Arc Mapping: Who and Why?

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Abstract:

Background
In 2020, the National Fire Protection Association (NFPA) released the 2021 edition of NFPA 921: Guide for Fire and Explosion Investigations. In this new edition, the technique of arc mapping is no longer considered one of four methods to determine the area of origin of a fire but instead has been reclassified as a fire pattern. This reclassification is a product of diverging opinions among experts in fire investigations.

Methods
To collect this information, the author circulated a survey tool to 98 professionals in the fields of fire investigation, fire science, and forensics. The survey tool comprised of 11 possible questions and sought to identify trends in arc mapping's use, success, and acceptance among the fire investigation field.

Results
Trends identified include: a correlation between training specific to arc mapping and the frequency of consideration, an increased frequency of use by private sector investigators, and a direct relationship between the use of arc mapping and the availability of resources. Finally, when considering these practitioners' experiences, the respondents' rate of success can be estimated at 78%.

Conclusion
A review of literature was used to outline the arc mapping principle most widely accepted among fire investigators. Similarly, the results of the survey tool provided insight into why investigators consider using arc mapping, what factors are considered when using arc mapping, and how this technique is used.

Key Words:
Arc mapping, arc surveys, electricity and electrical systems, fire investigations, fire pattern analysis, origin and cause determination

Introduction:

Arc mapping first appeared in the 2001 edition of the National Fire Protection Association's (NFPA) NFPA 921: Guide for Fire and Explosion Investigations as one of four ways to determine a fire's area of origin.[1] The detailed procedures associated with using this technique were introduced in subsequent editions. In order to perform arc mapping, investigators plot the locations of electrical artifacts on a three-dimensional diagram and identify areas of increased arc evidence. While the method for plotting arc sites has not changed, the understanding of arc mapping has evolved.

The 2021 edition of NFPA 921 cites three methods to determine the area of origin: witness information and/or electrical data, fire patterns, and fire dynamics.[2] This edition no longer expressly identifies arc mapping as a method to determine the area of origin; however, it incorporates this technique into the discussion of fire patterns when it mentions "patterns involving electrical conductors."

While the latest edition of NFPA 921 discusses how the original arc mapping hypotheses have been disproved, there are several principles that have been scientifically validated and accepted among the fire investigations community. First, the presence of an arc site on an electrical conductor confirms that power was present during the time of fire impingement. Furthermore, the absence of arc damage is not proof that the conductors were deenergized prior to the fire.[2-5] Secondly, the identification of a sever arc indicates that any arc site downstream had to have occurred prior or simultaneously to the arc melting closer to the power source.[2,5,6] *A Methodology for the Examination of an Electrical System by Fire Investigators and Engineers,* explains that this principle is only reliable if a sever arc occurs on the ungrounded (hot) conductor and without this, no conclusions can be made.[3] Additionally, arc mapping can be used to determine a sequence of events during an origin and cause investigation.[2,4,5,7] The final concept that is commonly agreed upon is the need to account for ventilation and fuel profiles, [2, 5, 8,9] fire patterns, and witness statements if available when interpreting the findings of an arc survey. [2, 5, 16]

In the Spring 2021 edition of Fire & Arson Investigator, authors Kurt Franzi, Cameron Novak, and Michael Keller demonstrate how circuit protection devices can inhibit the formation of arc characteristics.[5] In this article, the authors compare the reaction times of, and damage to; thermal magnetic devices (TM), ground fault circuit interrupters (GFCI), and arc fault circuit interrupters (AFCI). These experiments added several pertinent observations to the arc mapping discussion[5]. First, they established a hierarchy of failure times, with circuits protected by GFCIs failing the fastest, and the TM devices the slowest. This information can be used to establish a sequence of events pertaining to the cessation of electrical flow. Next, they reinforced the relationship between the time required to activate these devices and heat flux. Finally, they accounted for the lack of arcing on energized conductors when considering circuit protection. The authors concluded that arc melting occurred on AFCI protected circuits 70% of the time, 40% of the time on GFCI protected circuits, and 100% of the circuits protected by TM devices[5].

Diverging opinions exist among experts in the research areas of fire investigations. One area of active discussion among arc mapping critics is the identification of arc sites. Section 3.3.11 of

NFPA 921 defines arc sites as "locations on a conductor with localized damage that resulted from an electrical arc."[2] A 2012 study conducted by Roby and McAllister suggested that fire investigators could not accurately differentiate between arc melting and damage caused by exposure to the fire.[10] This conclusion was later refuted by other members of the fire investigations community and the recommendations of Roby and McAllister have not been adopted as part of NFPA 921. Conversely, members of the Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF) through systematic research have compiled a growing list of characteristics to assist fire investigators, electrical engineers, and others in the fire investigations community in differentiating between arc damage and fire melting.[3, 4, 7, 11] Many of these characteristics can also be seen in Dr. Vytenis Babrauskas's proposal to the NFPA 921 Committee titled *Distinguishing Melt Globules from Arc Beads.*[12]

In 2018, Dr. Vytenis Babrauskas, a fire protection engineer, published *Arc Mapping: A Critical Review* where he estimated that there is a 0.73% chance arc mapping would produce a reliable direction for fire travel if used alone. He continued to discuss how ventilation and fuel packages can produce concentrations of arc sites which would make arc mapping unreliable.[6]

In response to Babrauskas's document, the ATF released their technical bulletin titled *Arc Mapping as a Tool for Fire Investigations*. This document explains that arc mapping can act as a reliable tool if all aspects of the fire scene are considered. Pertinent conditions include the fire's fuel package, failure timing, the influence of ventilation, and the building's construction features such as wiring, circuit configurations, and vertical or horizontal barriers.[8] Furthermore, Carey and Nic Daeid discussed how arc sites were present in the area of origin 85% of the time or greater. Additionally, they were able to reproduce these findings 95% of the time.[13]

A third criticism of arc mapping can be found in the Fall 2020 edition of the Lincoln Memorial University Law Review. Here, Thomas May and David Icove discuss possible shortcomings when utilizing data derived from arc mapping during expert testimony.[14] May and Icove list the following criticism when conducting arc surveys:

"... (1) overpromises on the technique's precision, (2) exaggerated inferences from the available data (3) failure to adequately account for potential methodological flaws, (4) deficient scientific rigor in establishing evidentiary fire origin-related reliability, (5) errors due to deficient practitioner training and experience, and (6) indeterminate findings based upon subjective visual analysis."[14]

In the July 2021 edition of The Journal of the National Academy of Forensic Engineers, Icove and May joined Elizabeth Buc and Mark Goodson and published *State of the Arc (Mapping)* which compiled the latest peer reviewed information regarding arc mapping.[15] Icove et al. acknowledge that arc mapping is widely used and accepted among fire investigators but continue that "the quality of arc mapping varies."[15] They discuss how fire investigators and electrical engineers can differentiate between arc damage and exposure damage, then caution the practitioner when drawing conclusions without sufficient information.[15]

Our research was intended to analyze