "the human understanding, from its peculiar nature, easily supposes a greater degree of order and equality in things than it really finds" (p. 9). A fire-related example of this would be if an investigator observed an irregular burn pattern on the floor and then formulated a mental comparison between it and other similar burn patterns observed in the past. The previous patterns all may have positive laboratory results for the presence of ignitable liquids. Due to the overredundancy of other similar patterns testing positive, the investigator may become overconfident in their conclusion that this pattern was also created by the use of ignitable liquids. What they are failing to account for are other unknown factors specific to this particular pattern. It could merely be the result of how the floor was constructed, or by normal wear and tear before the fire.

Individuals can be guilty of what is known as observer effects. These are generally related to errors of apprehension, recall, or interpretation, that are a result of the person observing a particular trait they have or a state they are in (Risinger et al., 2002, p. 12). Many times the perceptions or interpretations of an individual can be influenced by their desires or expectations (Dror, 2009, p. 97; Risinger et al., 2002, pp. 12- 21). "It is the peculiar and perpetual error of the human understanding to be more moved and excited by affirmatives than negatives, whereas it ought duly and regularly to be impartial" (Bacon, 1620/2019, p. 9). These issues are the most formidable when there is a high degree of ambiguity. This is the time when an interpretation by the observer can be susceptible to expectation or confirmation bias (Risinger et al., 2002, p. 16). As a result of fallible human nature, individuals are inclined to accept, believe, and prove what they desire to be true. Oftentimes emotions can obstruct objectivity, limiting the ability to incorporate information and facts which may be contrary to predefined thoughts and beliefs.

Consequently, these factors can have profound effects when considering the interpretation of fire patterns at a scene. To put this into proper context, take the words of Francis Bacon, the father of the scientific method: “the human understanding resembles not a dry light, but admits a tincture of the will and passions, which generate their own system accordingly; *for man always believes more readily that which he prefers* [emphasis added]” (Bacon, 1620/2019, p. 10). If, before entering a fire scene, an investigator has been informed that a suspect entered the structure and subsequently poured an ignitable liquid inside, this can potentially taint the investigator’s observations. If they begin to search for damage that would correspond to an accelerated fire, then they have given in to bias. These issues can potentially distort the findings of an investigator and result in conclusions that are ultimately misleading.

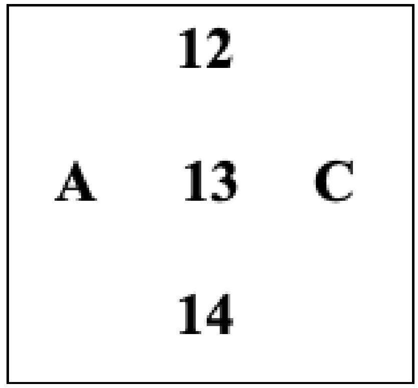
It has been argued that completely objective and detached scientific knowledge in real-world application is a fallacy. “Even in the least ‘personal’ of the sciences – physics – the process of discovery, the formulation of theories, and the procedures for testing hypotheses all involve a personal commitment on the part of the scientist” (Atkinson, 1990, p. 66). Michael Polanyi, a Hungarian scientist and philosopher, argues against the scientific knowledge by detachment approach emphasized by Enlightenment thinkers. Instead, Polyani emphasizes the fact that knowledge actually arises from one’s participation or what he calls ‘tacit knowledge’ (Atkinson, 1990, p. 66; Gelwick, 1977, p. 59; Polanyi, 1959/2014, p. 12). Much of the basis for these arguments involves the fact that conclusions involve personal judgments made by the scientist. The foundation for these judgments is the knowledge, skill, and experience of the individual; in essence, it comes down to the competency of the individual.

The methodology section of NFPA 921 (2020) provided thorough explanations of expectation bias as well as confirmation bias (p. 21). The text also stressed that an investigator must avoid any semblance of presumption about the fire scene or the events themselves (National Fire Protection Association, 2020, p. 21). By adhering to the scientific method, investigators cannot formulate hypotheses until a sufficient amount of data have been collected and analyzed. Following a documented methodology is an effective mechanism for minimizing bias (OSAC Task Group, 2019, p. 3). "Method is an effort to measure and control from the side of the interpreter; it is the opposite of letting the phenomenon lead. Ultimately, method creates a separation between the interpreters and the work, standing between them" (Palmer, 1969, p. 247). It is essential for hypotheses regarding the area of origin, ignition source, and fire spread to be opined through the lens of a properly prescribed and utilized methodology, the scientific method.

Figure 20 is a well-known example of observer effects and can be found in most psychology textbooks. The meaning of the central character is based on the context by which it is placed, either in the horizontal or the vertical. By viewing it the reader can gain an appreciation for these concepts. When the characters are read from left to right the Figure depicts "A, B, C." When the charaters are read from top to bottom the depiction is "12, 13, 14."

Figure 20

Observer Effects



Note. Adapted from Risinger et al., 2002, p. 13.

These factors must be taken into consideration any time an expert is working in a forensic field that relies on techniques involving subjective interpretation. As a result, an expert's observations and interpretations can be influenced by their inner desires and expectations. Observer effects can occur at any stage of the observation and, ultimately, be the cause of error. "The vague and subjective nature of fire pattern analysis makes it especially susceptible to expectation bias" (Bieber, 2013, p. 36). Risinger et al. (2002) conclude that "the more subjective and less instrumented a forensic technique is, the more subject to expectation-induced errors it is, and the more important finding a solution to such sources of expectation-induced error becomes" (p. 48).

The more ambiguous the data, the more likely the conclusion will be influenced by investigator bias (Dror, 2009, p. 98). Cognitive bias can prevent a valid conclusion from being reached (Lentini, 2015, p. 2). Investigators need to be cognizant that the potential for bias does in fact exist. In reality, Dror and Cole (2010) state that cognitive bias affects every forensic examiner (p. 162). Simply because bias exists it does not necessarily mean that it will lead the investigator to the wrong conclusion. Through self-reflection and identifying personal weaknesses as forensic investigators, they become cognizant of the potential issues and can apply countermeasures to combat them. When properly applied, the scientific method in fire investigation is also a useful tool for combating bias.

Bias and Error in Fire Scene Processing

When considering the larger picture of IoT systems and how the extracted data can be used in fire investigation this research must first turn and look backward to the beginning. The current study must work back toward the foundational issues upon which the ultimate conclusions of this research will lay. Recall that numerous experts have attacked fire investigation both generally and specifically. These experts include such practitioners as Lentini, Bieber, and Koehler (Lentini, 2013, 2015; Scherb, 2019, p. 1). One of their primary arguments is the subjective nature surrounding the field of fire investigation.

Furthermore, in their 2009 study, the National Academy of Sciences appeared to agree with these concerns (National Research Council, 2009, p.173). When considering what this argument entails, there is no choice but to realize that fire pattern interpretation is being placed under the microscope here. In essence, the concern is that the accuracy of forensic science, and more specifically fire scene investigations, can be undercut by subjectivity. This is not to mean that it is deliberately undermined, but most often as a result of issues involving cognition, bias, and error.

Looking at cognition and bias in the realm of fire investigation, Lentini (2015) made a bold statement by expressing that there is no field more apt to have its conclusions influenced by contextual bias than fire investigation (p. 1). After reviewing the literature, particularly works by Itiel Dror, who focused specifically on fingerprint interpretations, I disagree with Lentini. While the subjectivity of fire pattern interpretation can potentially contain vestiges of contextual bias, one cannot go so far as to say it is the most predominant field to face this issue. Forensic analysis areas such as fingerprints, DNA, tool marks, odontology, and the National Integrated Ballistic Information Network (NIBIN) all face potential impact from bias and cognition.

Dehghani-Tafti and Bieber (2017) explained the potential for concern in a more palatable manner, but still tended to embellish the issue a bit. They explained that "reliance on human perception and interpretation of images and patterns, whether they be fingerprints, bite marks, tool marks, handwriting, or fire patterns, is both common and concerning because expectation bias is most potent where the underlying analysis is subjective, ambiguous, or ill-defined" (Dehghani-Tafti & Bieber, 2017, p. 582). Greater agreement could be made if Bieber instead had stated "…the *potential for* expectation bias is most potent…" Notably, Bieber and Lentini have not offered any methodologies of their own for combatting bias, nor arguments for why the strict and robust use of the scientific method in fire investigation is insufficient to defend against bias.

As previously stated, merely because bias and cognitive errors can exist, it does not mean that investigative conclusions are always affected as a result. The current research does recognize the potential for wrongful arson convictions to exist as a result of cognitive error and bias on the part of the investigator. Investigators must remain mindful that conclusions drawn during the course of a fire investigation are generally only as reliable as the weakest link within the entire process (Dehghani-Tafti & Bieber, 2017, p. 588). Knee-jerk reactions that run counter to the scientific method within the context of

NFPA 921 are not the solution to this problem. The National Fire Protection Association (2020) clearly and specifically states, in section 18.2.1.2, that an investigator should use all available resources to not only develop origin and fire spread hypotheses, but to also determine which hypotheses correlate with all the evidence available (p. 221).

Furthermore, Lentini and Bieber argue that due to the potential for bias and cognition errors, fire investigators should engage the fire scene from a purely empirical approach. This approach emphasizes that fire investigators rely solely upon their observations contained to the fire scene itself, also excluding the statements of any witnesses or circumstantial information (Avato & Cox, 2009, p. 47). Essentially, the scene should "speak for itself."

There are several glaring issues with this approach. First and foremost, it stands in stark contrast to the point of being contrary to the methodology prescribed within NFPA 921. The text specifically stated that investigators are to consider and coordinate data obtained from witness information, fire patterns, and fire dynamics (National Fire Protection Association, 2020, p. 220). Also, electronic data are currently included with witness information within this section. As a result, if witness information was discarded and the focus is merely on the scene, investigators would also have to discard any electronic data (particularly those which were obtained off-site) because the National Fire Protection Association included it within the realm of "witness information." Avato and Cox (2009) emphasized the fact that a fire investigator should never discard or ignore information (p. 47).

By focusing on only the fire scene itself, the fire investigator is also being forced to place a heavier emphasis on fire pattern analysis. The 2020 edition of NFPA 921

(National Fire Protection Association, 2020) also cautioned that if investigators only look for patterns within the fire scene, other important data may not be included in the analysis (p. 31). More significant fire scenes often exhibit a greater degree of damage, which increases the complexity of the scene processing and evidence examination (Avato & Cox, 2009, p. 48). As a result, interpretation of fire patterns and damage observed within the scene of a significant fire becomes considerably less reliable due to the extensive damage to the structure, systems, and contents (Dehghani-Tafti & Bieber, 2017, p. 608).

Thus, Lentini's and Bieber's aforementioned recommendations actually run contrary to their earlier concerns and accusations about subjectivity. An investigator must synthesize all available information in an attempt to arrive at the correct conclusion. By collecting and considering all available data within their proper context, they actually assist in the prevention of bias and cognitive errors by the investigator.

Fire Pattern Analysis and Area of Origin Determination

For years, fire investigators have been taught to process the fire scene exterior of the structure first, then the interior (National Fire Protection Association, 1997, p. 73). They have also been trained that the structure should be processed from the areas of least damage to the areas of most damage (National Fire Protection Association, 1997, p. 73). It was a long-held belief that the area of most damage indicated the longest duration of burning, thus it would be the area of origin. However, as time progressed and research in the field was conducted, investigators have learned that this is not necessarily the case.

Fire pattern interpretation is central to the realm of fire investigation. In Section 4.2.4 of NFPA 1033 the interpretation of fire patterns was listed as a mandatory requirement of all fire investigators (Hewitt & McKenna, 2017, p. 32; National Fire

Protection Association, 2013, p. 8). Section 6.1.1 of NFPA 921 also emphasized the importance of collecting data at the fire scene, which includes fire effects and fire patterns (Hewitt & McKenna, 2017, p. 32 ; National Fire Protection Association, 2020, pp. 50-51). When an investigator opines an area of origin within a fire scene, they include an analysis of fire patterns along with information obtained from witnesses, electronic data, and fire dynamics (National Fire Protection Association, 2020, p. 220). As previously stated, fire patterns must be considered within the context of the totality of the fire scene.

Of extreme importance is the ability of the investigator to be able to not only identify the fire patterns present, but to also be able to analyze them sequentially. "The surfaces of the fire scene record all of the fire patterns generated during the lifetime of the event, from ignition through suppression, *although these patterns may be altered, obscured, or obliterated after they are produced, by the subsequent growth and spread of the fire* [emphasis added]" (National Fire Protection Association, 2020, p. 221). Once again, the investigator must consider that the longer the duration of the fire, the more damage is created, and the less reliable mere pattern interpretation is concerning origin determination.

An experiment was conducted in 2005 by ATF at a fire investigation seminar in Las Vegas, Nevada. Two identical single room burn cells were constructed and burned, transitioning through flashover. Subsequently, 53 participants (who did not observe the cells being burned) were asked to walk through each cell and without physically processing the scene, and determine which quadrant of the room the fire originated within (Carman, 2008, pp. 1-2; Lentini, 2013, 2020). Only three properly identified the quadrant in cell one, and three different participants correctly identified the quadrant in cell two (Carman, 2008, 2009; Lentini, 2013, p. 404). Further study by ATF and others have determined that even the most experienced fire investigators have difficulty in interpreting fire patterns post flashover (Carman, 2008, 2009; Gorbett et al., 2015, p. 31; Lentini, 2020, p. 26; Tinsley & Gorbett, 2013, p. 1). These studies are often cited by opposing experts to dramatically overstate the potential error rate of fire investigation. Several key factors must be considered related to these studies. First, investigators could not properly employ the scientific method as typically applied to fire investigation. They were provided no contextual data to apply except for the fire patterns within the compartment. Second, the origin size was predetermined by the instructors. Third, there was no option for the investigators to categorize the origin as undetermined. Because these studies do tend to be often cited, they are necessary for this current research.

Andrew Cox, an ATF CFI and former ATF FPE, conducted an extremely perceptive study concerning origin analysis with respect to fire pattern and damage analysis within a compartment fire. Not only was his study published by the *Fire & Arson Investigator* journal in July 2013, it has since been adopted into NFPA 921. The Cox study emphasized that consideration of only fire patterns may be of limited assistance to the fire investigator in cases where the fire has burned for a long duration following full room involvement (Cox, 2013, p. 37; National Fire Protection Association, 2020, p. 229).

Several key points were made within the course of the Cox article. When interpreting fire patterns and related damage, the fire investigator must consider what the material properties are of the objects burned (Cox, 2013, p. 40). Different materials respond differently to fire exposure. Investigators must be cognizant of their damage comparisons. A pine table will exhibit vastly different damage when compared to an upholstered chair. Investigators must not compare apples to oranges, but apples to apples.

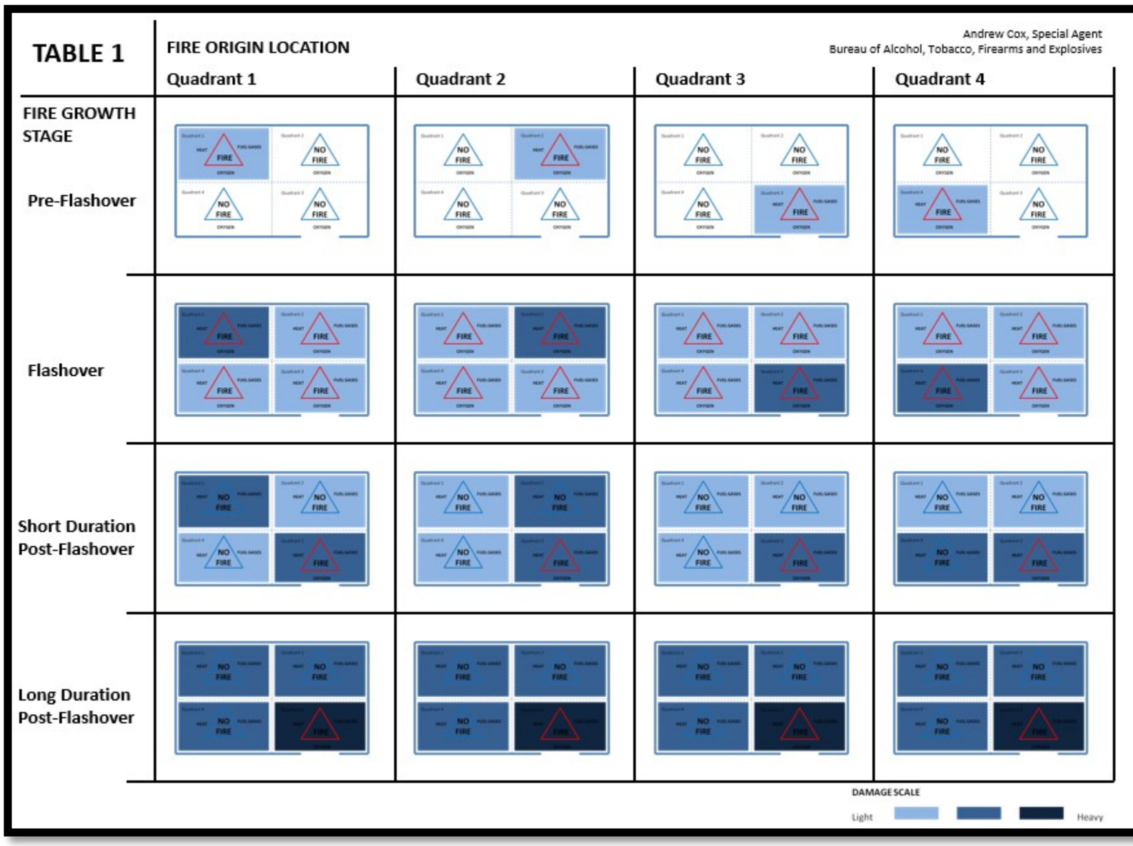
The duration of heat exposure as well as the intensity of that heat must also be considered. Objects exposed to longer duration heat tend to display a greater degree of damage. The intensity of the heat by which an object is exposed also plays a significant role. Fire burns more intensely in areas where it has available oxygen. Thus, once a fire has transitioned through flashover and full room involvement, the active fire will gravitate towards and burn near ventilation openings. The result of which will generate greater observed damage in the areas of ventilation openings as well as in areas involving the flow path of air into the compartment.

Investigators must educate themselves about these phenomena and remain cognizant of them while examining a fire scene. Once again, the totality of each pattern alone following flashover and full-room involvement will not be enough to determine an area of origin. Each pattern must be considered within the context of the entire scene. Cox (2013) recommended several steps when assessing fire damage within a compartment, namely: identification, documentation, and quantification of the fire patterns and damage (p. 41).

Gorbett et al. (2015) recommended a very similar process (pp. 27-28). By doing so and then opining the observations, it is possible to create an image to assist in the evaluation of what is observed. Figure 21 displays this matrix for a typical compartment fire. The investigator needs to consider what damage they would expect from a fire originating in different quadrants of the room. Eventually, postflashover, the greatest damage will always be in the vicinity of the ventilation opening, regardless of where the fire originated.

Figure 21

Compartment Fire Matrix



Note. Source: Cox, 2013, p. 46.

Investigators must also consider potential complicating factors when utilizing this technique. Such factors can include but are not limited to, potential multiple areas of origin, the effects of ventilation and their associated flow of air, and partial extinguishment (Cox, 2013, pp. 44-46). As always, investigators must remain diligent as to all of these considerations. It cannot be emphasized enough, that the longer the duration of the fire, the greater the extent of the damage, and the less reliable fire patterns can be to the investigator (Avato & Cox, 2009, p. 48; Cox, 2013, p. 37; Dehghani-Tafti & Bieber, 2017, p. 563; National Fire Protection Association, 2020, p. 229).

Additional research has been conducted concerning the persistence of fire origin patterns. Campanell and Avato published a study in the *Fire & Arson Investigator* in October 2016. The study involved observations within more than 400 compartmentalized training burns postfire. The study concluded that when an area of origin was outside of the postflashover fire ventilation flow path, discernable patterns remained observable (Campanell & Avato, 2016, p. 21). Previous research conducted by Hopkins et al. had also come to this conclusion, although that study only involved a total of 8 experiments involving single room burn cells (Hopkins et al., 2007, p. 16). NFPA 921 further stated that origin related damage located remotely from ventilation related openings may persist (National Fire Protection Association, 2020, p. 229). Fire investigators must continue to educate themselves regarding improvements in methodology as well as research which improves overall knowledge and understanding of fire behavior and fire dynamics.

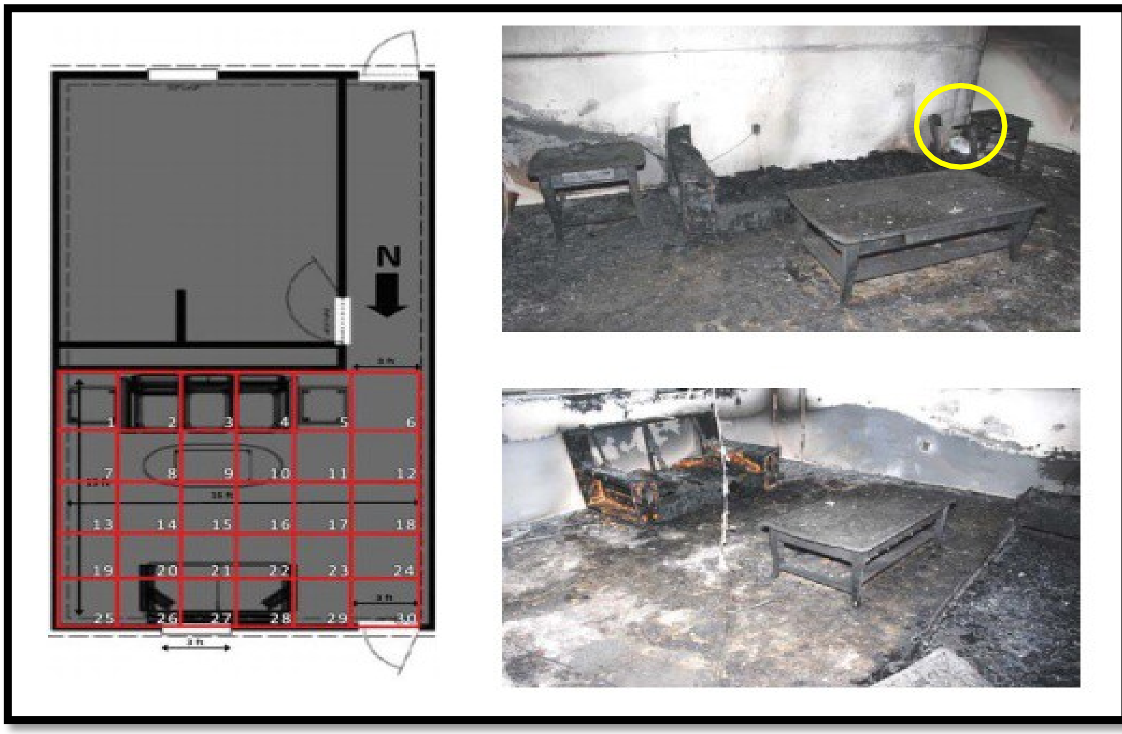
In 2013, Tinsley and Gorbett published a study regarding the determination of the area of origin during a fire investigation. The study involved self-reporting by fire investigators working in the field via the use of a multipart survey. The reporting population involved 586 participants (Tinsley & Gorbett, 2013, p. 26). A portion of the study also involved participants reviewing a single photograph of a fire-affected room and responding to questions regarding the presence or absence of certain fire patterns and fire effects. The final section involved the review of a set of photographs and a diagram depicting a structure postfire. Participants were asked to review the photographs and attempt to identify the area of origin.

This study generated some fascinating results. Several fire effects and patterns were identified by a large percentage of the participants that were not deemed to be present by the researchers (Tinsley & Gorbett, 2013, p. 33). Additionally, several participants identified fire effects have been previously identified as “myths” and erroneous. Researchers also determined that 15% of the participants misidentified the direction of fire movement within the space. The next portion of the Tinsley and Gorbett study supports the necessity of the research being conducted within the current study.

The third portion of the survey involved the examination of a series of photographs, with the participants indicating the area of origin within a gridded diagram (Tinsley & Gorbett, 2013). Figure 22 shows the gridded diagram used in the study as well as photographs of the north side of the room (top right) and the center and south side of the room (bottom right). The area of origin was identified by the researchers as being located within grid five, circled in yellow below.

Figure 22

Diagram and Photographs from Tinsley and Gorbett (2013)



Note. Source: Tinsley & Gorbett, 2013, pp. 34-35.

This identification was first performed by participants in the absence of any measurable data. During this phase, 73.8% of the participants correctly identified the area of origin (Tinsley & Gorbett, 2013, p. 36). The participants were subsequently provided with measurable data (in this particular case it involved depth of char and calcination measurements). As a result, the participant accuracy was increased to 77.7% (Tinsley & Gorbett, 2013, p. 36). Participants were then asked about their primary consideration involving their area of origin determination. Tinsley and Gorbett reported that none of the participants indicated that they considered the greatest degree of damage (p. 38). This finding is vastly different from the results reported in 2008 from the Carman study.

Several critical conclusions were drawn by Tinsley and Gorbett (2013). First, it was determined that those investigators who are active within the field whether by reading, attending training, and remaining educated regarding changes and improvements were observed to be more effective and accurate (Tinsley & Gorbett, 2013, p. 39). Furthermore, the researchers determined that the collection and provision of measurable data resulted in a significant statistical difference regarding the accuracy of the participants. The resulting recommendation was that the field of fire investigation could be improved by fire investigators collecting and documenting measurable data at fire scenes. This dovetails with calls for research to develop methods and procedures to determine areas of fire origin in situations involving extensive fire damage to a structure (Dehghani-Tafti & Bieber, 2017, p. 608).

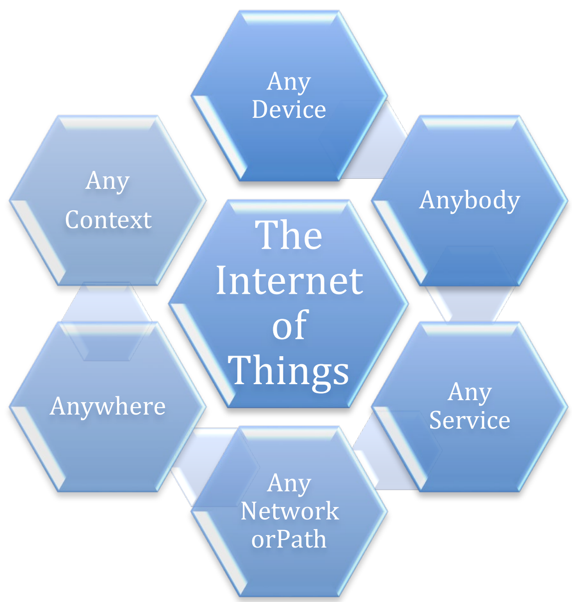
The Internet of Things (IoT)

The "Internet of Things" concept was created in 1999 by Kevin Ashton, to promote radio frequency identification technology (RFID), while he was working at Proctor and Gamble (Lueth, 2014, p. 2; Tzafestas, 2009, p. 98). Before that, it was generally referred to as "embedded internet" or "pervasive computing" (Lueth, 2014, p. 2). The concept remained fairly unnoticed until it gained extensive popularity beginning in 2010 and 2011 with the rise of Google. By 2014, IoT was front and center and no longer merely a concept.

Vijayalakshmi and Muruganand (2017) identified IoT as "a network of linking things through sensors and communication equipment, linking things among themselves and finally linking between people and things" (pp. 2141-2142). IoT involves interrelated devices, machines, and objects possessing unique identifiers that transfer data over networks without requiring any form of human interaction (Alabdulsalam et al., 2018, p. 35; Chandra et al., 2019, p. 750; IoT 101, 2018, p. 1; Kilic & Bayir, 2017, p. 197; Zhang & Yu, 2013, p. 314). Currently, IoT can potentially connect nearly 50 billion ‘things’ to the Internet (Tzafestas, 2009, p. 102). During the modern age, IoT connected systems, appliances, and items are encountered on a daily basis. IoT is pervasive and, as a result, so are the data that can be gleaned from it.   These IoT system sensors and components are connected to the internet in a multitude of different ways. They can be connected via WiFi, Bluetooth, routers, gateways, ethernet, cellular, satellite, and even by low-power, wide-area networks (LPWAN; IoT 101, 2018, p. 14; Khader et al., 2019, p. 81; Zhang & Yu, 2013, p. 314). The specific applications ultimately determine how the system or device is connected. Each connection option varies concerning its range and power consumption. Once the data from the IoT system or device is sent to the internet, the data must be processed by software for them to become intelligible. The information is then either provided to the user, maintained within the internet, or upon the system or device. Figure 23 shows the concept of IoT within the context of the world today.

Figure 23

The Internet of Things (IoT) in the World Today



Note. Adapted from Tzafestas, 2009.

IoT is currently considered "witness information" by investigators. The latest edition of NFPA 921 (National Fire Protection Association, 2020) included electronic data within the same category as witness information when identifying information that can be obtained and coordinated by investigators (p. 220). IoT has also been referred to as "digital witnesses" (Rajewski, 2019, p. 1; Servida & Casey, 2019, p. 22). Due to the prevalence of IoT, these opinions are not necessarily incorrect. One glaring issue is that IoT data are still an often neglected potential source of investigative information.

Many IoT devices include sensors or components which generate data. This data can either be generated autonomously, or can be generated in response to some manner of human action; such as the opening of doors and windows, user commands, or motion (Servida & Casey, 2019, pp. 22-23; Zhang & Yu, 2013, p. 314). Smoke and flame can also trigger some IoT devices. When reviewing the created data points, investigators need to be cognizant of an extremely crucial point. Lack of data can be just as important as the presence of data. It is also important to note that data can be locally stored even if not transmitted or recorded on the internet. For example, motion sensors on a nonarmed burglar alarm system still record motion activations locally in each sensor; they simply do not transmit the data because the system is disarmed.

IoT Building Systems and Fire

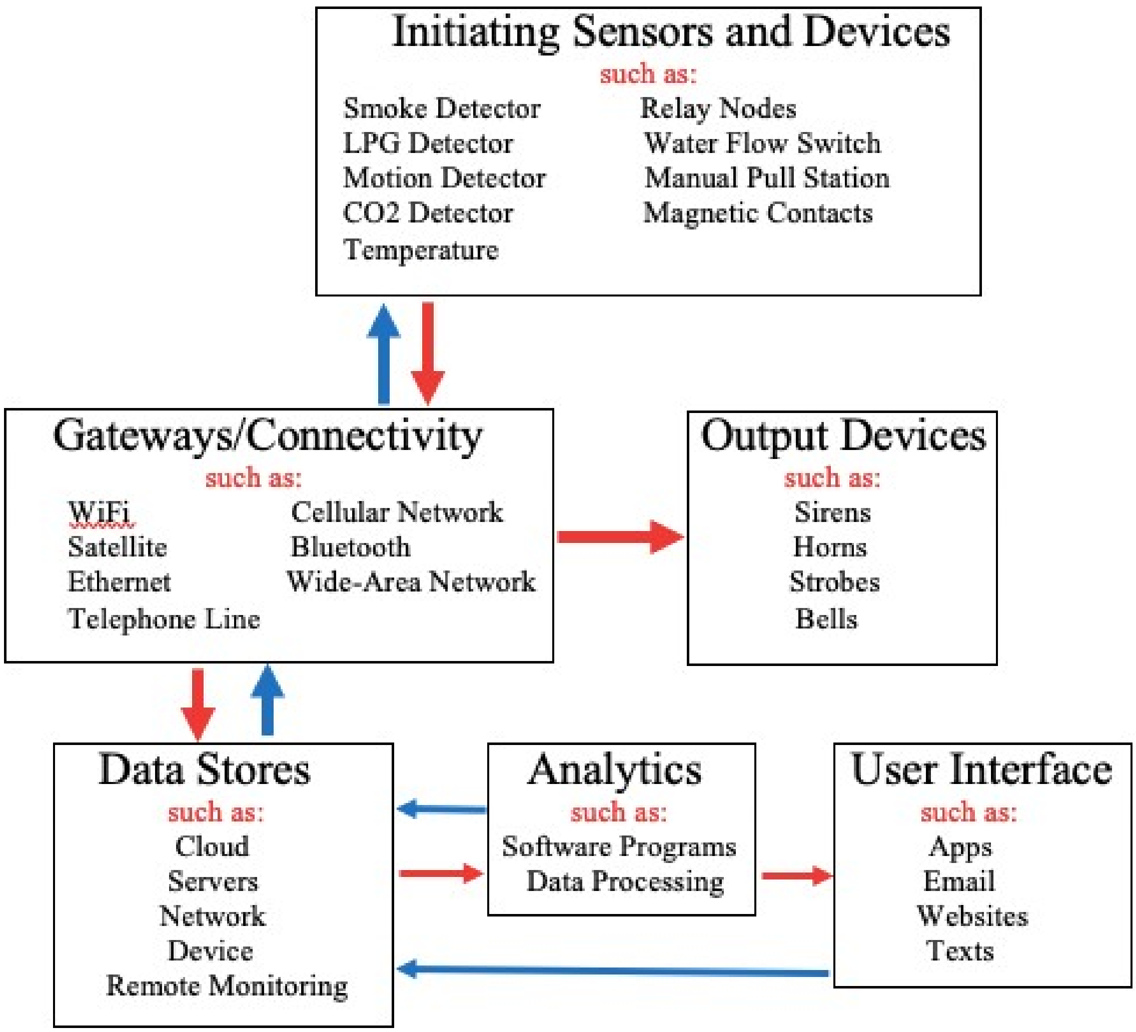
Servida and Casey (2019) advised that certain devices, such as smoke and carbon monoxide detectors, can assist investigators in the determination of where and at what time a fire began (p. 23). While that is accurate, this concept is not limited to only devices such as smoke and carbon monoxide detectors; but includes an array of IoT devices and systems (Khera, 2019, p. 3; Li et al., 2016, p. 174; Liu & Zhu, 2014, p. 578). The challenge for investigators is in identifying the IoT systems, appliances, and devices that are present within the fire scene. From a forensic science perspective, each separate IoT system or artifact can potentially possess data that could be beneficial to investigators during the fire scene examination process.

When attempting to obtain IoT data to assist with a fire scene examination there are several steps that must be accomplished. The various type of IoT devices or systems concerning the affected structure must be identified. Documentation of IoT systems as to location and specific function is critical. Placing this information within a diagram of the structure can also be helpful. How the information is communicated by the units must be discerned. The location of the resulting data must also be established. IoT data can be maintained in various locations to include the cloud, on a network, or within individual devices (Alabdulsalam et al., 2018, p. 38; Rajewski, 2019, p. 2; Scientific Working

Group on Digital Evidence, 2019, p.13; Servida & Casey, 2019, p. 27). The general manner in which IoT building systems operate can be observed in Figure 24.

Figure 24

Operation of IoT Building Systems



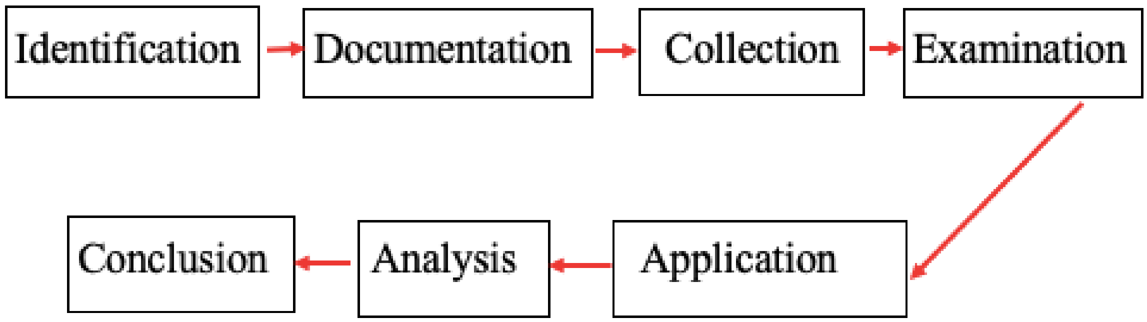
Of additional concern is the potential lifespan limitation of the data. IoT data can be overwritten or inadvertently erased (Alabdulsalam et al., 2018, p. 39; Rajewski, 2019, p. 3; Scientific Working Group on Digital Evidence, 2019, p. 5; Servida & Casey, 2019, p. 27). Ultimately, investigators must be cognizant of these concerns so that they can be addressed and, if need be, mitigated to ensure the data are properly preserved.

IoT data obtained during the course of an investigation fall under the realm of digital and multimedia evidence. As a result, IoT data are covered by the 4th Amendment search and seizure protections. Therefore, consent or a search warrant must be obtained for the data to be reviewed and utilized.

It is essential to ensure that all data within the timeline sequence are synchronized by normalizing data using websites such as Time.gov. Time readings provided by the IoT system regarding the sequence of alarms, activations and service disruption within each affected zone functions as empirical data points for analysis (Icove et al., 2013, pp. 165-166). By forensically mapping out this data it is possible to reconstruct the sequence of fire spread as well as potentially identify the initial stages of the fire (DeHaan & Icove, 2012, p. 313). Essentially, investigators ascertain the initial IoT system notifications from their starting point and subsequently track the location and time of additional notifications. The timeline analysis can help place fire early on in certain areas and the sequential failure of devices may reflect fire travel which can subsequently be mapped out. Timestamps of activities are of critical importance. When placed within the context of other timed activities (soft or hard times), they evoke a more empirical and accurate picture to the investigative team. Another important consideration is the identification of the location of device(s) in relation to the fire origin and or spread. The flow of this aforementioned process should progress as follows (Figure 25).

Figure 25

From Identification to Conclusion



Specific Case Examples of IoT Data Usage in Practice

A total of 10 sample cases in which IoT data were purportedly utilized to assist with area of origin determination were reviewed. These cases were identified as a result of a cursory email that was sent out among the ATF CFI, NRT, and engineer cadre requesting that they self-reported. The main purpose of that email was to determine if there would be enough available data to conduct the current research. The secondary rationale was to identify these cases for subsequent review during this study.

The cases were all the result of ATF NRT activations. The NRT is composed of a carefully selected cadre of experts who are employed by ATF and possess extensive experience in fire scene processing, origin and cause determination, postblast processing, and scene reconstruction. The team was developed in 1978 and since its inception has responded to over 700 incidents (Bureau of Alcohol, Tobacco, Firearms and Explosives, n.d.). General requirements for the activation of the NRT involve complex and large loss fire scenes, significant postblast incidents, incidents of national interest, and loss of life and/or injuries. When conducting an assessment of the scene before NRT activation, the requesting office must determine that the damage is more than $1,000,000 and/or that processing the scene would cause undue hardship to the local agencies.

Upon further study of the 10 cases, it was observed that 2 cases were unable to be utilized by the current research. One case is still pending within the court system and has not yet been adjudicated. The other case utilized an IoT building management system in order to understand why the fire alarm system did not alert residents of the structure to the fire. Ultimately, the system ceased being monitored approximately 6 months prior to the fire. Several zones within the system had been silenced by building residents. As a result, subsequent activations for those zones would not cause the system to go into alarm mode. As a result, the fire caused four deaths and 10 total injuries. The IoT system in this instance was not utilized to assist with an origin determination and was therefore excluded from this study.

The eight remaining sample cases involved industrial, commercial, and multiunit residential occupancy fires. Two cases involved multiple fatalities, one of which resulted in the Line of Duty Death of two firefighters. The structures ranged from single story warehouses to multiple story residential buildings and mixed-use structures. Damage totals ranged from $2,000,000 to in excess of $450,000,000. The fire affected square footage of these structures ranged from approximately 16,500 to nearly 370,000. These fire scenes were conducted within seven different states. Represented regions within the United States include the northeast, the midwest, the southwest, and the west coast. The IoT building management system’s utilized data involved fire protection systems (smoke alarms, fire alarms, and sprinklers), WiFi systems, burglar alarms, and smart meters. The current research will delve more deeply into the specifics of each case within the results section.

Summary

The literature rendered within this chapter provided a glimpse into the background of the issue upon which this research focuses, namely, Internet of Things (IoT) connected building systems and their use in fire investigation. The reader was provided with a holistic understanding of the primary issue at hand, along with its ancillary components. The areas of bias, cognition, and error present major concerns within the profession of fire investigation, more specifically fire pattern interpretation. If the area of origin is misidentified by the fire investigator then the cause of the fire will also be incorrect. The result has the potential to culminate in a wrongful conviction and imprisonment, which is an unwanted and catastrophic potential consequence.

Prior research concerning the accuracy of an area of origin determination within a fire scene has shown that fire investigators have room for improvement. The results between the Carman study in 2005 and those from the Tinsley and Gorbett study in 2013 depicted an increase in this precision. This was a result of deficiency identification regarding ventilation effects within compartment fire postflashover, and the interpretation of the resulting fire patterns. Research and training focused upon and began to address these issues. Tinsley and Gorbett (2013) were able to further conclude that accuracy is additionally advanced by the presence of measurable data. The stage is now set for the current research.

CHAPTER III

METHODOLOGY

The purpose of the current study is to examine the use of IoT technology during the fire scene examination process and to understand the manner in which IoT data are subsequently employed by the investigators. The researcher also intends to explore and document the experience and opinions of investigators who have used this particular method. This research improves the current procedures used in fire investigations when seeking to find the area of origin pertaining to the fires examined. This is accomplished by providing expert insights on the effectiveness of using IoT as a fire investigation tool.

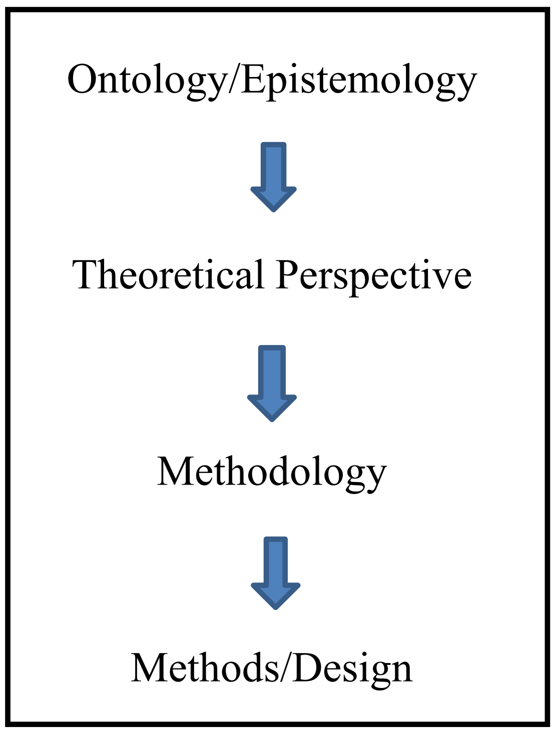
Chapter 3 presents the selected methodology, as well as the basic design of the current study. The population and sampling method are identified. The data collection process and interview protocols are examined and explained in detail in order to provide a comprehensive understanding of the study. Researcher positionality and bias reduction techniques are presented, as well as the credibility and transferability of this study. An explanation of the process of informed consent among the participants is provided, as well as a description of the interview template creation and field testing thereof.

Research Method and Design Appropriateness

In order to identify an appropriate research methodology, numerous elements must first be identified. Figure 26 provides a visual reference for the flow of research method and design selection. Note that general conceptions of the world must first be identified and defined prior to any specificity pertaining to an investigative approach.

Figure 26

Flow of Research Method and Design Selection



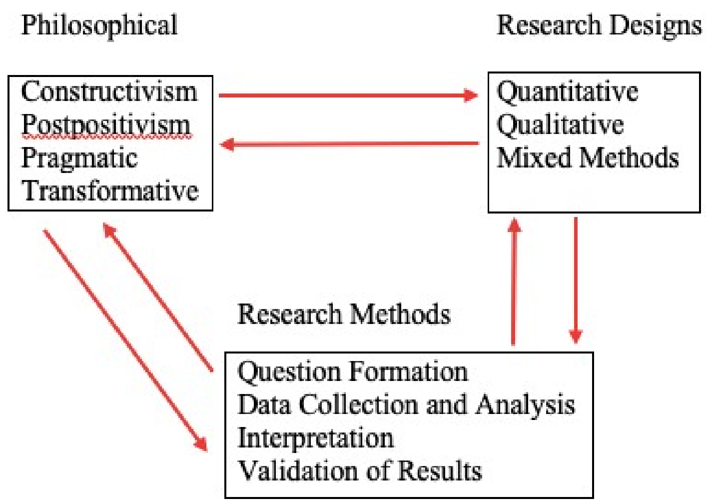
Ontology involves the study of reality. “It is concerned with ‘what is,’ with the nature of existence, with the structure of reality as such” (Crotty, 1998, p. 10). Ontology asks the question, what is out there to know? This is the global framework for conducting research. It asks the question, “what is reality?”

Epistemology can be defined as the manner in which knowledge can be understood, in other words, "how we know what we know" (Crotty, 1998, p. 3). This current study will operate through the lens of constructivism, which can be defined as the partnership of subject and object in the generation of meaning (Creswell & Creswell, 2018, p. 8; Crotty, 1998, p. 9). Meaning is extracted from the world as a result of interactions within it. "In the mixed methods research discourse, two epistemological positions are identified that matter most: a positivist approach that gives rise to quantitative methods, and a constructivist approach that is home to qualitative methods" (Crotty, 1998, p. 5; Timans et al., 2019, pp. 208-209).

Theoretical perspective is considered the "philosophical stance informing the methodology and thus providing a context for the process and grounding its logic and criteria" (Crotty, 1998, p. 3). This study will proceed in the path of an interpretivist perspective. This occurs through understanding the meaning attached by individuals to their actions. Constructivism and interpretivism approaches are often combined, and this combination is observed to be a useful approach to qualitative research (Creswell & Creswell, 2018, p. 7). Figure 27 provides a visual as to how philosophy, research methods, and designs come together to complement each other.

Figure 27

Interactions Between Philosophy, Design, and Method



Note. Adapted from Creswell and Creswell, 2018.

As for the research design methodology of this study, a mixed method approach integrating both qualitative and quantitative data was determined to be optimal. The particular approach to mixed methods utilized within this study is what is known as Sequential Explanatory Design. This particular design involves two distinct phases. First, quantitative or numeric data are collected and analyzed (Ivankova et al., 2006, p. 5; Schoonenboom & Johnson, 2017, p. 117). Afterwards, the qualitative or text data are collected and analyzed (Ivankova et al., 2006, p. 5; Schoonenboom & Johnson, 2017, p. 117). This allows the qualitative data to provide insight pertaining to the story of the quantitative data. During this stage there is a comprehensive exploration of participant views. A mixed methods approach was selected for this particular study because it enabled a seamless and thorough integration of the data, beginning from the population and subsequent sample selection through the analysis of case examples and the interpretation of the participant SMEs' direct experiences.

As a result, it was determined that priority would be given to the qualitative data stage, despite it being the second phase of the process. Thus, it is a quan→ QUAL theoretical drive (Schoonenboom & Johnson, 2017, p. 112; Terrell, 2012, p. 261). Theoretical drive "refers to which approach, quantitative or qualitative (or both), a researcher gives more weight or attention throughout the data collection and analysis part of the study" (Ivankova et al., 2006, p. 9). This decision was arrived at due to a number of factors. First, while the quantitative phase occurred first in the research process, the data collection was limited to one source. The purpose of the quantitative phase was to identify relevant Subject Matter Experts (SMEs) and specific case examples for exploration. The qualitative phase of this research was in-depth and extensive, focusing on the creation of themes and categories. The qualitative data also were derived from numerous different sources.

This research was implemented in a process in which the quantitative and qualitative data were collected in a consecutive manner, meaning they were collected one after the other. The qualitative data were collected as a result of the outcomes from the quantitative phase of the process (Ivankova et al., 2006, p. 10). The quantitative phase was conducted in order to identify and permit for the purposeful sampling of SME participants. The result was an integration of the quantitative and qualitative data of the research process.

A preliminary review of the literature occurred prior to the start of the research in order to identify pertinent research questions and areas from which data can be extracted for analysis (Almarzooqi et al., 2016, p. 84; Thai et al., 2012, p. 4). The literature review was conducted in order to provide a solid foundation upon which to build this study. The current research was led by research questions which assisted in focusing efforts of data collection in order to streamline the process. These research questions were as follows:

RQ1: How can IoT data extracted from building management systems and devices be successfully utilized to assist in determining the area of origin during a fire scene examination? This study is focusing upon the overall result in the utilization of the IoT data during fire scene processing and the resultant origin determination.

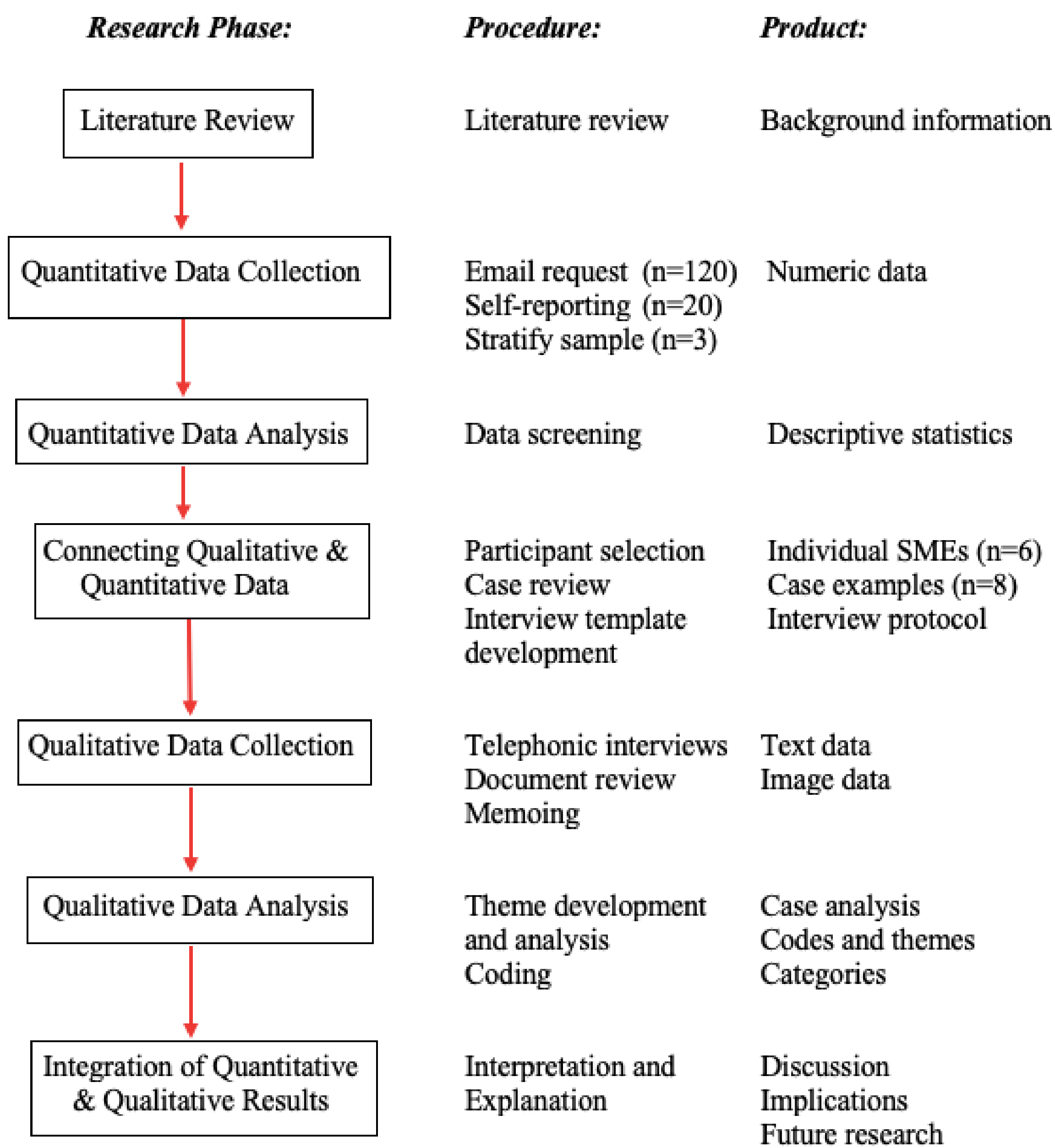
RQ2: How do these IoT building management systems operate? For this study to be able to understand what information would be available to the fire investigators for analysis it is critical to understand the basic operations of these systems.

RQ3: How is the extracted IoT data interpreted and subsequently applied to the scene? Ultimately, each IoT system provides slightly different data related to a fire event. For example, smoke alarms are triggered by smoke movement while sprinkler systems are activated by heat. This question will lead to a consideration of how the extracted data is correctly applied to origin determination.

Theoretical sensitivity can be defined as the researcher having insights into, and being cognizant of, the relevant issues, events, and occurrences which materialize during the data collection and analysis process (Corbin & Strauss, 2015, p. 78; Vollstedt & Rezat, 2019, p. 84). Theoretical sensitivity results in the ability of the researcher to generate concepts and subsequently relate them to events. Figure 28 shows the general process and basic data flow within the current study. A literature review was performed which then provided a foundation to facilitate the collection, comparison, and interpretation of data. The collected data were subsequently analyzed and placed into meaningful categories. Continuous reflection upon the data and the categories occurred throughout the analysis and memoing process.

Figure 28

General Process and Basic Data Flow in the Current Study



Note. Adapted from Ivankova et al., 2006.

Population, Sampling, Data Collection Procedures, and Rationale Population

This study included Subject Matter Experts (SMEs) from ATFs Certified Fire Investigators (CFIs), National Response Team (NRT), and engineering cadre from ATF's Fire Research Laboratory (FRL). Ultimately, the sample of SMEs involved in this study can be considered homogenous, in that they are all from the same agency and subject to the same training. Inclusion criteria assisted with the uniform and objective identification of a consistent and reliable sample (Garg, 2016, p. 4). The criteria for a participant being selected to take part in the current research involved the following: being an ATF SME, the involved case was either closed or adjudicated, and that IoT data were utilized to assist with the determination of an area of origin. The remainder were excluded from the study. Exclusion criteria involve factors that resulted in portions of the population being ineligible (Garg, 2016, p. 4).

ATF CFIs are the only federal law enforcement investigators to qualify as experts in origin and cause determinations (Bureau of Alcohol, Tobacco, Firearms and Explosives, n.d.). The ATF FRL is the world's largest laboratory which deals exclusively with fire origin and cause investigations (Bureau of Alcohol, Tobacco, Firearms and Explosives, n.d.). Together these experts form the cadre of the ATF NRT SMEs. The NRT consists of selected veteran investigators with significant fire and explosive investigative experience. As a result, the sample in this study will contain some of the world's most knowledgeable SMEs.

Sampling Frame

The sample selection for this study was purposeful and not selected at random. The sample was selected using the nonprobability method of stratified purposive sampling. This method was decided upon because the crux of this mixed-methods study is qualitative. Purposive sampling allows for the researcher to select the participants for the study especially when dealing with a specific population with unique attributes (Pajo, 2018, p. 144). Participants for the current research were selected based upon their response to a previously distributed email which inquired who from the total population of approximately one hundred twenty SMEs had utilized the IoT to narrow down the area of origin in a large fire scene. Twenty SMEs who had utilized IoT data to narrow down an area of origin were subsequently identified. SMEs who had not utilized this technique were identified and excluded from the study. The identified SMEs who had utilized this technique were invited to be participants in this research.

The SMEs were further fragmented, or stratified, into three distinct groupings. There were twelve CFIs, five Electrical Engineers (EEs), and three Fire Protection Engineers (FPEs), representing a total of 10 specific case examples. Two SMEs from each strata, for a total of six, were randomly selected to be interviewed.

Informed Consent

An informed consent form was provided to each SME interviewee via email prior to the beginning of the interview. The purpose of which was to ensure the participant that no personal identifying information (PII) was required. Participants were then invited to partake in the study by means of an audio-recorded interview via telephone. Once the informed consent forms were completed and returned, the participant was contacted in order to schedule a telephonic interview. A copy of the Informed Consent Form is provided in Appendix A. The parameters of this study were submitted to Oklahoma State

University's (OSU) Institutional Review Board (IRB), formally reviewed, and subsequently approved.

Confidentiality

Information provided by the participants was maintained in files within a locked filing cabinet not accessible to the public during the collection, review, and analysis. Any voluntarily provided personal identifying information was held in the highest confidence. Because all of the ATF related cases utilized during the course of this study have either been closed or adjudicated, they are a matter of open public record.

Geographic Location

This research drew from a sample of ATF SMEs nationwide. The SMEs in this study were located in various geographic locations and time zones within the United States. As a result, all interviews of SMEs were conducted telephonically, and audio was recorded.

Data Collection

This research relied on several sources of information. These sources included technical manuals, scholarly articles, prior research experimentation, structured interviews of participants, origin and cause reports, and researcher memos. The goal was to provide insight into the process and how it was subsequently applied to the fire scene at hand. Official documentation pertaining to the fire scenes discussed provided exact details across various situations. Table 4 identifies the sources of information utilized during the course of this study. It further pinpoints the strengths of each type of information source which was used in the research.

Table 4

Sources of Information Used for the Present Study

Sources of Information	Strengths
Literature Review	Foundational development Identification of issues
Interviews	Specifically focused on the topic Insightful Stability – templates, audio recorded, and Transcribed
Documentation	Stability – can be continuously referenced Precision – names, details, and processes Covers various situations Unbiased - created prior to and separate from this research
Memos	Documentation of entire research process Investigator self-reflection

Note. Adapted from Yin, 2003.

Once the sample of SMEs were identified, audio-recorded telephonic interviews of each SME were conducted. Interviews of SMEs involved open-ended questions to elicit their thoughts and opinions (Creswell & Creswell, 2018, p.187). The interview templates used by the researcher can be located in Appendices B and C. How the SMEs performed the data extraction, analysis, and application were critical to this research. Documents obtained for each case specific example were also reviewed in order to gain a thorough understanding pertaining to each case discussed in which IoT information was utilized. Following the completion of each interview the recordings were transported to a neutral third party for transcription.

Instrumentation

To initially identify the proper sample of SMEs an email was composed to all ATF CFIs, NRT members, FRL engineers asking if any of them had utilized the IoT to determine the area of origin at a fire. Once email responses were received, templates were created in order to focus on the processes utilized as well as the individual participant's experience and opinions while ensuring consistency between each interview. A field test of the structured interview templates was then conducted to ensure that the optimal questions pertaining to the focus of this study were being asked.

The field test consisted of a review of the templates by SMEs who were previously identified as those who were eliminated from the study and therefore not required for formal interviews. These SMEs were provided a background of the research and subsequently asked to review the interview templates to ensure the validity and dependability of the instrument (McGrath et al., 2018, p.1003). The templates were provided via email to one FPE, one EE, and one CFI for the field test. All three SMEs are members of the NRT as well. Subsequently, they reviewed the respective templates and provided their feedback. Adjustments and additions to the template were then made. The field test assisted with addressing any clarity issues to elicit the desired information from the SMEs. In essence, it calibrated the interviews as to length and information acquired.

Questions that were listed on the interview templates included the participant's job experience and responsibilities, as well as a gender and age range questions, for biographical purposes. The background questions were the same on both the CFI and engineer interview templates. Both templates also asked the same six questions pertaining to IoT data and systems as well as the participants' experience in using IoT as it related to fire scene examinations. The engineer template contained one additional question regarding best practices for IoT data extraction and storage. They consisted of open-ended questions to discuss the processes utilized pertaining to IoT data as well as elicit the thoughts and opinions of each participant (Creswell & Creswell, 2018, p.187).

Audio-recorded telephonic interviews were conducted of each identified SME. Before the beginning of each interview, an informed consent form was provided to each participant via email. Interviews of the participants involved utilizing the aforementioned structured template to ensure consistency of questions pertaining to each conversation. The manner in which the SMEs performed data extraction, analysis, and the subsequent application of the data to the fire scene were critical to this research. Following the completion of each interview, the recordings were shipped to a neutral third party for transcription.

Interview Protocol

Interviews of identified SMEs were conducted telephonically and the audio was recorded. Due to time zone considerations, interviews with participants were prescheduled between the hours of 10:00 a.m. and 2:00 p.m. with respect to the participant's location. Participants were advised that they were free to opt out of the interview at any time with no penalty. They were also ensured confidentiality and that no personal identifying information (PII) would be released. The participants were asked several background questions, such as their individual experience levels, in order to put their later answers into proper context within the collective study.

Interviews involved open-ended questions read from a previously established template to elicit their thoughts and opinions (Creswell & Creswell, 2018, p. 187). The template ensured consistency with respect to the questions asked of each participant. Consistent questions resulted in uniformity pertaining to the variety of data collected. The manner in which the participants performed data extraction, analysis, and subsequent application to the fire scene were critical to this research.

Documents pertaining to each specific case example in which the SMEs were involved, were reviewed prior to each conversation. This permitted comprehension by the researcher as to the background and processes involved pertaining to each specific case example that was discussed during the interviews. Following the completion of each interview the recordings were outsourced for transcription by a neutral third party. The participants will be contacted following the conclusion of the study via email regarding an offer to provide them with a copy of the final research report.

Credibility

When thinking about credibility, the essential question is: Did the researcher conduct the study in such a manner as to ensure that the subject matter was correctly portrayed? There were several steps taken by the current research to ensure that credibility was achieved. For example, participant interviews were forwarded to a third party for transcription. This step reduced the potential for researcher bias by permitting a neutral third party to review and transcribe the interview word for word. As a result, statements made could not be inadvertently misinterpreted or misheard due to any preconceived notions held by the researcher.

Once the transcriptions from the audio-recorded telephonic interviews were returned, the process of coding words into categories began. Memo writing was performed in conjunction with the interview and coding process. It facilitated continuous reflection upon and analysis of the data. Furthermore, it systematized the process as well as provided a mechanism for documentation during the entire process. It allowed the resulting theory to be conceptualized and refined ultimately by telling the story from the participant's point of view.

Transferability

Transferability ensures that the results of this study can subsequently be generalized to other situations (Halaweh et al., 2008, p. 8). Transferability of this study was enhanced by the research design. Data were constantly compared and contrasted with themselves, but they were also compared with existing literature (Thai et al., 2012, p. 22). Active listening skills were used during all participant interviews. Memo writing and audio recordings of interviews were used to memorialize the data provided. The data included within this research were ensured to be accurately recorded and portrayed.

Reliability

Upon the completion of the research, it will go through a process of validation. The process will incorporate what is known as member checking. "Selected representatives of the sample are given opportunities to review, prior to dissemination, copies of the transcribed data and the results section" (Vaterlaus & Higginbotham, 2011, p. 5). This was accomplished by permitting interviewees to review the transcripts of their respective interviews for content and accuracy. A technical review was also performed on the completed research by several SMEs to include a current member of the NFPA 921 technical committee as well as a past president of the International Association or Arson Investigators (IAAI). As a result, all content of the research was reviewed for accuracy in interpretation and portrayal to ensure trustworthiness of the data obtained as well as the conclusions reached.

Another way the accuracy of the data was cross checked involved a process of triangulation. The use of multiple data sources and multiple methods of data collection can reduce the potential for systematic bias (Thai et al., 2012, p. 22; Vaterlaus & Higginbotham, 2011, p. 5). An example of triangulation was the use of SME interviews, memo writing, document review, and case study identification and analysis. The convergence of the data from different sources reinforced the validity of the methodology utilized during this research. Table 5 visually displays potential issues which were anticipated involving the sources of data utilized throughout this study. It further shows the corrective actions which were taken in response to the issues.

Table 5

Potential Issues with Sources of Data

Data Source	Potential Issues	Corrective Actions
Interview	Poorly constructed questions	Field test
	Poor recall of answers	Audio recorded and transcribed
	Consistency	Template
	Misrepresented or inaccuracy in transcription	Transcript review by each participant
Documentation	Difficulty to obtain	Provided by interviewee
	Incomplete/Selective	Ensured that all reports were obtained and compared with ATF case system
	Blocked access	Did not encounter
	Sufficient time to review	Reviewed prior to each interview
	Privacy issues	Permission from ATF HQ legal and only used closed or adjudicated cases

Note. Adapted from Thai et al., 2012.

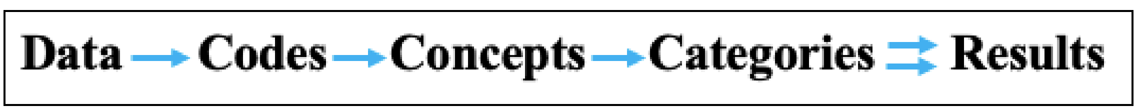
Data Analysis

Once the transcriptions of the audio-recorded interviews were returned, the process of analysis and coding words into categories began. Coding is the "analytical processes through which data are fractured, conceptualized, and integrated" (Almarzooqi et al., 2016, p. 87). The coding progression in the current study proceeded from simple concepts towards the complex, although the process was also cyclical.

Memo writing was also utilized to assist with the coding process. The memo writing assisted in documenting the entire process of data collection and analysis as well as the depiction and explanation of emerging conceptual relationships (Lawrence & Tar, 2013, p. 33). Essentially, it systematized the coding process. The importance of writing memos during this research cannot be stressed enough. “Memos don’t just report data; they tie together different pieces of data into recognizable cluster, often to show that those data are instances of general concept” (Lawrence & Tar, 2013, p. 33). Ultimately, the data in this current study tell the story from the participants’ points of view. Figure 29 provides a visual pathway indicating the basic sequential process followed during this study.

Figure 29

Basic Sequential Process Followed during the Study



Note. Adapted from Halaweh et al., 2008.

Questions pertaining to the collected data needed to be considered during the entirety of the coding process. The questions and interpretations were generated as a result of the researcher’s knowledge obtained from the literature review as well as prior experience within the field of fire investigation (Vollstedt & Rezat, 2019, p. 87). Examples of general questions pertaining to the collected data along with their specific derivatives are shown in Figure 30.

Figure 30

General Questions Pertaining to the Collected Data

What? – What is occurring at the scene? What phenomenon is being described?

Who? – Who are the people involved? What are their roles?

How? – What aspects are dealt with? What aspects are excluded?

When? How long? Where? – When is the phenomenon used? Where is it used?

Why? – What is the justification for the use of the phenomenon?

Whereby? – What are the strategies employed? Can they be constrained or facilitated?

What for? – What are the anticipated consequences?

Note. Adapted from Halaweh et al., 2008; Vollstedt & Rezat, 2019.

There is also a voluminous amount of coding categories which can be identified, considered, and used by the researcher. Table 6 exhibits just a sampling of categories and along with specific examples which could be classified as derivatives from the general categories.

Table 6

Sample of Categories and Derivatives

Category	Examples
Basics	Causes, Context, Contingencies, Consequences, Conditions, and Qualifiers
Process	Stage, Phases, and Progression
Degree	Limit, Range, Extent, Intensity, Probability, Continuum, and Amount
Dimension	Elements, Divisions, and Properties
Participant Identity	Self-concept, Self-worth, and Self-evaluation
Means and Goals	Purpose, Conclusion, Goals, and Products
Theoretical	Integration, Clarity, Fit, Relevance, and Modification

Note. Adapted from Vollstedt & Rezat, 2019.

Ethical Considerations

Consideration has been taken regarding any potential ethical issues which could arise during the research. First and foremost, SME participant participation was strictly voluntary. The purpose, process, and benefits of the research was explained in detail to each individual participant prior to their interview. They were also advised that they could obtain a copy of the results upon completion of the study. Ethical dilemmas could potentially arise due to the insider with collaboration positionality as a result of my ongoing professional relationships with the participants (Fleming & Zegwaard, 2018, p. 209). Great care was taken during the research to ensure the confidentiality of participants and their responses. There also were no supervisor/subordinate relationships between the identified SMEs and the researcher. Authorization to conduct this research was obtained from the ATF legal counsel located at ATF Headquarters in Washington, D.C.

Researcher Positionality

Researcher positionality impacts how data are interpreted and subsequently makes sense of learning. Multiple years of experience with regard to working in the field, investigating fires for ATF as both a CFI and a member of the NRT, places the researcher of this study as an insider. Being that the individual researcher is considered to have a critical role in the interpretation of data in a qualitative study, the neutrality of the data collection and analysis processed needed to be ensured (Lawrence & Tar, 2013, p. 31). As such, techniques such as memoing and audio recording during data collection were utilized. Memoing assisted with researcher reflection upon the data collection and analysis during the current study. It further assisted with the empirical identification of thoughts, and provided an avenue to cross check the wording from the interviews, ensuring that the personal opinions and preferred investigative techniques of the researcher were not subconsciously inserted into the results. The audio-recorded interviews were sent to a neutral third party for transcription, which further assisted with the reduction of any potential self-imposition by the researcher.

The researcher remained mindful while reviewing the transcriptions completed by the third party so that successful mitigation of any researcher influence occurred. This ensured that the essence of information collected was factually the information presented within the study. The completed transcripts were then sent to each respective interviewee for an accuracy check. This process is remarkably similar in nature to how a fire investigator should approach a fire scene. NFPA 921 (National Fire Protection

Association, 2020) speaks of the necessity for investigators to avoid presumption, expectation bias, and confirmation bias (p. 21). Maintaining researcher neutrality is critical to success, particularly in an interpretive study.

Summary

Chapter 3 focused on and explained the manner in which the current study was accomplished. Background was provided regarding the selected methodology, mixed methods, as well as an explanation as to why the chosen methodology was preferred. The appropriateness of the research design was also discussed.

The population and sampling method employed within this study was identified and explained. The data collection process and interview protocols were examined and explained in detail, resulting in a comprehensive understanding of how the study was envisioned to progress. Researcher positionality and bias reduction techniques were identified, as well as the credibility and transferability of this study. An explanation of the process of informed consent among the participants was provided, as well as a description of the interview template creation and field testing thereof. The current study aimed to ensure consistency through the processes employed.

CHAPTER IV

RESULTS

The purpose of this study was to explore the potential that IoT data from building management systems provide to the realm of fire investigation. The primary focus of the current research was the use of IoT data to assist in narrowing down or determining the area(s) of fire origin within large structures. The purpose of the current study was to examine the use of IoT technology during the fire scene examination process and to understand how IoT data are subsequently employed by the investigators.

In Chapter 4, the researcher explored and documented the experience and opinions of the investigators who have used this particular method. A total of six SMEs were interviewed regarding their individual experiences of utilizing IoT data during fire scene examinations and their subsequent application of that data to the scene. This research improves the current procedures used in fire investigations when seeking to identify the area of origin during a fire scene examination. Key areas within Chapter 4 include the results of the SMEs interviews, emergent core categories, and identified themes. An explanation of the data analysis process used to glean the common themes is also provided. The chapter also includes summaries of specific examples from eight different cases in which this technique was utilized by investigators.

The results of the SME interviews and case examples provided information that was directly related to the research questions. The results of the interviews provided a holistic view of IoT data usage in fire investigation, as well as the strengths and weaknesses of this technique. Chapter 4 concludes with a list of investigative considerations that must be addressed regarding the use of IoT data in fire investigation.

Research Questions

In Chapter 1, a comparison of fire investigation as an art and as a science was opined. Art is defined as a trade or craft with "a system of principles and methods used in the performance of activities," involving "a specific skill in adept performance, held to require the exercise of intuitive faculties that cannot be learned solely by study" (Webster's, 1988, p. 127). As previously discussed, more seasoned fire investigators often train new fire investigators through mentoring. While mentoring is a n effective mechanism to pass on knowledge to trainees, it can also inadvertently create an apparatus through which bad habits, misinformation, and inaccurate practices are transferred between generations of investigators. This issue can become more prevalent if mentoring is not accompanied by a formal professional training program.

Science is defined as "the observation, identification, description, experimental investigation, and theoretical explanation of natural phenomena. A methodological activity, discipline, or study" (Webster's II, 1988, p. 1045). The critical components of this definition are the concepts of methodology, discipline, and study. A consistent, methodological process is required to ensure a study’s validity, reliability, and repeatability. This process ensures that every fire scene is approached similarly by the investigator. Each fire scene is different and, as such, presents its own unique challenges and issues. What can remain consistent across the various fire scenes is the investigator's adherence to a proper and consistent methodology through which to reach their conclusions. NFPA 921 (2020) refers to this as a systematic approach, defining it as a method that “provides an organizational and analytic process that is desirable and necessary in a successful fire investigation” (p. 20).

Science adapts and changes as new, more reliable methodologies progress to the forefront. Because scientific activity is ultimately conducted and controlled by humans, who are flawed, the findings may be prone to bias. This is not to infer that humans deliberately miscalculate or misinterpret data, although this can happen. The majority of errors that occur in scientific interpretation and application are unconscious and accidental. The primary focus of the current research is to improve the accuracy of an origin determination in the field of fire investigation by employing the use of IoT data. Many IoT systems contain an interconnected network of sensors and devices, which operate either autonomously or in response to human actions; therefore, they can capture traces of activity, which can be useful in a fire scene examination (Servida & Casey, 2019, p. 22). Data extracted from IoT systems can be used to link digital traces created by a sensor or device activation with physical activities which can then be used for reconstruction (Servida & Casey, 2019, p. 28). The below research questions were the driving force behind the data collection of the current research.

RQ1: Why is the utilization of IoT data an appropriate method in fire investigation?

RQ2: How do these systems operate?

RQ3: How can IoT data be utilized successfully to assist in determining the area of origin during a fire scene examination?

Review of Data Collection

Participants

The participants in this study included subject matter experts (SMEs) from ATF's Certified Fire Investigators (CFI), National Response Team (NRT) members, and engineering cadre from ATF's Fire Research Laboratory (FRL). The initial selection of participants for this study was purposeful and nonrandom. The participants were selected using the nonprobability method of stratified purposive sampling. This method was decided upon because the crux of this mixed-methods study was qualitative data in the form of subjective experiences. Purposive sampling allowed the researcher to select participants from a specific population with unique attributes (Pajo, 2018).

The current participants were selected based upon their response to an initial email sent to approximately 120 SMEs; the email inquired who had utilized IoT data to narrow down the area of origin in a large fire scene. Twenty SMEs were identified based on their self-reports that they had utilized IoT data to narrow down an area of origin; these participants were included in the study. The SMEs who reported that they had not utilized this technique were subsequently identified and excluded from the study.

The SMEs were further stratified into three distinct groupings. There were 12

CFIs, five Electrical Engineers (EEs), and three Fire Protection Engineers (FPEs), for a total of 10 specific case examples. Two SMEs from each stratum, for a total of six, were randomly selected to be interviewed. Ultimately, two of the cases could not be included within the study due to having not been fully adjudicated at the time of the research.

Relevant Experience

The researcher interviewed six SMEs with 102 years of cumulative fire investigation experience. The mean amount of experience amongst the SMEs was approximately 17 years. The combined fire scenes investigated by these SMEs totaled in excess of 3,500, with more than 230 of those incidents requiring the activation of the NRT. The cumulative educational background of the SMEs consisted of six undergraduate degrees and four graduate degrees. These data are broken down by participant in Table 7 below.

Table 7

Demographic Data of SMEs

Participant	Experience	Fire Scenes	NRT Callouts	Education
P01	15 years	700	40	BS-Mechanical Engineering; MS-Fire Protection Engineering
P02	13 years	300	15	BS-Fire Protection Engineering
P03	18 years	400	38	BA-Business Administration; MS-Forensic Science

Participant	Experience	Fire Scenes	NRT Callouts	Education
P04	20 years	215	40	BS-Electrical Engineering; MS – Fire Protection Engineering
P05	6 years	150	28	BS-Computer and Electrical Engineering
P06	30 years	1800	70	BS-Biology; Juris Doctor

Data Analysis Procedures

Collection of the Data

The data for the current research were collected from multiple sources. These sources included technical manuals, scholarly articles, prior research experimentation, structured interviews with participants, Origin and Cause reports, and researcher memos. The goal of data collection was to provide insight into the particular process was used and subsequently applied to the fire scene at hand. Official documentation regarding the utilization of IoT data during the fire scene examinations provided exact details across various situations. Table 8 (adapted from Yin, 2003) outlines the sources of information utilized during this study, as well as the strengths of each type of source.

Table 8

Data Sources and Strengths

Sources of Information	Strengths
Literature (to include texts, technical manuals, and scholarly articles)	Foundational development Identification of issues
Interviews of SMEs	Specifically focused on the topic Insightful Stability – templates, audio recorded, and Transcribed

Sources of Information	Strengths
Documentation (to include Origin and Cause reports and engineering reports)	Stability – can be continuously referenced Precision – names, details, and processes Covers various situations Unbiased - created prior to and separate from this research
Memos	Documentation of the entire research process; Investigator self-reflection

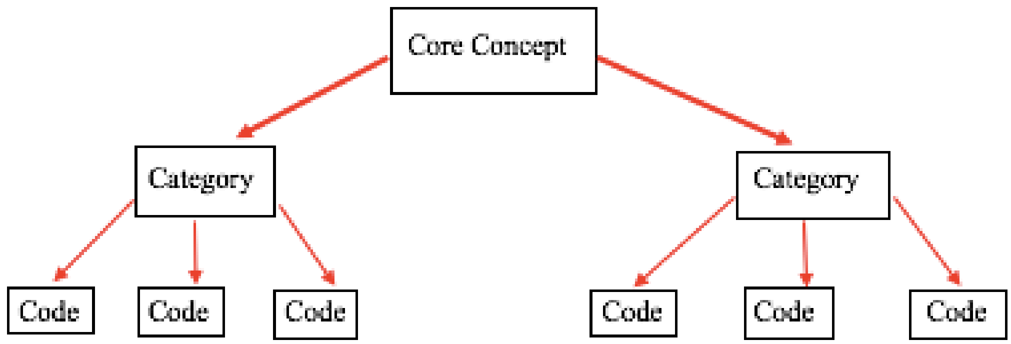
After the sample of six SMEs was identified, they were contacted via email with a brief synopsis as to the purpose of the study as well as an invitation to participate. Subsequently, informed consent forms were emailed to each participant and returned to the researcher in the same manner. Following the return of the signed informed consent forms, an audio-recorded telephonic interview of each SME was scheduled and conducted. The SME interviews involved background and demographic inquiries, as well as several open-ended questions to elicit their thoughts, direct experiences, and opinions (Creswell & Creswell, 2018). The interview templates used by the researcher are located in Appendices B and C. The manner in which the SMEs performed the data extraction, analysis, and subsequent application to the fire scene at hand was critical to this research. The documents obtained for each case-specific example were reviewed to gain a thorough understanding regarding each case in which IoT data were utilized to narrow down an area of origin. Following the completion of each interview, the recordings were provided to a neutral third party for transcription. Each SME was then asked to review the resulting transcription for accuracy. The SME interview process began on May 5, 2021 with the distribution of consent forms via email and interview scheduling. The process concluded on June 14, 2021 upon the return of the final reviewed transcript.

Dividing the Interview Data into Parts

Following the successful completion of all SME interviews, the researcher began the process of analyzing the textual data. Open coding was first used to identify and develop theoretical categories and concepts from the data (Lawrence & Tar, 2013). This is a common first step during the analysis of qualitative data. The textual data of the interview transcriptions were reviewed line by line and broken into parts. The results of the open coding process allowed for the separated verbiage to be continually compared and contrasted to further explore and enhance its meaning (Almarzooqi et al., 2016; Thai et al., 2012; Vollstedt & Rezat, 2019). Next, the data that had been fractured and separated during open coding were rebuilt to identify and develop relationships between the core concepts, categories, and subcategories (Almarzooqi et al., 2016; Lawrence & Tar, 2013; Vollstedt & Rezat, 2019). This process was approached in a purely neutral manner and undertaken with no specific attitude towards the SMEs or the underlying data. This process allowed for specific themes to emerge from the participants' point of view. Figure 31 depicts the overall relationships between the divided, separated, and rebuilt data.

Figure 31

Relationships Between the Divided, Separated, and Rebuilt Data



Synthesis of the Data

During this stage, the researcher began the process of drawing connections between the parsed data. As a result, the researcher determined how the identified codes could be grouped into various categories. “Relationships among the subcategories and categories are linked by identifying the (1) casual condition, (2) phenomenon or concept, (3) context, (4) intervening conditions, (5) action/interaction strategies, and (6) consequences” (Almarzooqi et al., 2016, p. 91). Examples of the initial results of the textual data analysis are depicted in Table 9 and Figures 32, 33, and 34 (adapted from Almarzooqi, et. al., 2016). In Figures 32 and 33, the various colors are used to depict different core concepts that the phenomena fall underneath, some of which can also overlap. Figure 34 exhibits a further breakdown of one of the core concepts.

Table 9

Initial Results of Textual Data Analysis

Casual Condition	Phenomena	Context	Intervening Conditions	Strategies	Consequences
Fire Incident	Investigation	IoT data	Information inaccessible/no IoT systems present	Scientific Method	Location of IoT data/IoT data analyzed & applied/narrowed area of origin

Figure 32

Actions Described by Subject Matter Experts

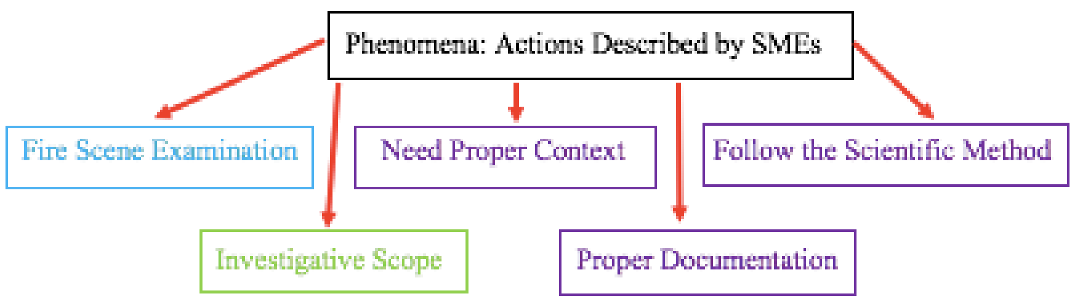


Figure 33

Core Concepts for Consideration

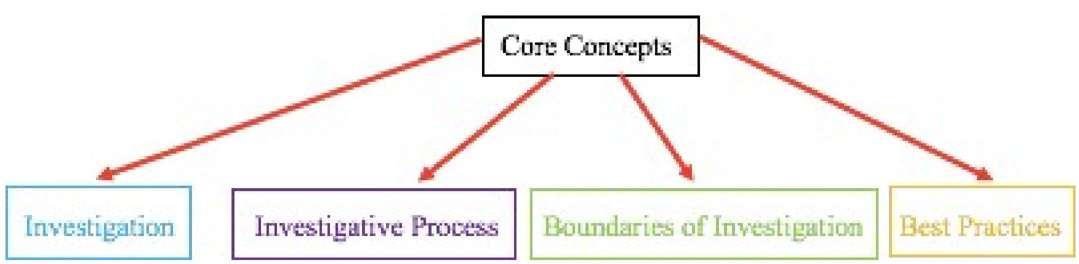
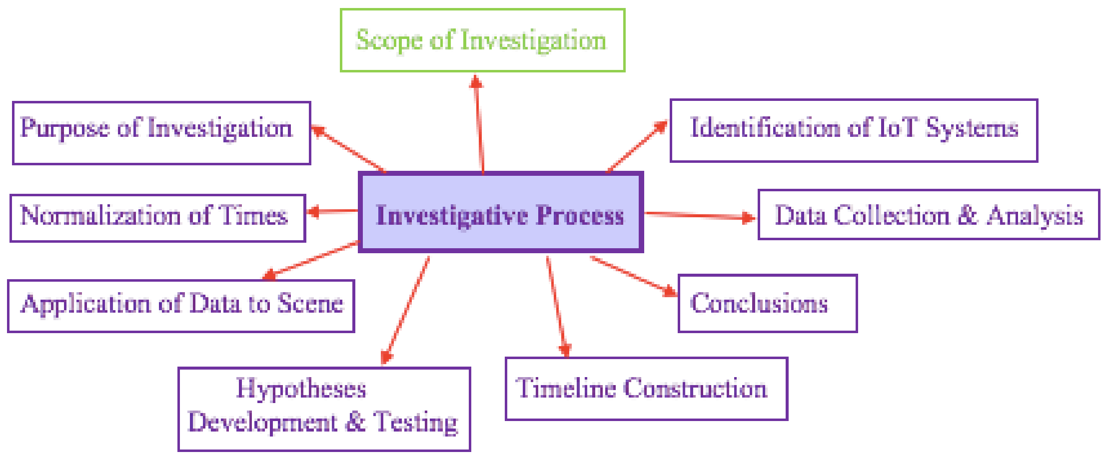


Figure 34

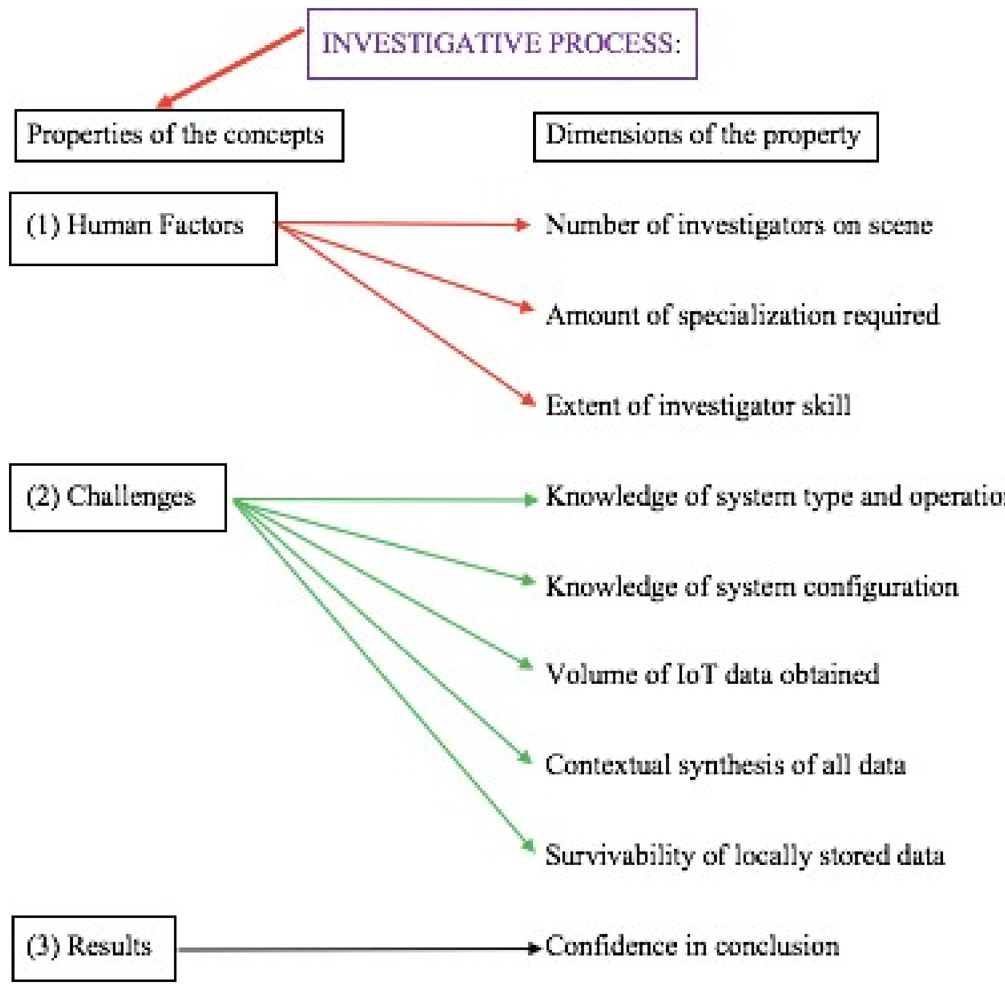
The Investigative Process



Towards the end of the textual analysis process, categories were related to each other and themes were developed. Figure 35 (adapted from Almarzooqi et. al., 2016) depicts an example of specific traits that could be identified within a particular concept. The identified traits could subsequently be further divided into measurable concepts involving the scope and/or magnitude.

Figure 35

Properties of Investigative Concepts and Their Dimensions

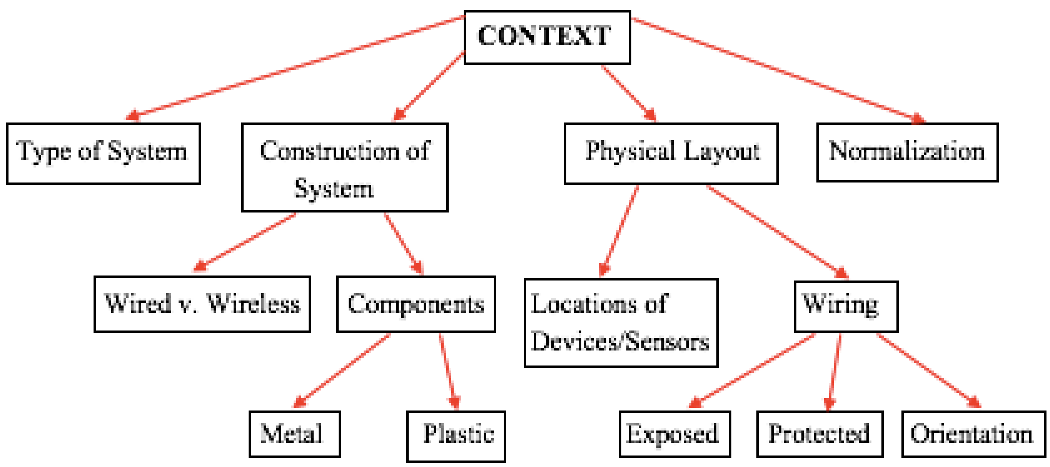


Emerging Themes

While reviewing and coding the transcripts and then synthesizing the data, the broad core concept of "context" was central to every SME interview. The exploration of what specifically constituted "context" within the confines of this study occurred next. Ultimately, "context" means that the investigator must fully understand and assess the circumstances related to an event or situation in order for clear, concise, and accurate meaning to be drawn. The related categories discussed by the SMEs during their interviews were extracted and subsequently combined to provide meaning concerning IoT systems and data in fire investigation and can be observed in Figure 36.

Figure 36

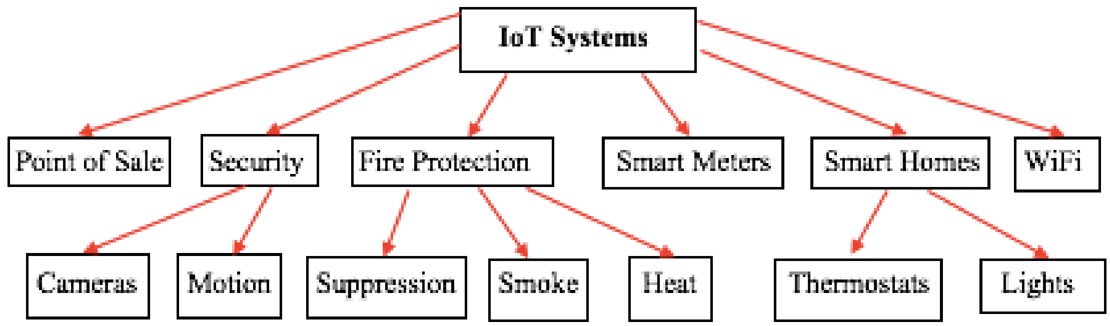
Contextual Considerations of IoT Systems



Next, the researcher focused upon the concept of IoT system types as described by the SMEs during their interviews. A vast array of systems was observed while gleaning the data from the transcribed recordings. Many of these systems could either be interrelated or further broken down, as observed in Figure 37. It stands to reason that the below is not an exhaustive list; it merely represents the systems mentioned by SMEs during their interviews.

Figure 37

IoT Systems Mentioned by Participants



During the SME interviews, specificity was provided as to what specific types of data could be retrieved from IoT systems. As each type of data was received by the SMEs, it was then considered within the context of the type of IoT system(s) in operation from the structure, or neighboring structures. The data were analyzed and then applied to the fire scene to gain meaning. Figures 38, 39, and 40 depict the coded diagrams of this process as explained by the SMEs.

Figure 38

Information Received from IoT Systems

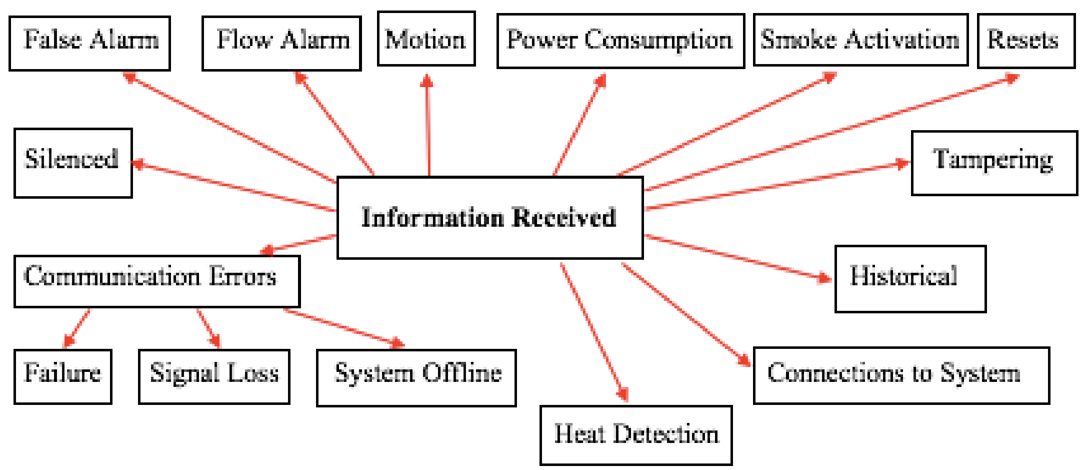


Figure 39

Processing of the IoT Data Received

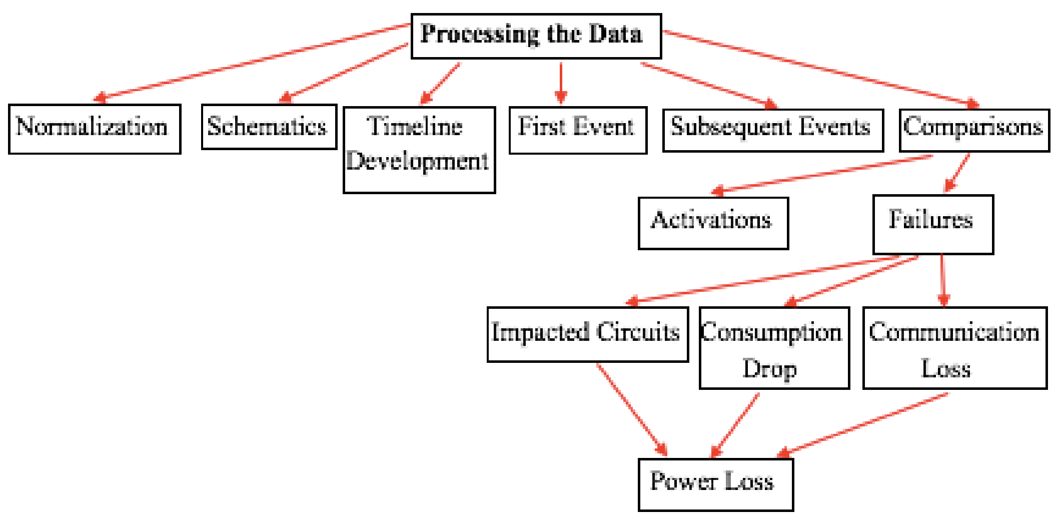
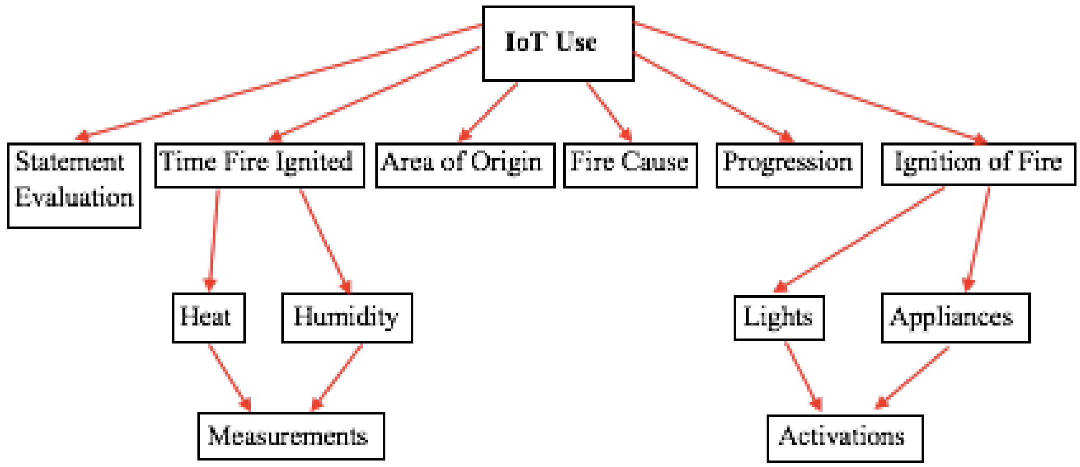


Figure 40

The Investigative Use of IoT Data



During each SME interview, a discussion occurred regarding the apparent strengths and weaknesses of using IoT data to assist the fire investigator in their determination of an area of fire origin. The researcher asked each SME to provide their personal opinions based upon their individual knowledge, training, and direct experience about the usage of IoT data during fire scene examination. While there were commonalities between the SME opinions in these two areas, each SME also provided their unique thoughts relative to the process and its merits. Figures 41 and 42 depict the identified themes for each particular concept.

Figure 41

Investigative Strengths of IoT Data

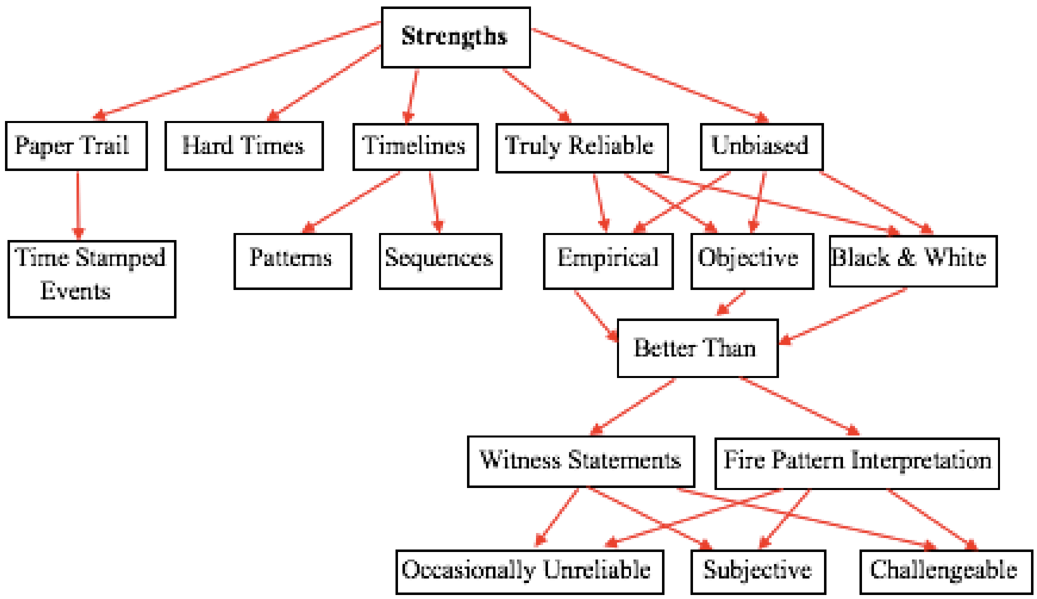
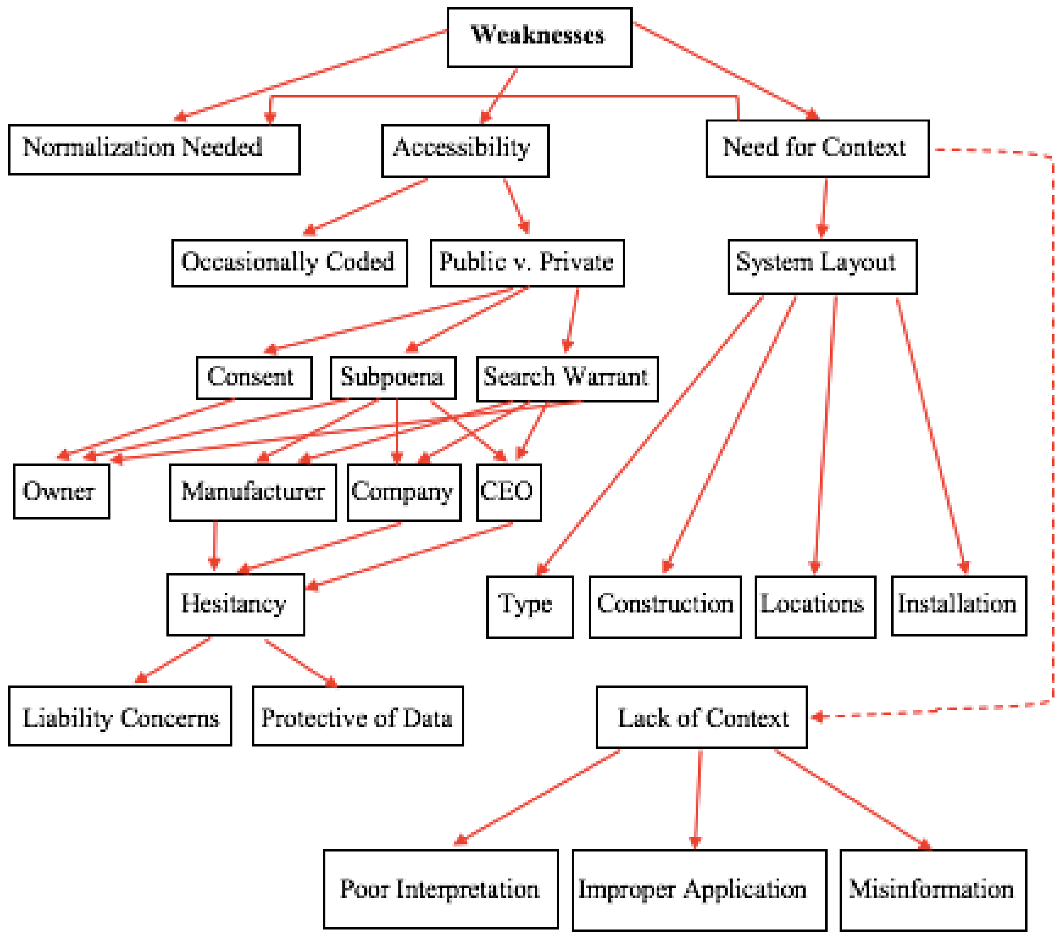


Figure 42

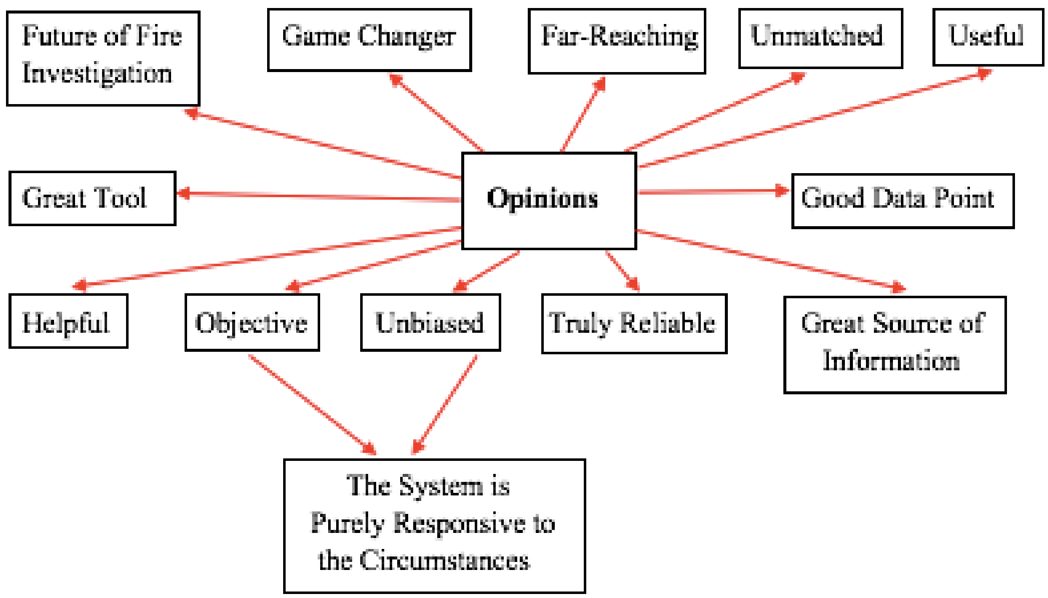
Investigative Weaknesses of IoT Data



Finally, the researcher conducted a close examination of the descriptive opinions employed by the SMEs about the use of IoT data. Each SME consciously provided their opinions as to the strengths and weaknesses of IoT data. Throughout each interview, however, SMEs provided multiple adjectives and brief remarks about IoT data and its usage during a fire scene examination. These descriptions are included in Figure 43.

Figure 43

Subject Matter Expert Opinions Regarding IoT Data Usage



Specific Case Examples of IoT Data Usage in Practice

The below-listed cases provide examples of IoT data being analyzed and then applied to each respective fire scene. It must be noted that the IoT data are just a portion of the information obtained during the fire scene examinations. In following NFPA 921 Section 18.1.2, investigators coordinated and considered information about witness information, electronic data, fire patterns, and fire dynamics (NFPA 921, 2020, p. 220). A time normalization process was utilized to ensure that the sequential nature of the data was accurate. The time.gov website was often utilized. IoT data analysis was incorporated to assist in the determination of areas of origin. The IoT data also served as empirical, factual data points which supported the investigative conclusion as to the area of origin.

Wine Central, 710 L Street, Building 627, Mare Island, Vallejo, California

Date of Fire: October 12, 2005

IoT Building System(s) Utilized: Smoke Alarm and Environmental Control Systems

At approximately 3:38 PM on October 12, 2005, a fire was reported at a wine storage warehouse. The structure stored wines and vintage wine collections for approximately 100 different vineyards worldwide. The total loss as a result of this incident was originally estimated at $250,000,000 and later upgraded to $450,000,000. The floor area of the building measured approximately 240,000 square feet. The structure consisted of a ground floor and a mezzanine. Figure 44 (ATF Case, 2005, file photo) provides an exterior perspective of the affected structure.

Figure 44

Exterior Photograph of Fire Scene

Figure 45 (ATF Case, 2005, file photo) depicts an interior photograph of the structure following the fire.

Figure 45

Interior Photograph of Fire Scene

During the scene examination, investigators analyzed the fire alarm system, which consisted of beam detectors and smoke detectors. They also examined data extracted from monitored temperature sensors connected to the environmental control system. As a result, investigators were able to develop a timeline of events regarding the incident. Figure 46 (ATF Laboratory Report, 2009, p. 2) depicts the timeline established concerning beam smoke alarm activations; the first three detectors to activate are outlined in red. Figure 47 (Lord IAAI ATC 2019 PowerPoint, Slide 193) displays a diagram of the structure exhibiting the locations of the smoke alarm activations. It was observed that the first three detectors to activate were 5, 6, and 8. It was later learned that detector 7 was disconnected. These detectors are delineated within the black box.

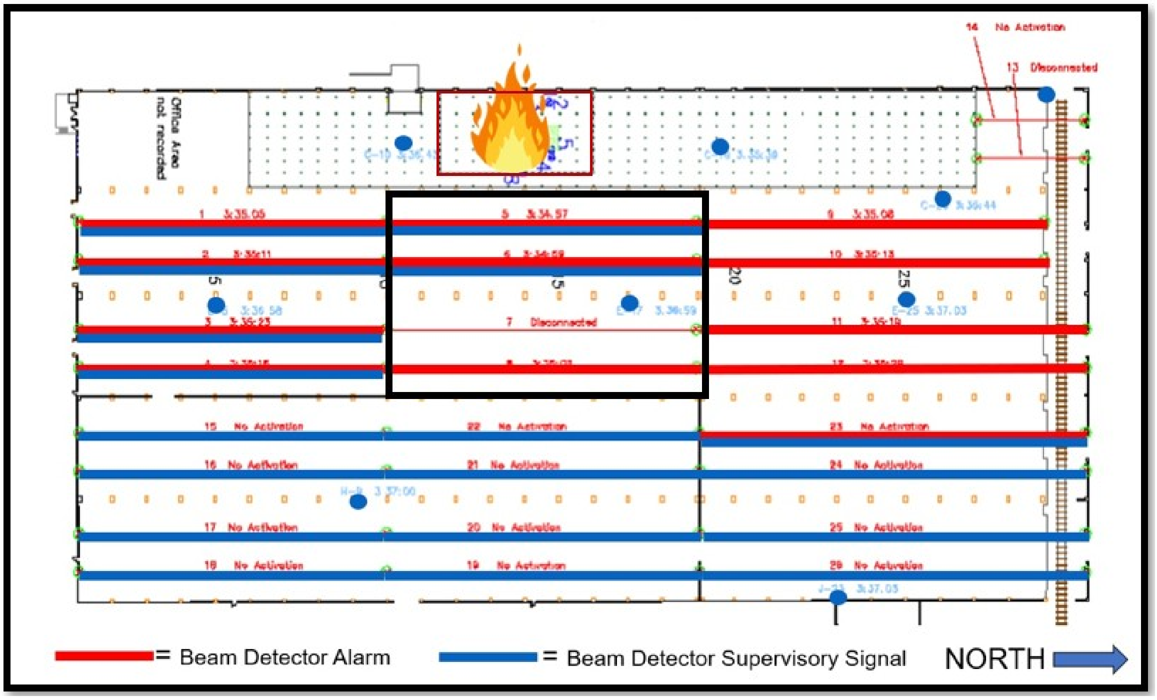
Figure 46

Timeline of Smoke Alarm Activations

Activation Time [hr:min:sec, PM]	Time from First Activation [min:sec]	Location
3:34:57	0:00	Beam Smoke Detector # 5
3:34:59	0:02	Beam Smoke Detector # 6
3:35:02	0:05	Beam Smoke Detector # 8
3:35:05	0:08	Beam Smoke Detector # 1
3:35:08	0:11	Beam Smoke Detector # 9
3:35:11	0:14	Beam Smoke Detector # 2
3:35:13	0:16	Beam Smoke Detector # 10
3:35:16	0:19	Beam Smoke Detector # 4
3:35:19	0:22	Beam Smoke Detector # 11
3:35:23	0:26	Beam Smoke Detector # 3
3:35:29	0:32	Beam Smoke Detector # 12
3:36:49	1:52	Beam Smoke Detector #23

Figure 47

Locations of Smoke Alarm Activations



Supported by the IoT system data analysis, investigators were able to determine the area of origin of this incident to be atop the first level of the mezzanine within section B14-15 (depicted by the red box and flames in Figure 47).

2608 Independence Avenue, Kansas City, Missouri

Date of Fire: October 12, 2015

IoT Building System(s) Utilized: Advanced Metering System or "Smart Meters"

The fire was reported at 7:27 PM on October 12, 2015. The structure was three stories in height and contained four commercial occupancies on the first floor and 16 apartment units above the commercial occupancies. An adjacent business was also affected. The fire resulted in two Kansas City Fire Department firefighter fatalities and two additional firefighter injuries. The fire caused approximately $2,000,000 in damage. The overall property was listed as .76 acres. The affected structure measured approximately 16,500 square feet. Figure 48 (ATF Case, 2015, file photo) depicts the scene following the fire incident (outlined in yellow) and Figure 49 (ATF Case, 2015, file photo) depicts the structure before the fire.

Figure 48

Scene Following Incident

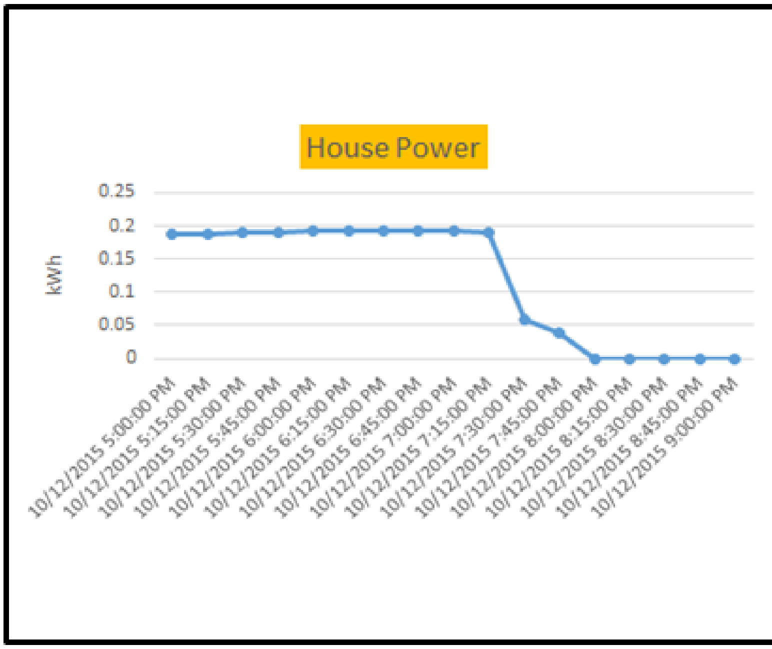
Figure 49

Scene Preceding Incident

During the fire scene examination, investigators analyzed IoT data that were recovered from a bank of smart meters. These data pertained to electrical energy consumption by the units within the structure (except for Apartments #2, #3, and #A). The meters measured and recorded this data in 15-minute increments and subsequently transmitted the information every 4 hours. These data were analyzed and compared with daily usage data for approximately 2 weeks before the incident. This enabled a typical pattern of activity to be established. A timeline was later developed concerning electrical power usage on the day of the fire. Figure 50 (ATF Report, 2015, p. 36) depicts the house power usage on October 12, 2015. Figure 51 (ATF Report, 2015, p. 37) depicts the power usage for LN Nails and Spa on October 12, 2015.

Figure 50

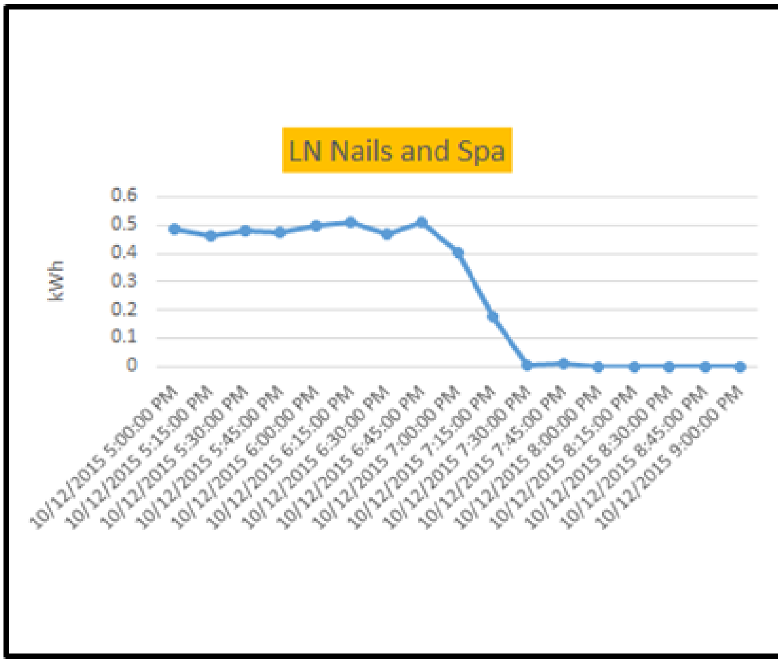
House Power Usage on October 12, 2015



House Power	
Time	kWh
10/12/2015 5:00:00	0.189
10/12/2015 5:15:00	0.1878
10/12/2015 5:30:00	0.1896
10/12/2015 5:45:00	0.1908
10/12/2015 6:00:00	0.192
10/12/2015 6:15:00	0.192
10/12/2015 6:30:00	0.1926
10/12/2015 6:45:00	0.192
10/12/2015 7:00:00	0.192
10/12/2015 7:15:00	0.1914
10/12/2015 7:30:00	0.0588
10/12/2015 7:45:00	0.0396
10/12/2015 8:00:00	0
10/12/2015 8:15:00	0
10/12/2015 8:30:00	0
10/12/2015 8:45:00	0
10/12/2015 9:00:00	0

Figure 51

LN Nails and Spa Power Usage on October 12, 2015



LN Nails and Spa	
Time	kWh
10/12/2015 5:00:00	0.4854
10/12/2015 5:15:00	0.4644
10/12/2015 5:30:00	0.4806
10/12/2015 5:45:00	0.474
10/12/2015 6:00:00	0.498
10/12/2015 6:15:00	0.5118
10/12/2015 6:30:00	0.4704
10/12/2015 6:45:00	0.513
10/12/2015 7:00:00	0.4056
10/12/2015 7:15:00	0.1782
10/12/2015 7:30:00	0.003
10/12/2015 7:45:00	0.0078
10/12/2015 8:00:00	0
10/12/2015 8:15:00	0
10/12/2015 8:30:00	0
10/12/2015 8:45:00	0
10/12/2015 9:00:00	0

The data provided by the meters were determined by investigators to be consistent with:

- The fire impinging the house power branch circuits and causing them to decrease consuming energy before 7:17 PM and
- The fire impinging the apartments B, C, D, E, F, G, H, I, J, K, L, and M branch circuits and decreasing energy consumption to 0 kWh by 7:17 PM.

By comparing the electrical activity observed upon the electrical conductors with the timelines created, showing when each available unit's meter began dropping to 0 kWh of usage, investigators were able to determine the area of origin was located within the northeast corner of the storage room inside the first-floor business of LN Salon and Spa, located at 2614 Independence Avenue, Kansas City, Missouri. Figure 52 (ATF Case, 2015, file photo) depicts the overall footprint of the structure postexcavation. LN Salon and Spa is outlined in red. Figure 53 (ATF Case, 2015, file photo) shows the identified area of origin.

Figure 52

Postexcavation Footprint of Structure

Figure 53

Identified Area of Origin

Brian Toliver Ford, 1040 Gilmer Street, Sulphur Springs, Texas

Date of Fire: January 15, 2016

IoT Building System(s) Utilized: Wi-Fi System Failures

At approximately 3:36 AM on January 15, 2016, a fire was reported at a single-story auto dealership. The fire caused approximately $4,000,000 in damage. The structure measured approximately 25,000 square feet. The fire scene examination lasted 6 days. An overall exterior photograph of the fire scene is included in Figure 54 (ATF Case file, 2016).

Figure 54

Exterior Photograph of Fire Scene

Investigators examined the Wi-Fi system within the structure and were able to develop a timeline depicting the failure of the various system antennas. Figure 55 (ATF Report, 2016, p. 11) depicts the timeline analysis of these antenna failures.

Figure 55

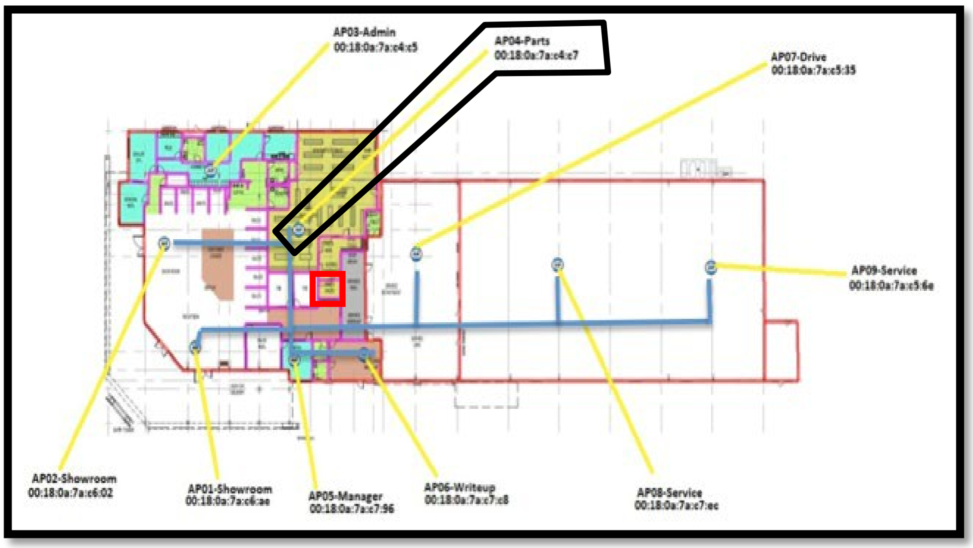
Timeline Analysis of Antenna Failures

Time	Message	Addresses
03:31	1 access point has become unreachable	00:18:0a:7a:a7:a7
03:34	The switches have become unreachable	88:15:44:1d:7e:15
		88:15:44:1d:9c:b9
		88:15:44:77:42:8f
03:34	The security appliance had become unreachable	88:15:44:69:53:10
03:34	15 access points have become unreachable	00:18:0a:23:e9:64
		00:18:0a:23:e9:de
		00:18:0a:23:ed:c4
		00:18:0a:23:ef:96
		00:18:0a:23:ef:b8
		00:18:0a:7a:95:71
		00:18:0a:7a:a1:4d
		00:18:0a:7a:a1:95
		00:18:0a:7a:a5:d8
		00:18:0a:7a:a5:de
		00:18:0a:7a:a7:91
		00:18:0a:7a:a7:a2
		00:18:0a:7a:a7:d7
		00:18:0a:7a:a7:d9
		00:18:0a:7a:a7:fa

Figure 56 (ATF Report, 2016, p. 10) is a schematic of the structure depicting the locations of the various Wi-Fi access points contained within the building. The first access point to become unreachable is outlined in black. The identified area of origin is outlined in red.

Figure 56

Locations of Wi-Fi Access Points



An analysis of the IoT data involving the Wi-Fi access points and when they became unreachable was conducted. This analysis was subsequently applied to the fire scene and scrutinized within the context of all available data. As a result, investigators were able to determine that the area of origin for this fire was located within the break room. Figure 57 (ATF Case file, 2016) consists of a close-up diagram of the area of origin along with adjacent surroundings within the structure. The red X's indicate the location of artifacts upon the electrical conductors. The green O indicates the first access point to become unreachable. The area of origin is outlined in red.

Figure 57

Area of Origin Diagram

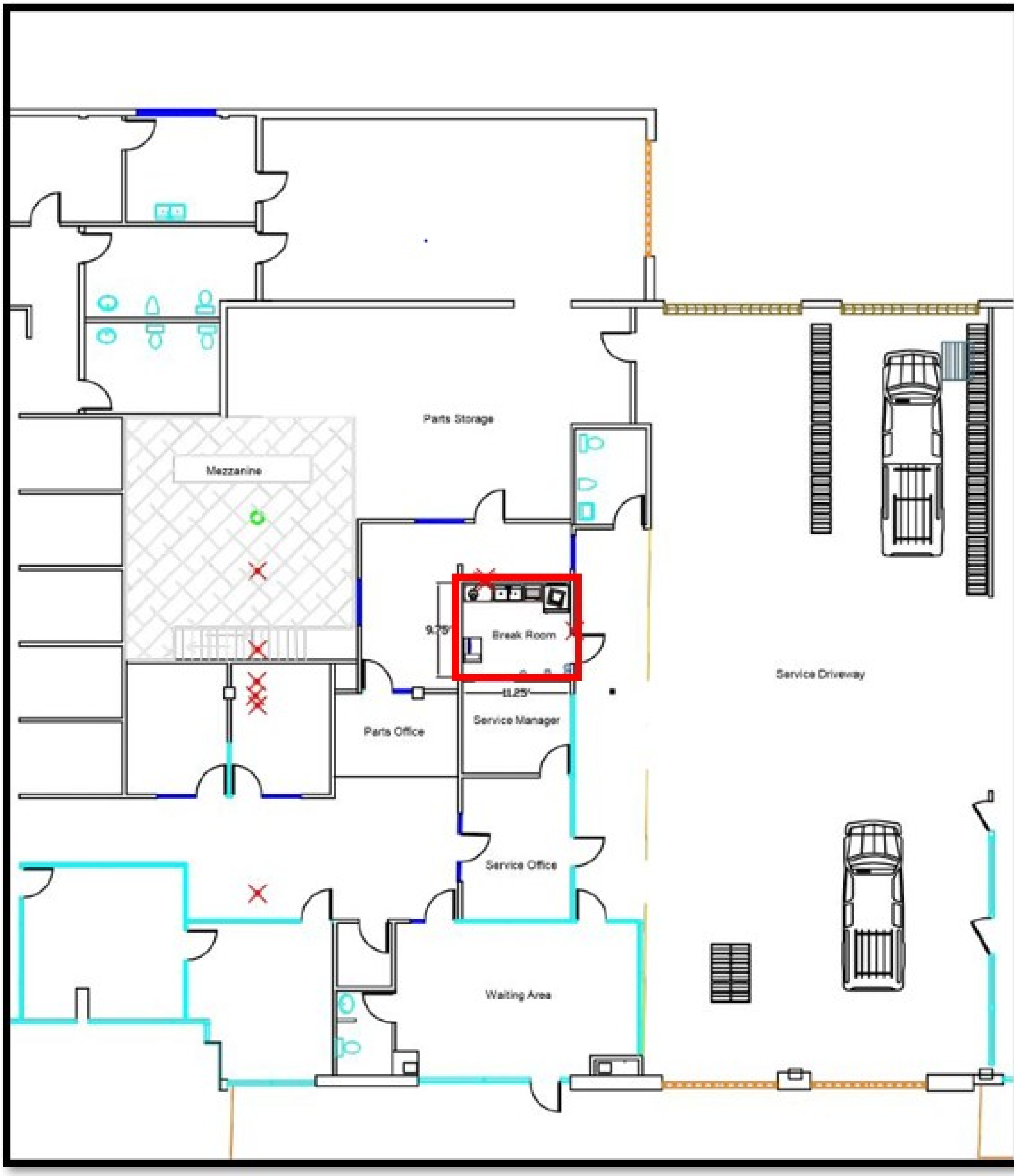


Figure 58 (ATF Case file, 2016) shows the identified area of origin located within the employee breakroom outlined in red.

Figure 58

Area of Origin Outline

Veterans Industrial Park, Hillsboro, New Jersey

Date of Fire: February 11, 2016

IoT Building System(s) Utilized: Fire Alarm and Fire Sprinkler System

At 2:54 PM on February 11, 2016, the fire department responded to a structure fire/water flow alarm labeled as “C/D West” at Veteran’s Industrial Park. Upon arrival, they observed fire through the roof of Building 14, Unit C. It required the responses of 90 fire companies and took two days to completely extinguish the fire. The fire resulted in the complete destruction of one building and the partial destruction of a second building. The total structural loss was approximately 360,000 square feet, and the financial losses were estimated at approximately $50,000,000. Figure 59 (ATF Report,2016, p. 20) shows a portion of the postfire damage to the involved structure.

Figure 59

Postfire Damage

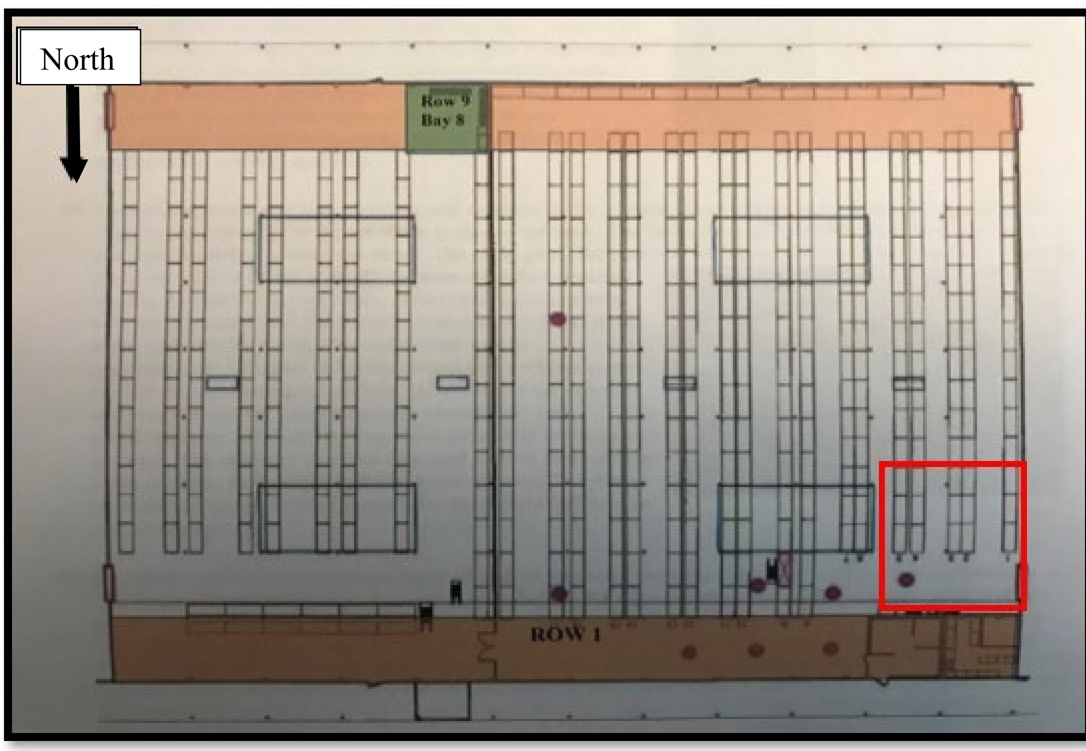
A review of extracted data concerning the fire alarm and fire sprinkler system was critical in supporting the witness statements provided by responding agencies and employees. The following conclusions were made:

- The sprinkler on the west side of Unit C was activated first.
- Within 1 minute of the water flow alarm, a failure was noted on a telephone line that was located 20 feet from the north wall of the unit.
- The east sprinkler activated within 2 minutes of the west sprinkler.
- A sprinkler alarm wire, located 24 feet from the north wall, failed 1 minute later.

The area of origin was determined to be within a high rack storage area in Building 14 in the west side of Unit C. Figure 60 (ATF Report, 2016, p. 22) is the ATF scene diagram of Unit C, with the approximate area of origin outlined in red.

Figure 60

ATF Scene Diagram of Unit C



Bogey Hills Country Club, St. Charles, Missouri

Date of Fire: February 16, 2017

IoT Building System(s) Utilized: Burglar Alarm, Fire Alarm, and Smoke Detectors

The fire was reported on February 16, 2017 at approximately 11:49 PM. Flames were initially reported at the rear of the building. The total damage was estimated to be $7,000,000. The fire resulted in one firefighter injury. The structure was two stories in height and consisted of approximately 38,000 square feet. Figure 61 (ATF Report, 2017, p. 27) depicts a side view of the postfire damage exhibited by the affected building, with the area of origin outlined in red.

Figure 61

Side View of Postfire Damage

Data were collected from the burglar alarm system as well as the activation sequence of the smoke detector and fire alarm systems to narrow down the area of origin. A diagram of the scene depicting system activations was subsequently produced by investigators and is included in Figure 62, with the area of origin outlined in red (ATF Report 2017, p. 13). Furthermore, a timeline of events established by investigators is listed in Figure 63 (ATF Report, 2017, p. 12). Figures 62 and 63 can be reviewed simultaneously, as the system activations are labeled on both.

Figure 62

Diagram of System Activations

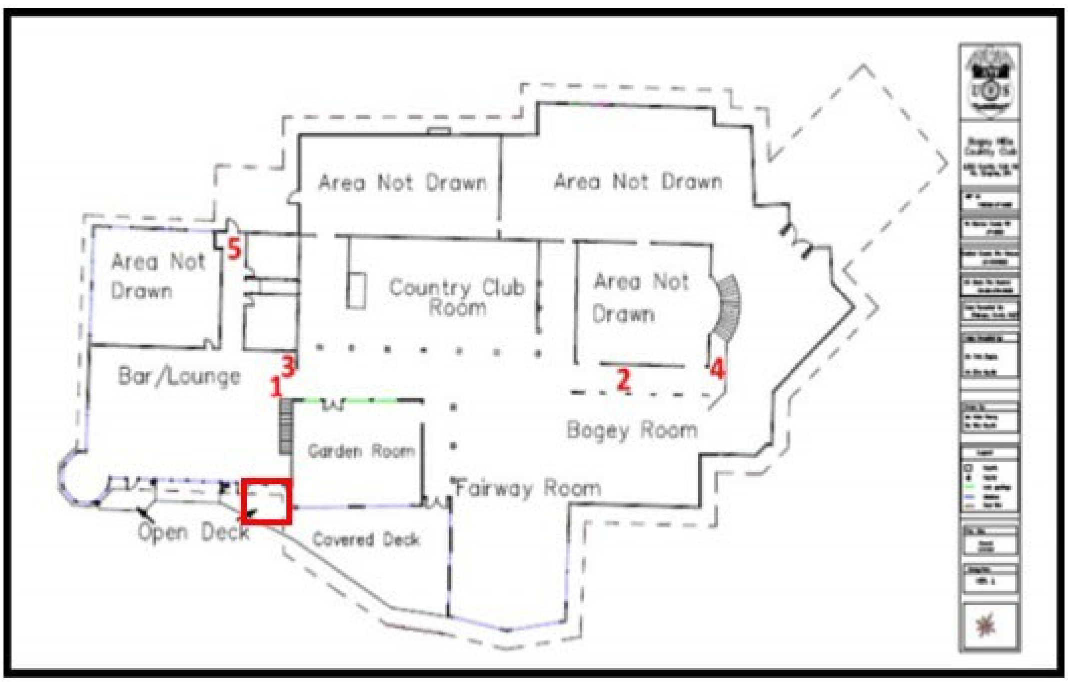


Figure 63

Investigator Timeline of Events

Time	Event	Data Source	Date	Diagram Key
23:00:47[1]	Security System Armed by "No Dust" Cleaning	Erker Monitoring	02/16/2017	
23:49:20	1st 911 Call from Earl Smith (Flames from Back of Building)	St. Charles County Dispatch	02/16/2017	
23:50:48[1]	Fire Alarm: Main Lounge Smoke Detector (top of stairs near bar)	Erker Monitoring	02/16/2017	1
23:50:51[1]	Fire Alarm: Lobby Hallway Smoke Detector	Erker Monitoring	02/16/2017	2
23:52:XX	Video by 911 Caller Immediately After Disconnecting the Call (Facing East) 	Earl Smith's Phone	02/16/2017	
23:55:34	1st Engine Company Arrives on Scene	St. Charles County Dispatch	02/16/2017	
23:55:42[1]	Burglar Alarm: Bar/Lounge Motion Detector (top of stairs near bar)	Erker Monitoring	02/16/2017	3
23:58:18[1]	Fire Alarm: Second Floor Office Smoke Detector (Top of stairs in Lobby)	Erker Monitoring	02/16/2017	4
23:58:22[1]	Burglar Alarm: Northwest Bar Door/Lounge (Fire Department Entry Shortly After)	Erker Monitoring	02/16/2017	5
23:59:XX	2nd Video from 911 Caller (Facing East) 	Earl Smith's Phone	02/16/2017	
0:00:13[1]	Fire Alarm: Lower Level Liquor Smoke Detector	Erker Monitoring	02/17/2017	
0:01:45[1]	Fire Alarm: Second Floor Hall	Erker	02/17/2017	

Time	Event	Data Source	Date	Diagram Key
	Smoke Detector	Monitoring		
0:05:00[1]	Fire Alarm: Pro Shop Storage Smoke Detector	Erker Monitoring	02/17/2017	
0:06:28	Fire Department Interior Evacuation	St. Charles County Dispatch	02/17/2017	
0:06:33[1]	Fire Alarm: Lower Level Lounge Smoke Detector	Erker Monitoring	02/17/2017	
0:10:05[1]	Fire Alarm: Electric Utility Smoke Detector	Erker Monitoring	02/17/2017	

The area of origin was identified as the exterior rear deck in the vicinity of the northeast corner. The exterior lounge and Garden Room walls intersected at this location. This area is indicated by the red box in Figure 61 (ATF Report 2017, p. 13).

Underwood Fruit and Warehouse Company, 6550 West Steuben Street, Washington

Date of Fire: October 18, 2017

IoT Building System(s) Utilized: Burglar Alarm, Failure of Interior Video Security System

This fire was reported on October 18, 2017 at 5:36 AM. The incident resulted in the complete destruction of the 104,000 square foot building, totaling an estimated loss of $50,000,000. Figure 64 (ATF Case, 2017, file photo) depicts one of the four affected sections of the structure following the fire incident.

Figure 64

Affected Sections of Structure

The company provided investigators with sketches depicting the video camera locations, as well as the electric circuitry and ethernet contained within the structure. Investigators were able to utilize signal loss notifications for each interior security camera (Figures 65 and 66; ATF Report, 2017, pp. 35-36) and burglar alarm activations to develop a timeline of events (Figure 67; ATF Report, 2017, pp. 34-35).

Figure 65

Scene Relevant IoT and Witness Data

Event	Time	Description
1	5:29:43 AM	Email sent to Jamie Alenbach (UPS Event Message)-Utility Power Failed
2	5:31:05 AM	Surveillance System: Video Signal Lost-SmallPearLine(D2)
3	5:31:31 AM	Surveillance System: Video Signal Lost-ShippingDock1(D4), BackDock1(D5), PearMezzanine(D6), FieldmanOffice(D8), AdminCounter(D9)
4	5:31:32 AM	Surveillance System: Video Signal Lost-BigPearLine(D1), ShippingDock2(D3)
5	5:31:52 AM	Surveillance System: Video Signal Lost-PearRepack(D7), PearSeg(D20), MainStBehindPear(D21), PearSortLines(D24), AgritechCam(D25), PearBinDump(D28)
6	5:32:38 AM	Arcing event visible on lumbar yard video

Figure 66

Schematic Overlay of IoT and Witness Data

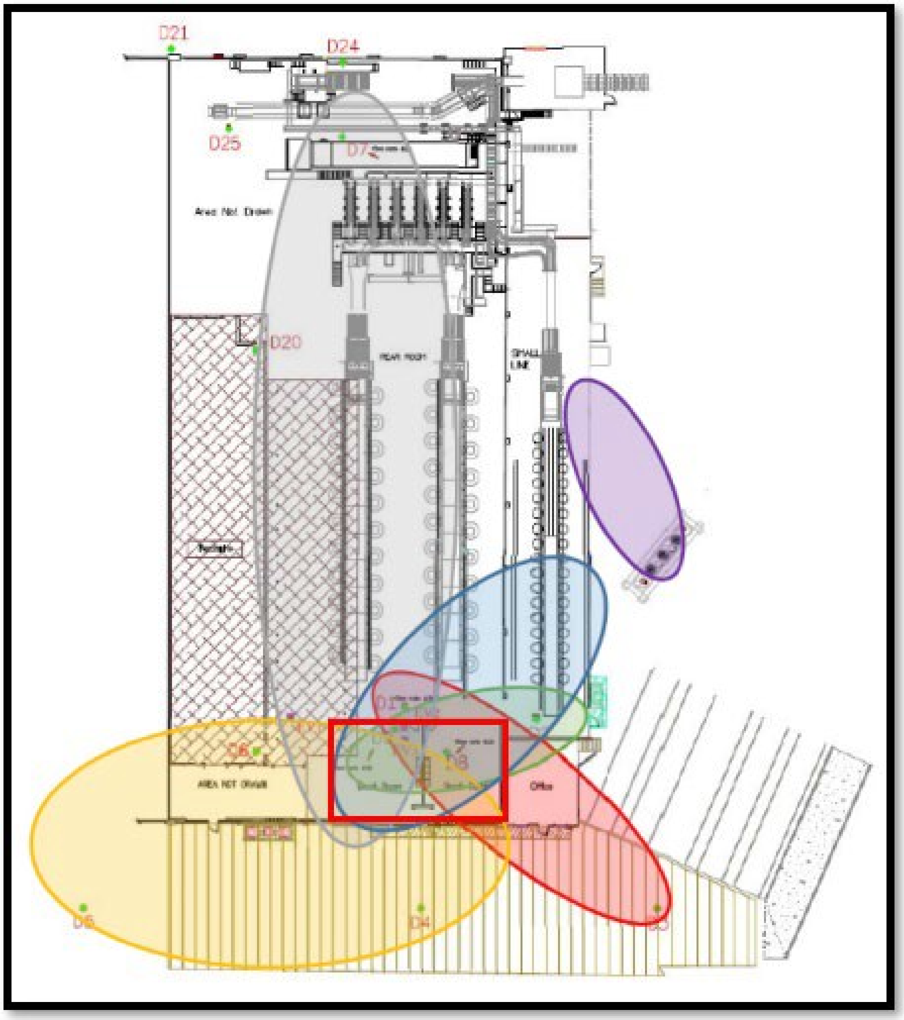


Figure 67

Incident Timeline

Time	Event
2:02:25 AM	Trucker logs into sleeping berth
2:27:00 AM	Security guard departs facility
3:30:00 AM	Cleaning crew departs facility
5:11:00 AM	Phil Morgan observes smoke from tug boat east of facility
5:28:41 AM	Utility Power Failure-transfer to backup (MDF)
5:29:43 AM	Email notification (UPS Event Message)-Utility Power Failed
5:31:05 AM	Surveillance System: Video Signal Lost-SmallPearLine(D2)
5:31:14 AM	Fire visible from lumber yard video
5:31:31 AM	Surveillance System: Video Signal Lost-ShippingDock1(D4), BackDock1(D5), PearMezzanine(D6), FieldmanOffice(D8), AdminCounter(D9)
5:31:32 AM	Surveillance System: Video Signal Lost-BigPearLine(D1), ShippingDock2(D3)
5:31:52 AM	Surveillance System: Video Signal Lost-PearRepack(D7), PearSeg(D20), MainStBehindPear(D21), PearSortLines(D24), AgritechCam(D25), PearBinDump(D28)
5:32:38 AM	Arcing event visible on lumber yard video
5:33:00 AM	Attempted 911 call by Patricia Gallardo & Elpidio Ruiz, they observe fire along the east side of building
5:33:00 AM	Phil Morgan observes flames, calls 911 (first 911 call but routed to Oregon)
5:33:06 AM	Surveillance Systm: Video Signal Lost-Waste Water Station(D18)
5:33:07 AM	Surveillance Systm: Video Signal Lost-Main Entrance 2(D17)
5:34:08 AM	Burglary Alarm (W Office Motion Detector)
5:34:08 AM	Burglary Alarm (Upstairs W Office Door)
5:34:08 AM	Power Failure-General
5:34:09 AM	Restore on Zones 9,16,15,14
5:34:09 AM	Burglary Alarm (Upstairs W Office Door)
5:34:09 AM	Burglary Alarm (E Office Motion Detector)
5:34:09 AM	Restore on Zone 14
5:34:10 AM	Bypassed Zone 9
5:34:10 AM	Restore on Zone 9
5:35:49 AM	911 call (first notification on Washington side) and fire department dispatched
5:37:58 AM	Surveillance System: Video Signal Lost-BackDock2(D22)

Time	Event
5:38:02 AM	Surveillance System: Video Signal Lost-Room47South(D23), Room1(D26), Room2(D27), Room4(D29), Room5(D30), Room13Seg(D32)
5:41:00 AM	Trucker calls 911
5:43:19 AM	Surveillance System: Video Signal Lost-Room 13 Seg(D32)
5:43:24 AM	Surveillance System: Video Signal Lost-Room47South(D23), Room1(D26), Room2(D27), Room4(D29), Room5(D30)
5:45:24 AM	Email notification (UPS Event Message)-UPS Battery Low
5:47:50 AM	Bingen Police Officer Frank Randall arrives on scene
5:52:00 AM	Auto Email: Meraki Cloud Network Access Point Unreachable
5:53:12 AM	Bingen E-33 arrives on scene, first fire unit
5:54:41 AM	Trucker moves truck away from loading dock
7:21:46 AM	Natural gas secured

The area of origin was determined to be within the compartmented area contained within the footprint of the employee break rooms and office space. This area is indicated by the red box in Figure 64 (ATF Case, 2017, file photo) and Figure 66 (ATF Report, 2017, p. 36).

Barclay Friends Senior Center, 700 North Franklin Avenue, West Chester, Pennsylvania

Date of Fire: November 17, 2017

IoT Building System(s) Utilized: Smoke Alarm System and Fire Sprinkler System

This fire was reported at 10:46 PM on November 16, 2017 and involved a two-story residential nursing home building. The incident resulted in four deaths and multiple injuries. Total damage was estimated at $10,000,000. The senior complex measured approximately 93,500 square feet. Figure 68 (ATF Report, 2017, p. 24) depicts the structure postfire.

Figure 68

Postfire Structure

A review of extracted data detailing the smoke alarm and fire sprinkler system was critical in supporting the witness statements provided by residents, reporting parties, and responding agencies. Figure 69 (ATF Report, 2017, p. 41, 48) depicts the timeline constructed from smoke detector activations, sprinkler activations, and system notifications. Figure 70 (ATF Report, 2017, p. 52) is a diagram labeling the locations and the sequence of the activations and notifications.

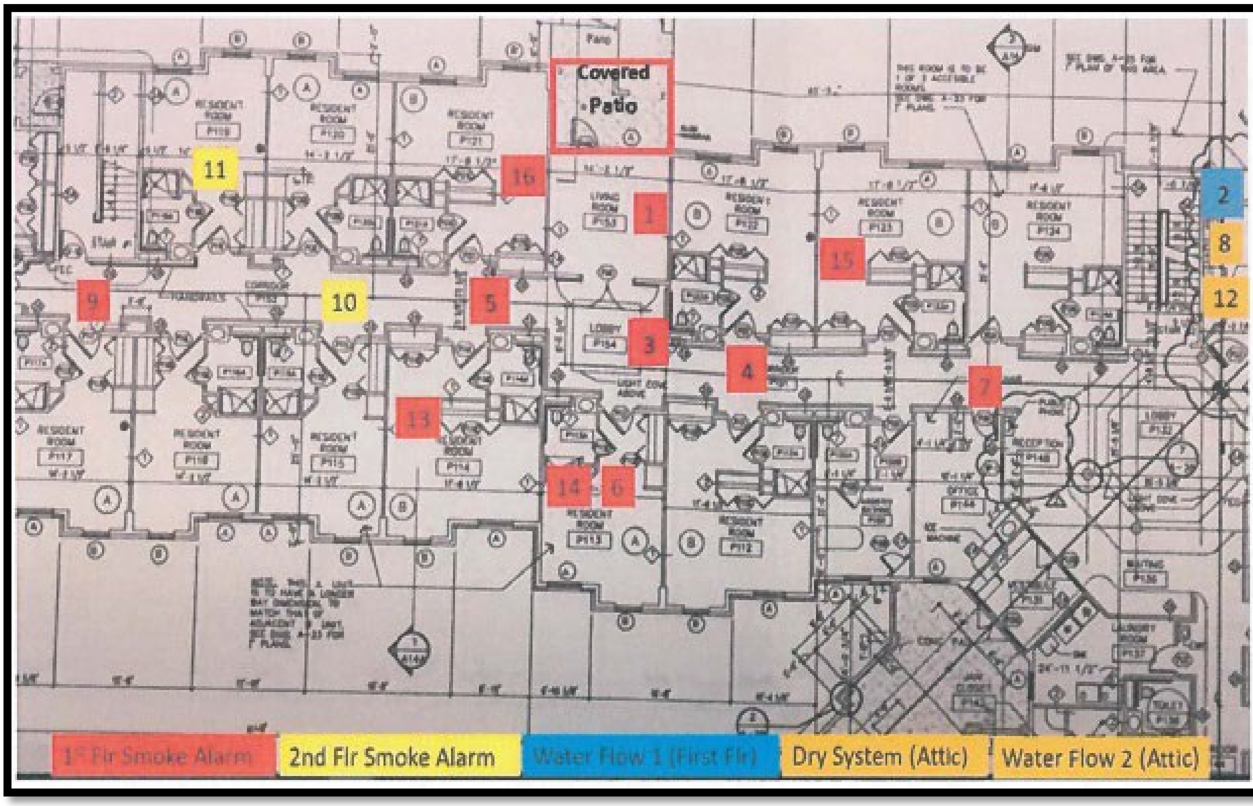
Figure 69

Timeline of Smoke Detector Activations, Sprinkler Activations, and System Notifications

10:43:08	"Alarm Verification in Progress" (first indication of smoke detector activation – likely from the "Garden Room"; this activity does not denote specific location, only that a smoke detector has activated.)
10:43:34	Woolman Basement Waterflow 1 (subtracting the built-in system delay of 25 seconds)
10:43:37	Woolman 1st floor Living Rm smoke detector (M4-85) ("Garden Room") Alarm Verified (No Answer at 10:44:20)
10:43:38	Woolman 1st Floor Lobby smoke detector (M4-75) Alarm Verified
10:43:50	Woolman 1st Floor Hallway smoke detector (M4-74) Alarm Verified
10:43:54	Woolman 1st Floor Hallway smoke detector (M4-76) Alarm Verified
10:43:59	Woolman Basement Waterflow 1 (M4-119) Fire Alarm
10:44:07	Woolman 1st Floor Rm113 Living Rm smoke detector (M4-106) Alarm Verified
10:44:20	Woolman 1st floor Living Rm smoke detector (M4-85) No Answer
10:44:28	Woolman 1st floor Hallway smoke detector (M4-73) Alarm Verified
10:44:29	Woolman Basement Dry System Low air (M4-123) Supervisory Abnormal
10:44:31	Woolman 1st floor Hallway smoke detector (M4-77) Alarm Verified
10:44:35	Woolman 2nd floor Hallway smoke detector (M45-47) Alarm Verified
10:44:35	Woolman 2nd floor Rm 219 Living Rm smoke detector (M45-72) Alarm Verified
10:44:37	Woolman Basement Waterflow 2 (M4-120) Fire Alarm
10:44:45	Woolman 1st Floor Rm114 Living Rm smoke detector (M4-103) Alarm Verified
10:44:49	Woolman 1st Floor Rm113 Living Rm smoke detector (M4-106) Alarm Verified (repeat)
10:45:01	Woolman 1st Floor Rm124 Living Rm smoke detector (M4-80) Alarm Verified (repeat)
10:45:05	Woolman 1st Floor Rm121 Living Rm smoke detector (M4-86) Alarm Verified
10:45:14-20	Woolman 1st Floor multiple smoke detector (M4-48, 51, 52, 54, 56, 58, 59, 60, 62, 63, 65) - Output Abnormal

Figure 70

Locations and Sequence of Activations and Notifications



As a result of the analysis of these systems, investigators were able to determine that the fire originated exterior to the structure in the covered patio area indicated in red in Figure 70 (ATF Report, 2017, p. 52). The fire then progressed into the structure through various openings, including windows that had auto-ventilated as a result of heat and flame impingement.

Keystone Automotive, 5835 South Vining Road, Greenville, Michigan

Date of Fire: December 7, 2019

IoT Building System(s) Utilized: Burglar Alarm and Fire Alarm Systems

The first report of this fire was at approximately 10:24 PM on December 7, 2019. The entire site of Keystone Automotive consisted of multiple structures—some connected, some unattached—on an 11-acre site. The total size of the affected area measured approximately 368,300 square feet. The total loss was estimated at $9,000,000. Initial reports were flames being observed through the roof of Warehouse 1. Figure 71 (ATF Report, 2020, p. 1) depicts the location postfire, with Warehouse 1 identified in yellow.

Figure 71

Location Postfire

During the fire scene examination, the structure referred to as Warehouse 1 was subsequently divided into quadrants for documentation purposes. A timeline of events was established by an analysis of the IoT data from the combination burglar/fire alarm system. No wiring diagram for the alarm system could be located, however, and the employees could not provide an accurate layout of the system’s wiring in any level of detail. Figure 72 (ATF Report, 2020, pp. 47-48) contains the timeline developed from the alarm system data. Figure 73 (ATF PowerPoint, 2020, Slide 14) depicts a diagram of the fire scene with an overlay of sequential IoT event data.

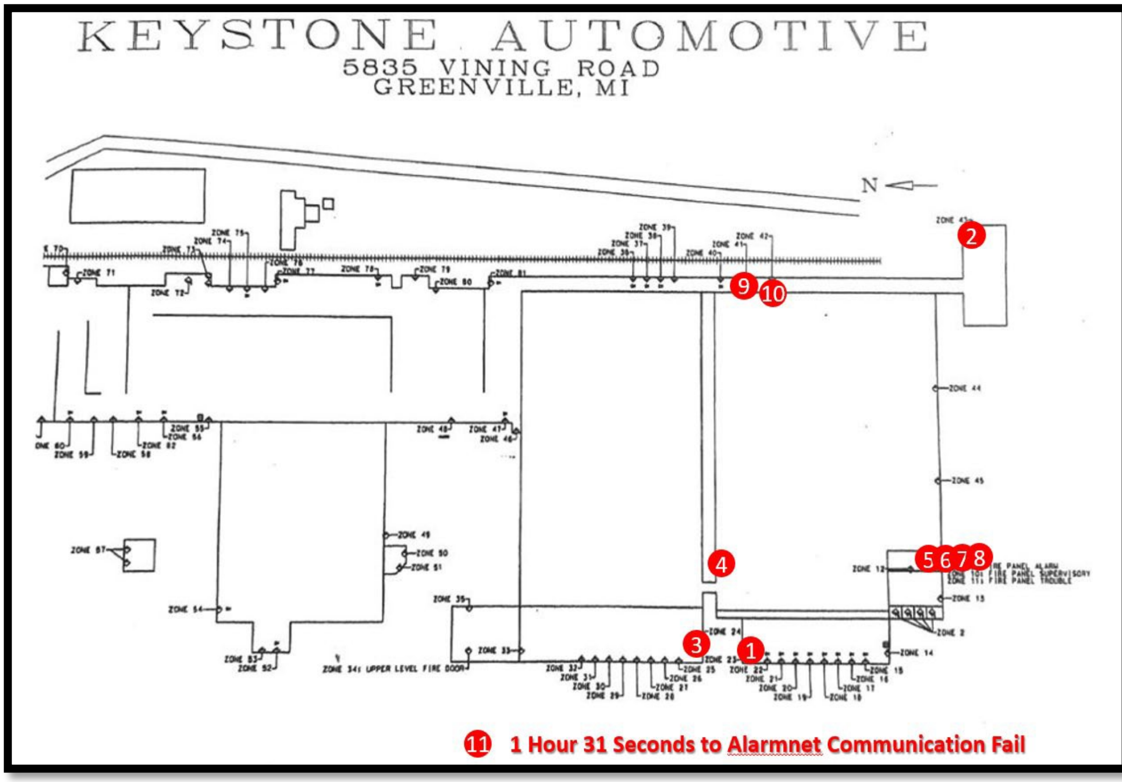
Figure 72

Timeline Developed from Alarm System Data

Date	Time	Event description	Zone
12/6/19	22:27:24	Closing by user Jeff Wright	015
12/7/19	03:17:53[1]	Test report	0
12/7/19	22:20:30[2]	Entry/Exit Burglary	23 – SOUTH DOCK NORTH MAN DR
12/7/19	22:21:52	Burglary	43 – PERIMETER SE WHSE MAN DR
12/7/19	22:24:37	Burglary	24 – PERIMETER SOUTH MAN DR BY SLIDERS
12/7/19	22:24:38	Fire	11 – FIRE ALARM HANDPULL; AREA 2
12/7/19	22:24:42	Trouble	1 – FIRE LOOP TROUBLE SMOKE; ABOVE PANEL
12/7/19	22:24:42	Trouble	972– GROUND FAULT (TROUBLE) ZONE 972[3]
12/7/19	22:24:47	Restore	1 – RESTORE FIRE LOOP TROUBLE (RTR) SMOKE; ABOVE PANEL
12/7/19	22:24:51	Trouble	1 – FIRE LOOP TROUBLE SMOKE; ABOVE PANEL
12/7/19	22:24:55	Restore	1 – RESTORE FIRE LOOP TROUBLE (RTR) SMOKE; ABOVE PANEL
12/7/19	22:24:57	Burglary	41 – PERIMETER EAST HALL OH DOOR #5
12/7/19	22:25:03	Burglary	42 – PERIMETER EAST HALL OH DOOR #6
12/7/19	23:21:01	Notify	950 – ALARMNET COMM FAIL[4]

Figure 73

Diagram of Fire Scene Depicting Alarm System Activity



Because specific details of the alarm system could not be ascertained, investigators were unable to determine whether the burglar alarm activations were a result of doors being opened, heat and fire impingement on the corresponding circuitry, or a combination of both. As a result, the area of origin was only able to be narrowed down to occurring inside of Warehouse 1.

Findings

Investigative Considerations

There are several considerations related to the accuracy of the information which must be accounted for when utilizing IoT data to assist in an investigation. Many of these considerations have to do with obtaining knowledge about the specifics of the IoT system(s), human factors, and ensuring the proper context of the data. As a result of the research and qualitative interviews, several of these considerations are listed below. It is important to understand that this is not an exhaustive list, but rathter encompasses a majority of the critical data which must be obtained and considered by the investigator.

System and Device/Sensor Type

First and foremost, an investigator must be able to identify the specific type of system and its related devices. To understand what data are available, an investigator must be able to ascertain the specifics. Different systems and devices are activated by different occurrences. For example, a smoke detector will be activated by smoke. A heat detector is activated by a rise in temperature. A motion detector can be activated by smoke as it moves throughout a compartment. A great example involving the differentiation of device types involves the two most common types of smoke detectors. Ionization detectors are generally more responsive to flaming fires (NFPA, N.D., p. 1; NFPA 921, 2020, p. 103). An ionization detector's chamber is constructed with radioactive material situated in between two electrically charged metal plates, current flows back and forth in between the plates (NFPA, 2008, p. 14-20; NFPA N.D., p. 1). The smoke entering the chamber disrupts the flow of ions, which reduces the flow of electric current, resulting in an alarm activation (NFPA 2008, p. 14-20; NFPA, N.D., p. 1). In contrast, photoelectric detectors are generally more responsive to smoldering fires (NFPA, N.D., p. 1; NFPA 921, 2020, p. 103). A light source is located within the device's chamber. When smoke enters the chamber, this light source can either be completely obscured or it can be scattered, both resulting in alarm activation (NFPA, 2008, p. 14-21; NFPA, N.D., p. 1). Understanding what can potentially cause a sensor or device to activate or alarm can assist in the interpretation and application of the IoT data extracted.

Device/Sensor Construction

To understand how and when a device or sensor can or will fail, the investigator must take the actual construction of it into account. According to an interview conducted on Monday, May 17, 2021, the SME specifically stated that the material which compromises the device or sensor has a direct impact on how much heat the object can withstand. Obviously, devices or sensors consisting of plastic can be subjected to less heat than can a similar device or sensor constructed of metal before failure. This knowledge provides the investigator with perspective and context concerning device and sensor failure.

System Intallation (Wireless vs. Wired System)

This is another data point that enables the investigator to view the data retrieved within its proper context. Wireless and wired systems can provide different failure data (SME interview, 5/20/2021). If the system is wired, the orientation in which the conductors and/or feeds are run and where they are located (i.e., above or below the ceiling) can become critical (SME interview, 5/17/2021). Fire can impinge upon the conductors or feeds of a device or sensor at a location upstream from the device or sensor (between the sensor/device and the panel), causing a power or feed loss. Identifying the locations and routes of the feeds or conductors is critical. If they are located above the ceiling, they may not be affected as rapidly as those below the ceiling (SME interview, 5/17/2021). A wireless system may provide different forms of information due to the system not employing feeds or conductors.

Locations of Devices/Sensors

Another corresponding piece of information that is required to assist with this analysis is some manner in identifying the locations of each sensor or device (SME interview, 6/4/2021; SME interview, 5/20/2021; SME interview, 5/17/2021). This can include a schematic of the structure or a map of the system. It is far more helpful for an investigator to know that the first sensor to activate was located in the “XYZ” area of the building, as opposed to knowing that a device or sensor activated, but no determination could be made as to specifically where the device was located.

Normalization of Times

The normalization of the timestamps involving the data is critical for the formation of an investigative timeline (SME interview, 5/20/2021; SME interview, 5/14/2021; SME interview, 5/17/2021; NFPA 921, 2020, p. 238). Data are not useful to the investigator if the times are not synchronized. For example, there is a fire at a large commercial warehouse. The first 9-1-1 caller observed flames through the roof and reports the fire at 4:45 AM. Investigators begin to collect IoT data and observe a recorded failure of a smoke detection device which was recorded at 2:30 AM, but the time on the system is behind by 2 hours (i.e., the failure actually occurred at 4:30 AM), which is not adjusted or accounted for. This lack of normalization changes the investigative timeline rendering it inaccurate, invalid, and unreliable. Data from this scenario could be erroneously interpreted to indicate a slow 2-hour long developing event, as opposed to a more rapidly occurring event.

Proper Interpretation and Application of the Data

Data cannot be properly interpreted without proper context (SME interview, 6/4/2021). This can include an analysis of device/sensor locations within a structure, as well as the normalization of timestamps (SME interview, 6/4/2021; SME interview, 5/20/2021; SME interview, 5/17/2021; SME interview, 5/22/2021; SME interview, 5/14/2021). A device activating in a structure without understanding where within the structure that device is can limit the usefulness of that data. Perhaps the investigator can have a more general idea as to when the fire incident began (i.e., alarm activation inside versus when a witness on the exterior first sees smoke or fire and reports it). This information, however, may not be as useful in the area of origin determination as knowing that “Device 1 – located within the machinery room activated first.” By identifying the locations of the sensors/devices within a structure, normalizing the times, and sequentially plotting the activations on a schematic, the retrieved data can then be applied and begin to tell the story of the event (SME interview, 5/20/2021).

Summary

In this mixed-methods study, the researcher utilized initial self-reporting by ATF SMEs to determine who had utilized IoT data from building management systems to narrow down the area(s) of fire origin during a fire scene examination. The general population included 120 SMEs, 20 of which subsequently self-reported. The SMEs were further fragmented or stratified, into three distinct groupings. There were 12 CFIs, five Electrical Engineers (EEs), and three Fire Protection Engineers (FPEs), representing a total of 10 specific case examples. Two SMEs from each stratum, for a total of six, were randomly selected to be interviewed.

Following the completion of each interview, the recordings were provided to a neutral third party for transcription. Each SME was then asked to review the resulting transcription for accuracy. The SME interview process began on May 5, 2021, with the distribution of consent forms via email and interview scheduling. The process concluded on June 14, 2021 following the SME review of the final transcript. Following the successful completion of all SME interviews, the process of analyzing the textual data was initiated. The major themes that emerged included the context of the data, human factors (such as normalization and gaining knowledge of the IoT system), as well as the need for the proper interpretation and application of the data.

Official documentation pertaining to the utilization of IoT data during the fire scene examinations by SMEs provided exact details across various situations. The document review enabled specific examples of this IoT data usage in practice. This material provided the researcher with exceptional instances of the overall scene scope, the process of applying the IoT data, and the results. The documentation also bridged any gaps between the information provided by the SMEs during their respective interviews and the authentic application of this technique.

Conclusion

The major focus of Chapter 4 involved an analysis of SME interviews and related official documentation of fire scenes processed. Specific themes and patterns emerged during a line-by-line analysis of each interview transcript. These themes and patterns were then synthesized to form a holistic picture of the interpretation and application of the IoT data process during a fire scene examination.

Chapter 5 focuses upon the conclusions of this study as well as recommendations for the future as they pertain to fire investigation and future research. Chapter 5 also includes the contemplation of the potential error related to IoT data and the human investigator. The strengths and weaknesses of using IoT data are enumerated and explained. Chapter 5 contains the summarized data from this research as well as the discussion of findings and conclusions that can be drawn. Chapter 5 concludes with recommendations for the fire investigation community, suggestions for future researchers, and a summary.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

In the current study, the researcher explored the use of IoT data in fire investigation. During a scene examination, an assessment is conducted according to the observations made by the investigator regarding fire-related patterns or artifacts. The investigator considers the possible casual factors (i.e., hypotheses) that led to the creation of these patterns. This inquiry ultimately concludes with the formation of opinions as a result of the investigator's interpretation.

One of the greatest criticisms facing the field of fire investigation involves the potential for subjectiveness in the investigator's interpretation of the identified fire effects and fire patterns. The NAS report identified potential issues and recommended improvements to various forensic disciplines to increase their effectiveness. One salient conclusion related specifically to the field of fire investigation, emphasizing that it needed to be placed on a more scientific footing due to a "paucity of research" underlying the interpretation of fire effects and fire patterns (National Research Council, 2009, p. 173).

In this study, the researcher explored the issue from several aspects; including a review of the literature, analysis of case-specific examples, and SME interviews regarding their personal experience and opinions. In Chapter 5, the researcher discusses and interprets the research results, including the significance and implications of the findings. The researcher also outlines several recommendations for the fire investigation community and future researchers interested in this topic. Chapter 5 concludes with a general summary of the research findings.

Interpretation of Results

Themes

Several themes emerged following a review and subsequent analysis of the textual data from the SME interviews. There was much consistency between the interview content as a whole. The perspectives given provided the researcher with a rich understanding of the process, what it is used for, how it is applied, and why it is important to fire investigation. Reviewing the case-specific information and documentation was useful in understanding the concrete process of IoT data application and its result. The SME interviews provided a clear and intimate perspective regarding each SMEs personal experience and opinions concerning the procedure. These data would not have been gleaned from the investigative documents. The most prevalent emerging themes and concepts are discussed below.

Need for Context

A resounding 100% of the SMEs interviewed emphasized the need for the IoT data to be interpreted and applied within the proper context. Each data point needs to be considered and analyzed in a manner that clarifies its actual meaning. The sequence of data obtained must be examined holistically. Of particular importance in this theme were the categories of normalization (50%) and physical layout (67%). For the time-stamped data to be properly used within a timeline, all of the times must be synchronized. Without normalization, investigators are essentially comparing apples to oranges. The physical layout of the IoT system was also of critical importance. An investigator must have a basic understanding of the type of system being analyzed because different systems can produce different data points; even similar systems that are designed differently can produce different data points. The physical locations of the devices and sensors need to be identified so that the area of initial activation or detection can be pinpointed. Understanding whether the system is hard-wired or wireless provides information as to how the activation signal or signal loss is received by the system as well as what elements could affect or cause that data point. A basic understanding of the material in which the sensors and devices are constructed, as well as the orientation of conductors and feeds, is also important. To understand how something works or how it fails, an investigator must ascertain what it is and what it consists of.

Primary Use

All interviewed SMEs provided useful insight as to what IoT data can be used for in a fire scene examination. Several categories were mentioned multiple times. Timeline development (83%) was the most frequently mentioned. Following closely behind were the data's ability to produce hard times (67%), the ability to determine sequences and patterns (67%), ascertain fire progression (67%), and narrow down the area(s) of fire origin (67%). There were a few profound uses that had not necessarily been considered by the researcher and can be categorized as outliers. While these uses were not anticipated, they are worthy of mention within the research. These outliers are that IoT data can be used for witness statement evaluation (17%) and for fire classification purposes (33%). The sabotage of an IoT-connected system, while not providing data to area of origin, may be significant related to any potential fire cause hypotheses.

Strength of IoT Data and Fire Investigation

The interviewed SMEs continually emphasized the glaring strengths of using IoT data within the realm of the fire scene examination. A vast majority of SMEs reported more than one strength regarding this technique. The three most frequently mentioned strengths were the creation of hard times (67%), and that the data received were truly reliable (50%) and unbiased (50%). While unanticipated, several SMEs also added that the analysis and subsequent application of IoT data to the fire scene tended to be superior to the use of witness statements (50%) and more reliable than fire pattern interpretation (33%). Of the SMEs who added these aforementioned opinions, 100% specifically stated that they were able to come to that conclusion due to the unbiased information from IoT data in comparison with the subjectiveness and occasional unreliability of witness statements and fire patterns. These SMEs further added that witness statements and fire pattern interpretation can be subject to alternate hypotheses by opposing experts.

Perceived Weaknesses of IoT Data in the Use of Fire Investigation

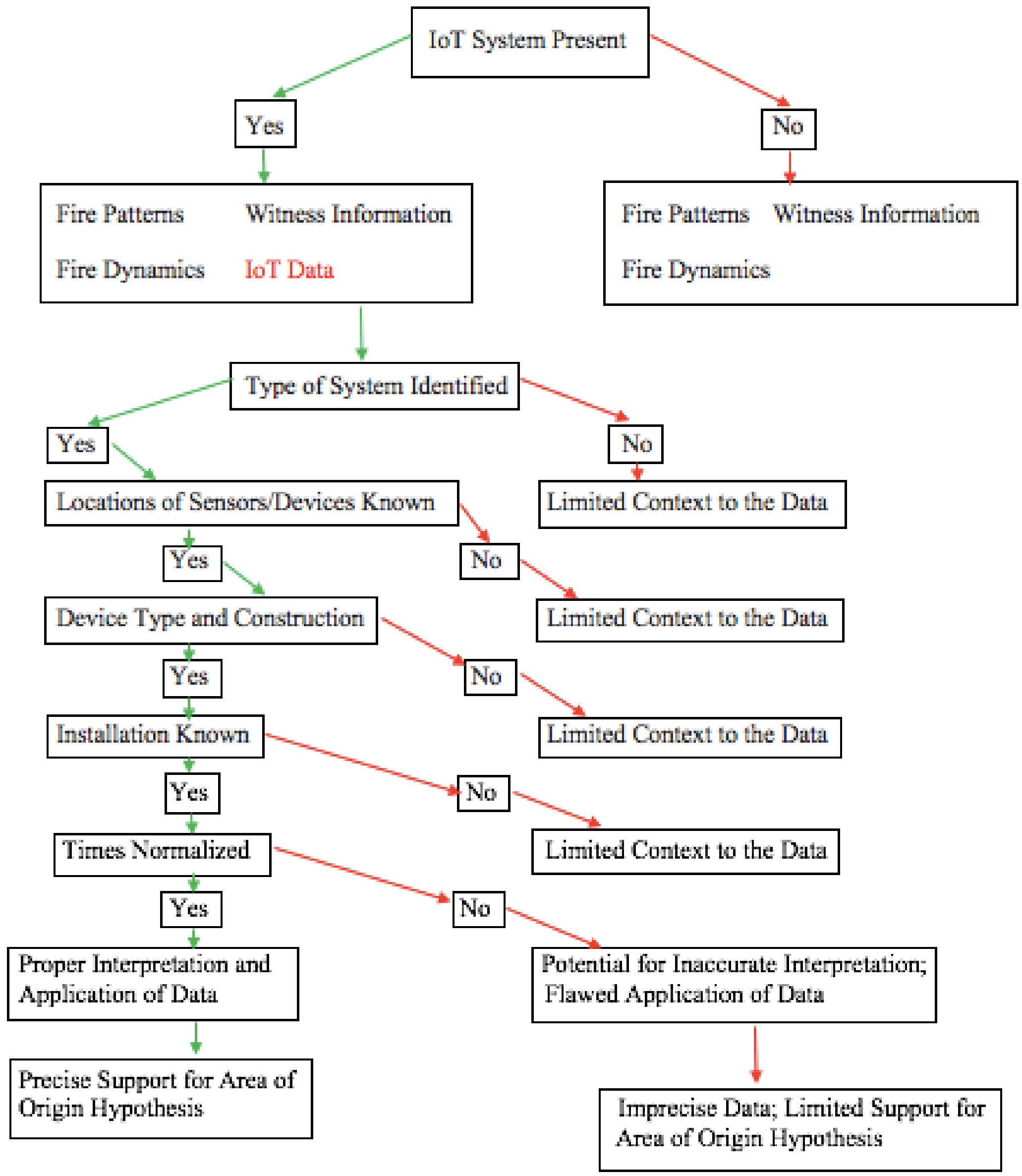
Two of the most prevalently identified weaknesses that emerged from the SMEs involved the potential for systematic error (100%) and the possible issue of accessing the data in the first place (33%). The potential for systematic error can primarily be divided into two categories: normalization (50%) and contextual (67%). Normalization refers to the intentional synchronization of the time-stamped data. Oftentimes, an investigator must recall and consciously take that step in the IoT data analysis process because on many occasions different IoT systems may have clocks that display the incorrect time. Failure to normalize the times can result in an inaccurate timeline of events. Applying the IoT data within the proper context is also essential. As discussed above, context involves the holistic application of the data points. Investigators must be aware of and account for such elements as the physical layout of the system, device and sensor construction, and installation information. While shortcomings of IoT data were discussed during each interview, the shortcomings identified were not as plentiful as the listed strengths. Because the potential for error was raised during a significant number of SME interviews, however, it is necessary to further delve into the potential reasons.

Event Tree Analysis

Fault trees can provide a dramatic visual aid for an investigator regarding the process of a sequential activity. A fault tree is a graphical and intuitive diagram that is developed from the top-down utilizing a deductive reasoning approach (NFPA 921, 2020, p. 239). Conditions or events are placed within the diagram in sequential order and can be used to break down an event or activity into its individual component parts (NFPA 921, 2020, p. 240). An event tree is very similar in nature; it consists of a top-down modeling approach that explores responses that can be used to analyze a system. Figure 74 depicts a modification of the analyses for the specific purpose of this research. It identifies the flow and basic premises for utilizing IoT data during a fire scene examination. Figure 74 also highlights the important considerations, which must be accounted for by the investigator, as well as the potential results from the component parts of the data either being present or not present.

Figure 74

IoT System Event Tree for Analysis



Potential for Error

Error can arise when utilizing IoT data during a fire scene examination because of several reasons. Some of these result from human error, but error can also be due to estimations and limitations of the devices, systems, or recorded data. Some factors which affect accuracy/usefulness and/or potentially lead to error involve defining the system failure to be examined and include such elements as (a) normalization of times, (b) type of system, (c) device type and construction, (d) locations of sensors/devices, and (e) installation (wireless versus wired) considerations. While the aforementioned list remains pertinent, to consider accuracy rate determination there are additional factors that need to be identified and considered: (a) to list and analyze the human error that could occur and (b) to consider issues specifically related to the utilization of IoT data using a fault tree as listed above (Safeopedia, n.d., p. 1).

The critical concept concerning IoT data is that an incorrect assumption on behalf of the investigator or an overlooked event can inadvertently lead investigators to the wrong conclusion (Servida & Casey, 2019, p. 28). In some forensic disciplines, it is possible to use an error rate to explain the potential for false positives, false negatives, or other inaccuracies (SWGDE, 2018, p. 3). Once identified, an error rate can depict the strength of a particular technique as well as the potential limitations in using it (SWGDE, 2018, p. 9).

The utilization of IoT data ultimately involves digital and multimedia evidence (DME) forensics. Digital forensics can be defined as “the branch of forensic science concerned with the recovery and investigation of material found in digital and computer systems" (Sunde, 2017, p. 14; UNODC, 2013, p. 159). While error rates involve one of the factors that need to be considered under Daubert, it must be recognized that DME forensics and forensics based upon natural sciences differ. Due to the fundamental differences in many of the digital and multimedia forensics processes, attempting to use statistical error rates is inappropriate and can potentially be misleading (SWGDE, 2018, p. 3). The natural components of an evidence sample can remain static, and the basic science does not change. DME forensics information technology is constantly in flux, however, and involves innumerable combinations of hardware and software (SWGDE, 2018, p. 10).

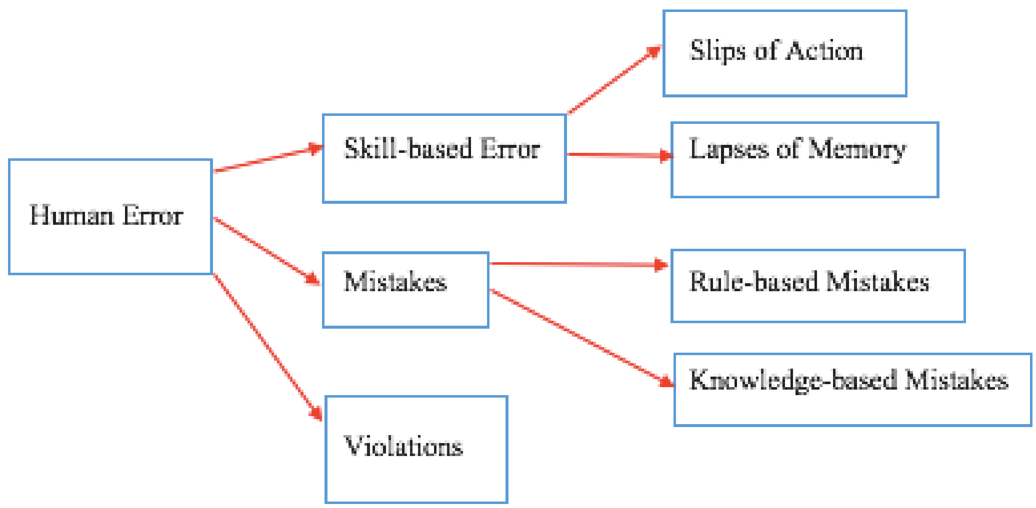
As a result of the rapidly ever-changing nature of DME forensics, predictions required by error rates cannot be made. Digital forensics, including IoT data extraction and analysis, is far more prone to systematic errors. Random errors are always present and are characterized by error rates due to the inability to perfectly measure a condition or process (SWGDE, 2018, p. 3). Systematic errors are often caused by the process itself. An example would be the imperfect implementation of computer software during a data extraction process, which creates an incorrect result (SWGDE, 2018, p. 3). In other words, random error can be explained statistically, while systematic error cannot. The technological and investigative competence of the scene examination personnel is also crucial and must be considered. Errors, whether human or data-related, can propagate across different phases of the investigative process and negatively affect the result. Such elements include the lack of time normalization, the inadequate or misinterpretation of data, or the overlooking of data. Error mitigation techniques and analysis can greatly aid in minimizing their potential impact.

Human Error

Human Error Rate Prediction (HERP) or Human Reliability Assessment (HRA) can be useful in the application of IoT data (Sandia Laboratories, n.d., p. 1). This technique was developed by Sandia Laboratories for the U.S. Nuclear Regulatory Commission in the 1960s to conduct a safety analysis of nuclear power plants (Sun et. al., 2011, p. 2). Concerning the current research, this process must be modified slightly. First, the portions of the process where human error has a greater likelihood of producing an error must be defined (such as error in collection of the data or interpretation of the data) (Sandia Laboratories, n.d., p. 2). Second, for each task during the IoT collection, data analysis, and subsequent interpretation, the potential errors within each step must be considered (Sandia Laboratories, n.d., p. 2). These potential errors can include the following: (a) errors of omission, or leaving out a step or task in the process; (b) errors of commission, such as the data being recorded and applied inaccurately; (c) errors of selection, including errors in the use of controls or in issuing commands; (d) errors of sequence, in which a required action is carried out in the wrong order; (e) errors of timing, in which task is executed before or after it was required; and (f) errors of quantity, involving inadequate or excessive amounts (Collazo, N.D., p. 1). An excellent portrayal of the basic human errors can be observed in Figure 75 (adapted from HSE.gov.uk, n.d.).

Figure 75

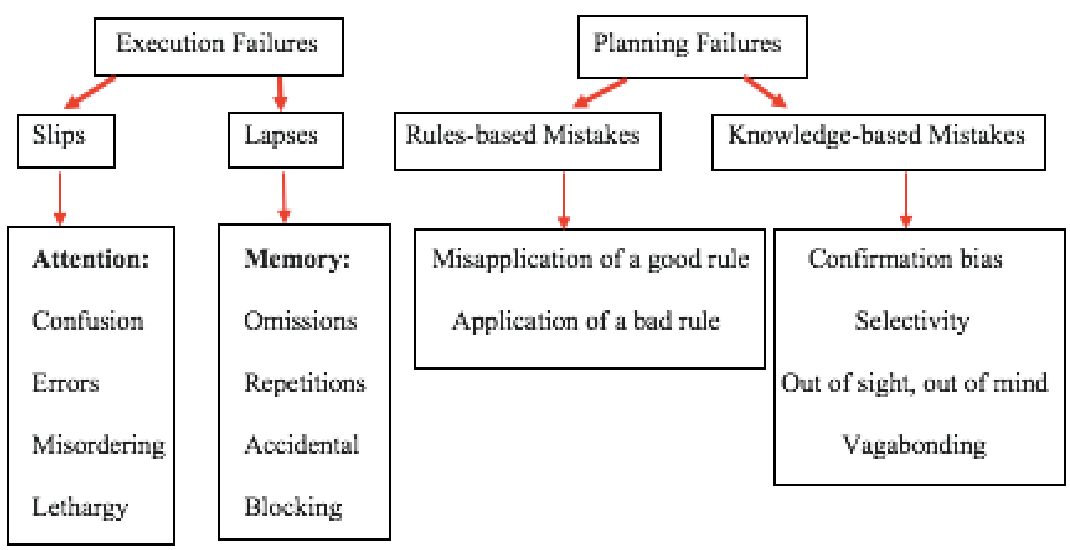
Basic Human Error Analysis



Another diagram that synthesizes well with the above figure has been provided by the Flight Safety Foundation (n.d.) and can be observed in Figure 76.

Figure 76

Analysis of Human Failure



An estimation of the relevant error probabilities needs to be considered. It might be more effective to consider a modified type of fault tree analysis. Successes and failures can be observed in conjunction with one another. Estimated error frequencies can also be generally identified. Skills-based (SB) errors form the larger percentage of human errors, followed by rules-based (RB), and lastly, knowledge-based (KB; Flight Safety Foundation, n.d., p. 3).

Another way to consider this is:

$$\text{SB} >> \text{RB} > \text{KB}$$

(Flight Safety Foundation, n.d.)

The Flight Safety Foundation has been able to ascertain some generalized results as to frequencies of various human errors. Sixty-one percent involve skills-based errors, 27% involve rule-based errors, and 11% are knowledge-based errors (Flight Safety Foundation, n.d., p. 3). Being that data from IoT systems provide empirical data regarding time and location, it is the current researcher's opinion that extensive focus must be placed upon the potential for systematic error concerning the extracting, analyzing, and interpretation of this data. The need for a holistic contextual analysis and interpretation cannot be emphasized enough.

IoT Data Error

The forensic recovery and subsequent application of IoT data can also potentially lead to errors. These errors include incompleteness, inaccuracy, and misinterpretation. Incompleteness results from a failure to acquire all of the relevant information (SWGDE, 2018, p. 3). Inaccuracy occurs when the forensic tool fails to report the information accurately. Accuracy can be assessed by considering the actual existence of reported data, the potential for altered data, and the possibility of corrupted data (SWGDE, 2018, pp. 3-4). Misinterpretation involves the act of forming an incorrect understanding of something.

Error Mitigation

Any potential sources of error need to be identified and actions taken to subsequently mitigate them. To attempt to mitigate errors, the following questions must be answered. "1. Are the techniques used to process the evidence valid science? 2. Are the implementations of the techniques correct and appropriate for the environment where they are used? 3. Are the results of the tools interpreted correctly?" (SWGDE, 2018, p. 9). Errors associated with DME tools, interpretation of results, and human factors can be addressed most effectively by proper training, proficiency testing, oversight, the use of a technical review, and adherence to a best practices approach (SWGDE, 2018, p. 12).

It is also helpful for the investigative team to be aware of typically identified issues concerning DME evidence and its interpretation. Specific to the current research, these issues have primarily been identified as ensuring time normalization, using the proper personnel to access and interpret the data (if coded), as well as understanding the installation, construction, and physical layout of the IoT system(s) regarding the incident. Being able to conduct a thorough error mitigation analysis addressing the potential sources of error and explaining how they are accounted for and subsequently mitigated greatly assists with addressing Daubert-type concerns about DME (SWGDE, 2018, p. 16;

Servida & Casey, 2019, p. 29). Adherence to a quality assurance approach is critical to the proper use of IoT data during a fire investigation.

Conclusions

Strengths

The use of IoT data during a fire scene examination provides the investigator with several benefits. These benefits serve to support the investigation by providing empirical data points to assist the investigator in the formulation of hypotheses concerning the area of fire origin. The data points also provide reliable, factual support for the final hypothesis selected as to area(s) of origin. Furthermore, the IoT data can be utilized in the development of investigative timelines, fire progression analysis, and—on occasion—support fire classification.

Unmatched Reliability

Properly interpreted and applied IoT data furnishes an investigator with unbiased, time-stamped information. Fire patterns, while useful, open the investigator to possible challenges in court as to their interpretation. Witness statements also have the potential to be unreliable. Witnesses may provide inaccurate information for reasons such as deception, incorrect perception, incorrect recollection, and miscommunication (Cox et al., 2019, p. 21). The utilization of this technique can provide investigators with a degree of confidence in their conclusion as to the area of fire origin.

Hard Times

Normalized IoT data provides the investigator with accurate timestamps of events occurring at the fire scene. The 2021 edition of NFPA 921 defines a hard time as a specific point in time that can be either directly or indirectly linked to an accurate and reliable clock or timing device (p. 238). Every SME interviewed in the present study emphasized the importance of being able to have an actual time for events such as sensor or device activations, fault detections, or communication errors. As one SME specifically stated, “It’s hard to argue with a time stamp” (SME interview, 5/14/2021). IoT data is a great addition to timeline development and analysis.

Removal of Subjectivity

Reviewing the IoT data points in conjunction with such elements as knowledge of the particular system, device and/or sensor locations, the orientation of associated feeds or conductors can provide the investigator a holistic picture of the early fire incident. Having a contextual understanding of what specific data points mean, such as an initial smoke detector activation or a device suddenly being unreachable, enables the investigator to avoid subjectivity. The data points are empirical, which ensures their accuracy, quality, and integrity. The use of IoT data can assist the investigator in verifying or refuting their hypotheses and conclusion. These data can also assist the investigator in determining the accuracy or veracity of witness statements.

Can Assist with Area of Origin and Fire Progression

Investigators can combine IoT data with schematics to discern the locations of such activities as a first device/sensor activation, subsequent device/sensor activations, a circuit fault within the system, and/or portions of the system becoming unreachable. These events are not only hard times, indicating a precise moment in time when the event occurred, they can also be strung together to tell the story of the incident pointing to an area of fire origin, as well as the progression of fire throughout the structure. The time of the first activation or power loss can assist in narrowing down the time the fire began as well. An investigator must also think outside of the proverbial box of the fire scene interior when seeking IoT systems that may provide data. Nearby IoT systems attached to or within adjacent locations or neighboring structures may also be able to provide useful data.

Can Assist with Cause Hypotheses

Several SMEs have been able to use IoT data to place an individual at or near a location immediately before a fire. Data points such as a cellular telephone connecting to a Wi-Fi system within a structure or at another location in the vicinity can be helpful for several reasons. It can assist investigators when developing interview lists or identifying potential suspects. It can also be used to support an incendiary classification, especially if no one was supposed to be at the location prior to the fire. Signs of prefire sabotage of an IoT-connected system is also worthy of exploration and consideration by investigators.

Weaknesses

As with any technique, several areas that could be potential shortcomings have been identified. Some of these limitations can be directly addressed by the investigator, while others pertain to concerns that may involve other entities. All involve issues which can significantly impact the contextual accuracy of the IoT data as applied to the investigation.

Accessibility of the Data

There may be a difference in the accessibility of IoT data between public and private fire investigators. IoT data is covered by the Fourth Amendment's search and seizure protections. Therefore, consent or a search warrant must be obtained in order for the data to be reviewed and utilized. Some companies may hesitate to release the data that they have accrued through IoT-connected devices. The rationalization behind their hesitancy may be due to the companies not wanting the public to be aware of the sheer volume of data that can be accrued (SME interview, 5/27/2021). Obtaining the data could also be time-consuming. The data itself also may be difficult to parse, as it is often extracted in the form of codes (SME interview, 5/27/2021). As a result, an SME such as an Electrical Engineer or Fire Protection Engineer may be necessary to successfully and accurately interpret the data. There are also potential issues regarding survivability of the data. This can include concerns such as the data being overwritten or simply lost if not captured in a timely manner. It is also necessary for investigators to ascertain whether there is any local storage on a device or sensor that needs to be downloaded and analyzed.

Ensure the Normalization of Times

For the data to be meaningful, it must be synchronized. The issue of time normalization can adversely affect investigative timelines, area of origin determination, and fire progression analysis. Inaccurate time stamps lead to any analyzed IoT data being out of its proper context. The repercussions of a lack of synchronization can result in the timeline being inaccurate and ultimately invalid.

Knowledge of Physical Layout, Construction, and Installation of the System is Crucial

In order for the IoT data to have any semblance of useful context, the specifics of the system must be known. Many times, the fire scenes have such extensive fire damage that the locations of the devices or sensors are not able to be discerned. The building owner may occasionally have this data, but there is also a significant chance that they do not. Installers may be able to advise as to where devices or sensors are located, the orientation of circuitry and feeds, and specifically how the circuitry and feeds are run. Information as to where a specific device was when it first activated tells a significantly different story than merely knowing a device activated but not knowing its location. Being that devices and sensors activate as a result of different stimuli, it is also critical that an investigator know what type of system it is.

Implications and Significance of Findings

One of the more pervasive criticisms regarding the field of fire investigation involves the subjective nature of the investigator’s interpretation of collected data. This issue is especially pertinent concerning the fire investigator’s interpretation of fire effects and fire patterns while analyzing the observed damage to the structure. The U.S. Congress authorized a study to provide an in-depth view of the various disciplines contained within the forensic science community, which has come to be known as the 2009 National Academy of Sciences (NAS) report. The focus of that study was to recommend improvements to the various disciplines of forensic science within the United States so as to increase their effectiveness. One glaring conclusion by this study related specifically to fire investigation was that it needed to be placed on a more scientific footing as they found that there was a "paucity of research" underlying the interpretation of fire effects and fire patterns (National Research Council, 2009, p. 173).

The fire investigation community is continuously searching for techniques that can be utilized to bolster the investigator's effectiveness and accuracy when processing fire scenes. The methodology and techniques employed during a fire scene examination must be reliable and valid. The conclusions of an investigator may occasionally come under scrutiny by opposing experts who raise potential issues of cognitive errors and bias. In the current study, the researcher explored the utilization of empirical data extracted from IoT building management systems and related devices located at the fire scene to assist in the identification of fire origin.

When considering the research questions employed by the study, the current researcher strived to thoroughly answer each one. The research questions are listed below, along with an explanation as to the findings of this study concerning each line of inquiry.

Research Question 1

RQ1 asked: Why is the utilization of IoT data an appropriate method in fire investigation? The current findings have successfully shown that the proper utilization of this technique will address the aforementioned issues raised by the National Research Council. As a result, it provides a mechanism to place fire investigation on a more solid scientific footing. It also addresses concerns voiced by opposing experts regarding the subjective interpretation of fire patterns by providing a procedure that can assist in obtaining and utilizing hard data points and definitive facts, which can be relied upon in determining the area of origin. The information gleaned from the IoT-connected systems and devices, when normalized and applied with context, empirically supports the determination of the area of origin. The data obtained from these IoT-connected systems and devices can be further utilized to address additional factors and concerns during a fire investigation such as timeline development, discerning fire progression throughout the structure, and evaluation of witness statements.

Research Question 2

RQ2 asked: How do these systems operate? The review of the literature, as well as the various SME interviews, were critical in providing a solid background on the basic operation of these various systems. Currently, the IoT potentially connects nearly 50 billion 'things' to the Internet (Tzafestas, 2018, p. 102). IoT-connected systems, appliances, and items are encountered on a daily basis in modern society. IoT is pervasive and ubiquitous; as a result, so is the data that can be gleaned from it. IoT system sensors and components are connected to the internet in a multitude of different ways. They can be connected via Wi-Fi, Bluetooth, routers, gateways, ethernet, cellular, satellite, and even by low-power wide-area networks (LPWAN; Khader et al., 2019; Leverege, 2018; Zhang & Yu, 2013). The specific applications ultimately determine how the system or device is connected. Each connection option varies concerning its range and power consumption. Once the data from the IoT system or device is sent to the Internet the data must be processed by software for it to become intelligible. Then, this information is either provided to the user, maintained within the Internet, or stored upon the system or device.

Research Question 3

RQ3 asked: How can IoT data be utilized successfully to assist in determining the area of origin during a fire scene examination? SME interviews and a complete review of case-specific examples solidified the utilization of IoT data during a fire scene examination. Several crucial factors were identified which must be addressed and considered by investigators.

System and Device/Sensor Type

First and foremost, an investigator must be able to identify the specific type of system and its related devices. To understand what data are available, an investigator must be able to ascertain the specifics. Different systems and devices are activated by different occurrences. Understanding what can potentially cause a sensor or device to activate or alarm can assist in the interpretation and application of the extracted IoT data.

Device/Sensor Construction

To understand how and when a device or sensor can or will fail, the investigator must take the actual construction of it into account. The material which comprises the device or sensor impacts its resistance to heat exposure. Devices or sensors composed of plastic are more susceptible to thermal exposure than items constructed with or encapsulated by metal. Comprehension of this factor can provide the investigator with the proper perspective and context concerning device and sensor failure.

System Installation (Wireless vs. Wired System)

Knowledge of the system installation further enables the investigator to view the data retrieved within its proper context. Wireless and wired systems can provide different data regarding failures. If the system is wired, the orientation in which the conductors and/or feeds are run and where they are located (i.e., above or below the ceiling) is critical. Fire does not necessarily need to impinge upon the device or sensor to cause a failure. It can impinge upon the conductors or feeds distant from the device or sensor thus causing a power failure or communication loss. A wireless system may provide different forms of information due to the system not employing feeds or conductors.

Locations of Devices/Sensors

Another corresponding piece of information that is required to assist with this analysis is some manner in identifying the locations of each sensor or device. This can include a schematic of the structure or a map of the system. Knowledge of the physical layout enables investigators to map out data such as activations, communication loss, and power failure to the various parts of the IoT system.

Normalization of Times

The normalization of the data so that the times are synchronized is critical for the formation of an investigative timeline. Lack of normalization can grossly affect the investigative timeline rendering it inaccurate, invalid, and unreliable. Normalization adds to the context of the data being interpreted. It can have a captious impact concerning the time of fire origin, the progression of the fire, and the evaluation of witness statements. Sequences or patterns observed within the data can become meaningless without synchronization.

Proper Interpretation and Application of the Data

Data cannot be properly interpreted without their proper context, which includes an analysis of the physical layout and installation within a structure as well as the normalization of timestamps. A device activating in a structure, without accurate knowledge as to where within the structure that device is, can limit the usefulness of the data. By identifying the locations of the sensors/devices within a structure, normalizing the times, and sequentially plotting the activations on a schematic, the retrieved data can then be applied and begin to tell the story of the event.

Overall, the use of IoT data during a fire scene examination constitutes the implementation of fire investigation technology. Fire investigation technology is defined as "applied technology subjects related to and used in fire investigation including, but not limited to, specialized knowledge and skills in documentation of the investigation, scene and evidence processing, and failure analysis and analytical tools" (NFPA 1033, 2013, p. 7). To further emphasize this point, Hazard and Wendt (2018) specifically stated that "arguably, no aspect of fire investigation has changed more than the technology that is available to make the investigative process more efficient and effective" (p. 32). As such, fire investigators must remain current in their training and education regarding this subject area. It is contingent on the individual investigator to continually research, become familiar with, and apply new technologies during their investigative pursuits as they become apparent.

Reflection of Experience

The experience of identifying potential issues regarding fire investigation practices provided the researcher with a holistic understanding of the investigative process, as well as the various advantages and drawbacks of different approaches and techniques. Reviewing the NAS Report, as well as previous studies and scholarly articles, aided the researcher in gaining an appreciation for the various concerns raised by opposing experts related to fire pattern interpretation. As a result, the researcher gained a more extensive depth of analytic understanding in relation to cognition, bias, and error, as well as how these factors can potentially affect fire scene processing. The entire process of this research morphed into a desire for additional knowledge and understanding in conjunction with effective problem-solving.

The low self-reporting of ATF SMEs was anticipated. This particular population of SMEs are continuously in the field responding to scenes and teaching nationwide. It was assumed that the low self-reporting could have been the result of several factors. These could have included accidental or deliberate omission, the fact that the topic did not apply to the SMEs' specific experience, and workload conflicts. The review of case examples was an insightful way to monitor the step-by-step process and evaluate how the data was applied and interpreted for each specific instance. The SME interviews permitted colorful individual encounters permeated by descriptive experiences, thoughts, and opinions. The information gleaned from the interviews added a critical level of understanding and appreciation for the totality of the subject. Interview templates assisted in uniformity across the interviews, leading to consistency while permitting unique viewpoints to emerge. The infusion of both steadiness and innovativeness in the SME answers to the interview questions yielded distinct aspects and categories during textual analysis. Despite the initial low response rate by SMEs, the research was still a resounding success. The collective experience of the SMEs interviewed far exceeded that which was anticipated by the researcher. Ultimately, many perspectives were provided, which comported with the anticipated results. There were multiple aspects exposed regarding IoT data usage and interpretation, which were not originally considered by the researcher. Each SME interviewed was friendly and receptive to the study, many of which expressed their eagerness to review the results of this research.

The utilization of a qualitatively focused theoretical drive during this mixed-methods approach was an extremely useful methodology to employ for this specific study. This research was implemented through a process in which the quantitative and qualitative data were collected sequentially, meaning that they were collected one after the other. The qualitative data were collected as a result of the outcomes from the quantitative phase of the process (Ivankova, 2006). The quantitative phase was conducted to identify and allow for the purposeful sampling of SME participants. The result was an integration of the quantitative and qualitative data of the research process. The data in this study ultimately provides the unique perspectives of the individual participants. This collective experience led the researcher to gain an enhanced appreciation for the rigors of qualitative research. The depth of the study was significantly enriched by the inclusion of the SME interviews.

Recommendations

The researcher's recommendations for the fire investigation community include the assurance that the results of this research are communicated in the form of both publication and oral presentation. The use of IoT data from building management systems provides empirical data to assist with scene processing, but also with the formulation of event timelines and hypotheses. Given that witness information can tend towards challenges involving reliability and subjective observation, the recommendation of this research is to separate electronic data from witness information within NFPA 921.

Witness data are not always necessarily objective. In this specific case, objectivity refers to data that are neutral and detached. People generally interpret their observations based upon their assumptions, interpretations, and beliefs. In contrast, electronic data and IoT data are objective and empirical. When employed and interpreted within their proper context, these data points can be extremely reliable as to area(s) of origin determination, investigative timelines, and fire progression.

As a result, the researcher will be authoring a public input to the NFPA 921 technical committee recommending a change. The current edition of NFPA 921 states the following:

> 18.1.2 Determination of the origin of the fire involves the coordination of information derived from one or more of the following:
> (1) *Witness Information and/or Electronic Data.* The analysis of observations reported by persons who witnessed the fire or were aware of conditions present at the time of the fire as well as the analysis of electronic data including but not limited to security camera footage, alarm system activation, or other data recorded in an around the time of the fire event.
> (2) *Fire Patterns.* The analysis of effects and patterns left by fire, which may include patterns involving electrical conductors.

> (3) *Fire Dynamics.* The analysis of the fire dynamics [i.e., the physics and chemistry of fire initiation and growth…and the interaction between the fire and the building's systems… (NFPA 921, 2020, p. 220)

The recommendation which will be made by the researcher is to amend section 18.1.2 to read as follows, with proposed changes in bold:

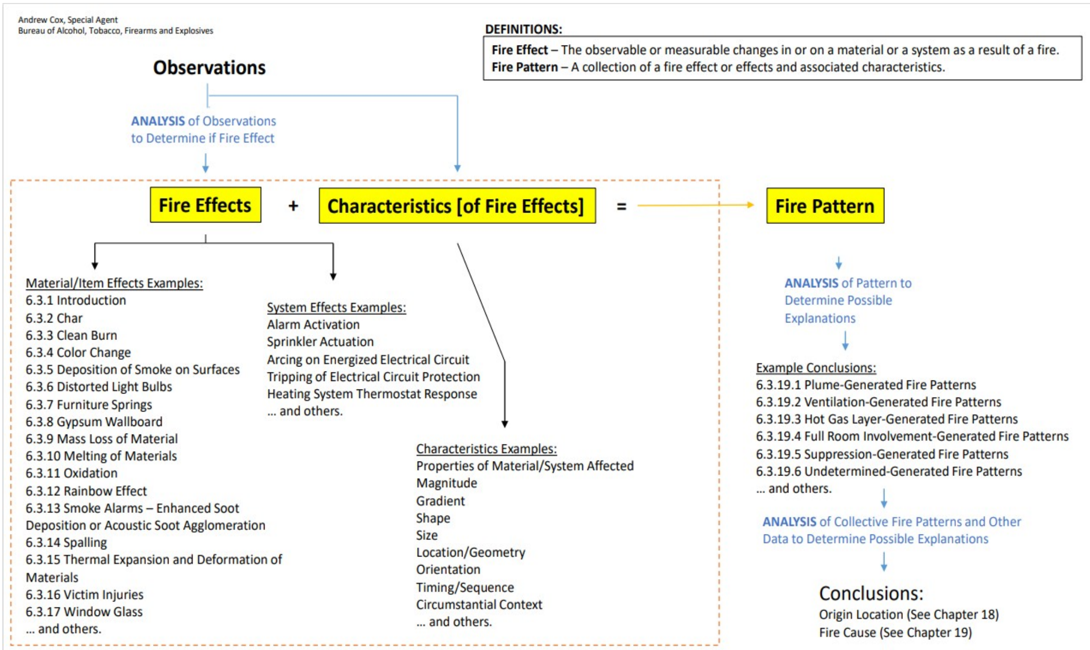
> Determination of the origin of the fire involves the coordination of information derived from one or more of the following:
> (1) *Witness Information.* The analysis of observations reported by persons who witnessed the fire or were aware of conditions present at the time of the fire.
> ***(2) Electronic/IoT data. The analysis of electronic and /or IoT connected system data including but not limited to security camera footage, fault detection, alarm system activation, communication errors, or other data recorded in and around the time of the fire event.***
> (3) *Fire Patterns.* The analysis of effects and patterns left by fire, which may include patterns involving electrical conductors.
> (4) *Fire Dynamics.* The analysis of the fire dynamics [i.e., the physics and chemistry of fire initiation and growth…and the interaction between the fire and the building's systems… (NFPA 921, 2020, p. 220)

The researcher will also be recommending an additional chapter to NFPA 921 concerning electronic and IoT data, its use, and subsequent application to a fire scene examination. The basic premise of IoT systems and their operation will be included, as well as a background of how these systems can be used to augment fire investigations. Examples of usage will include fixed video surveillance systems, Wi-Fi connections, and the mapping out of activation, detection, and failure data. Investigative concerns which must be addressed will also be incorporated.

The results of this research also supports an additional change to NFPA 921 which has been proposed by ATF CFI Andrew Cox. That proposal looks at creating a more thorough understanding of the terms "fire effect" and "fire pattern." Furthermore, it emphasizes the importance of the "characteristics of fire effects." Cox recommends a conceptual equation of *Fire Effects + Characteristics (of fire effects) = Fire Pattern.* A fire effect can include examples such as char, clean burn, melting, mass loss, oxidation, arcing, and system activations. The characteristics of fire effects include shape, size, location, orientation, and sequence. Cox's proposal contends that individual IoT system activations and failures can be considered a fire effect. The totality of the timeline for all of the system activations and failures results in a fire pattern which can subsequently be analyzed by the investigator in order to determine possible explanations. This proposal is very similar in nature to the NFPA 921 change in the 2021 edition involving arc artifacts on energized electrical systems and arc mapping. Figure 77 (Cox, 2021, p. 1) depicts a visual graphic of Cox's proposal.

Figure 77

Cox's Proposed Changes



Note. Source: A. Cox, personal communication, 2021.

Further Research

There are several areas in need of additional research as a result of the current study. Additional research should be conducted as to best practices for both requesting the data as well as processing the data. For example, the development of a step-by-step list regarding the process of requesting the data from frequently encountered companies. Moreover, SMEs could work with researchers to produce a flowchart related to IoT data extraction, preservation, and application for the general types of building systems.

While the use of IoT data is a useful tool for fire investigators processing a large fire scene, it can also be applied to smaller incidents such as residences. With the plethora of smart appliances, smart homes, Nest thermostats, and other devices, it is prudent for research to be conducted on the use of this data within a smaller scene footprint. An example would be the use of the temperature rise recorded by a Nest thermostat to assist in timeline development. Research should be conducted to ascertain the methods or processes that are needed to successfully employ this process in smaller fire scenes.

Finally, the potential use of IoT data within a court of law must be explored, including the potential legal challenges regarding this information. In 2016, the President's Council of Advisors of Science and Technology (PCAST) wrote *Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods*. They concluded that there were two important gaps in the field of forensic science that must be addressed. The first is that clarity is needed regarding the scientific standards employed involving validity and reliability (PCAST, 2016, p. x). Second, specific forensic methods must be evaluated to ascertain whether they have been concluded to be scientifically proven to be valid and reliable (PCAST, 2016, p. x).

PCAST was able to establish two types of scientific validity for forensic methodologies. Foundational validity "requires that it be shown, based on empirical studies, to be repeatable, reproducible, and accurate, at levels that have been measured and are appropriate to the intended application" (PCAST, 2016, p. 4). PCAST also defined validity as applied to be the proper application of the method in practice. These concepts are what is considered within Federal Rule of Evidence (FRE) 702. FRE 702 specifically states that the trial judge shall conduct 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 in issue" (509 U.S. 579, 1993, pp. 592-593).

Summary

Chapter 5 opened with a discussion about the textual themes encountered during the analysis of SME interview transcriptions. The key themes included the need for context when interpreting and applying the data, the primary use of IoT data, in addition to the perceived strengths and weaknesses of the technique. The potential sources of error related to this process are considered. These involve not only the possibility of human error, but also error potentially inherent to the extracted data itself. Mitigation processes are examined with a heavy emphasis on a quality assurance approach to the data. When investigators are aware of the potential sources of systematic error, they can take steps to ensure that proper procedures and adjustments are in place to facilitate the proper application and interpretation of data.

The benefits and drawbacks to the use of IoT data in fire investigation were opined and enumerated in this chapter. The research questions that drove the current study were reviewed, and the investigative findings of each were concisely explained. Self-reflection by the researcher was undertaken and described the personal experience of the research process, the depth of understanding, distinctive expectations, and resulting outcomes. The case reviews, coupled with individual SME interviews, provided a rich and profound understanding of the entire process. Recommendations to the fire investigation community identifying the need for training related to this approach, as well as an augmentation in NFPA 921, were provided. Additional pathways for future research in this particular area were identified, including the definition of best practices, the application of this technique to smaller scenes, and the identification of any potential for legal challenges in a court of law.

The significance of the current research findings is that IoT-connected building systems can potentially provide critical data points for fire investigators. These data points can be applied and interpreted to assist with not only determining the area(s) of fire origin, but additional factors such as timelines, fire progression, statement evaluation, and possibly even fire classification. The use of IoT data during a scene examination represents a significant step forward in the realm of fire investigation technology awareness and its subsequent application in the investigation of incidents.

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Appendix A

IRB Approval

OSU CHS IRB
Approval Effective:
April 27, 2021

RESEARCH SUBJECT INFORMATION SHEET

Title:	**Internet of Things (IoT) Connected Building Systems and Their Use in Fire Investigations: A Mixed Method Study**
Protocol No.:	2021034
Sponsor:	Oklahoma State University Center for Health Sciences
Investigator:	Dawn T. Dodsworth
	1521 1st Avenue S.
	Suite 600
	Seattle, WA 98134
	United States
Daytime Phone Number:	860-778-3796
24-hour Phone Number:	862-219-9338

You are being invited to take part in a research study. A person who takes part in a research study is called a research subject, or research participant.

What should I know about this research?

- Someone will explain this research to you.
- This form sums up that explanation.
- Taking part in this research is voluntary. Whether you take part is up to you.
- You can choose not to take part. There will be no penalty or loss of benefits to which you are otherwise entitled.
- You can agree to take part and later change your mind. There will be no penalty or loss of benefits to which you are otherwise entitled.
- If you don't understand, ask questions.
- Ask all the questions you want before you decide.

Why is this research being done?

The purpose of this research is to delve more deeply into the use of Internet of Things (IoT) connected building systems (such as WiFi, fire protection and alarm systems) and its ability to assist fire investigators with narrowing down or determining area(s) of fire origin. This research will provide fire investigators the ability to use empirical data points in their fire scene examinations.

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How long will I be in this research?

We expect that your taking part in this research will last of total of approximately 2 hours. Up to one hour for a recorded interview. Additionally, up to one hour for you to later review the transcription of your interview for accuracy.

What happens to me if I agree to take part in this research?

If you agree to be in this study, we would ask you to do the following things: Be available for an audio and/or video recorded interview regarding your experience with the researcher at a mutually convenient time during your normal work hours. This interview will focus on your personal experience in utilizing IoT connected building systems in order to narrow down or identify an area(s) of fire origin during a fire scene examination. The researcher can provide you with a copy of the Origin and Cause Report and any associated engineering reports from the fire scene(s) you participated in, in which this data was utilized upon your request.

Could being in this research hurt me?

There are no known risks associated with this project which are greater than those ordinarily encountered in daily life.

There is a potential risk of breach of confidentiality which is minimized by the securing of all materials related to your participation within a locked filing cabinet in a restricted-access office. The only people with access to this information will be the researcher and the transcriber for the interviews. The transcriber will sign a nondisclosure/confidentiality agreement prior to having access to any of the materials related to your participation.

Will it cost me money to take part in this research?

Taking part in this research will not cost you anything.

Will being in this research benefit me?

There are no direct benefits to you for participating in this study. More broadly, this study may help the researchers learn more about IoT connected building systems and their use in narrowing down and/or determining area(s) of fire origin. The research may help in furthering this technique as an additional tool for fire investigators during fire scene examinations.

OKLAHOMA STATE UNIVERSITY
CENTER FOR HEALTH SCIENCES

What other choices do I have besides taking part in this research?

Your only alternative is to not take part in the research.

What happens to the information collected for this research?

Your private information (such as your name, job experience and email) will be shared with individuals and organizations that conduct or watch over this research, including:

- The research sponsor
- People who work with the research sponsor
- The Institutional Review Board (IRB) that reviewed this research
- The interview transcriptionist

We may publish the results of this research. However, we will keep your name and other identifying information confidential.

We protect your information from disclosure to others to the extent required by law. We cannot promise complete secrecy.

Who can answer my questions about this research?

If you have questions, concerns, or complaints, or think this research has hurt you or made you sick, talk to the research team at the phone number listed above on the first page.

This research is being overseen by an Institutional Review Board ("IRB"). An IRB is a group of people who perform independent review of research studies. You may talk to them at 918-561-1400 or chsirb@okstate.edu if:

- You have questions, concerns, or complaints that are not being answered by the research team.
- You are not getting answers from the research team.
- You cannot reach the research team.
- You want to talk to someone else about the research.
- You have questions about your rights as a research subject.

What happens if I agree to be in this research, but I change my mind later?

If you decide to leave this research, simply notifiy the research team so that you will no longer be contacted pursuant to your interview and/or transcription review.

There are no potential adverse consequences to a subject who withdraws.

Will I be paid for taking part in this research?

You will not be paid for taking part in this research.

You have read or have had read to you a description of the research study as outlined above. The investigator or his/her representative has explained the study to you and has answered all the questions you have at this time. You knowingly and freely choose to participate in the study. A copy of this consent form will be given to you for your records.

______________________________________ ______________
Signature of adult subject capable of consent — Date

______________________________________ ______________
Signature of person obtaining consent — Date

Appendix B

Questionnaire Template for CFIs

1. How long have you been employed with ATF?
2. What does your job entail?
3. What is your cumulative fire investigation experience?

The following questions constitute the data for the study that helps answer the research question. As a reminder, you may opt out of taking part in this interview at any time with no penalty.

4. In your experience, what can the Internet of Things (IoT) potentially bring to the table in fire investigation?
5. How have you utilized IoT related systems (for example: fire protection systems, security systems, home automation) to narrow down or determine an area of origin?
6. What type of system was it?
7. How was the data interpreted and applied?
8. What are the strengths of using IoT systems when determining an area of origin in a fire?
9. What are the shortcomings?

Appendix C

Questionnaire Template for FRL Engineers

1. How long have you been employed with ATF?

2. What does your job entail?

3. What is your cumulative fire investigation experience?

The following questions constitute the data for the study that helps answer the research question. As a reminder, you may opt out of taking part in this interview at any time with no penalty.

4. In your experience, what can the Internet of Things (IoT) potentially bring to the table in fire investigation?

5. How have you utilized IoT related systems (for example: fire protection systems, security systems, home automation) to narrow down or determine an area of origin?

6. What type of system was it?

7. How was the data interpreted and applied?

8. What are the strengths of using IoT systems when determining an area of origin in a fire?

9. What are the shortcomings?

VITA

Dawn Terri Dodsworth

Candidate for the Degree of

Doctor of Philosophy

Dissertation: INTERNET OF THINGS (IoT) CONNECTED BUILDING SYSTEMS AND THEIR USE IN FIRE INVESTIGATIONS: A MIXED METHOD STUDY

Major Field: Forensic Science

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Completed the requirements for the Doctor of Philosophy in Forensic Science at Oklahoma State University, Stillwater, Oklahoma in December 2021.

Completed the requirements for the Master of Arts in your Leadership and Public Administration at Centenary College, Hackettstown, New Jersey in 2004.

Completed the requirements for the Bachelor of Arts in your Sociology at Moravian College, Bethlehem, Pennsylvania in 1997.

Experience:

Senior Special Agent/Certified Fire Investigator – Bureau of Alcohol, Tobacco, Firearms, and Explosives

Professional Memberships:

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International Association of Arson Investigators (IAAI)

Washington State Chapter of IAAI – Board of Directors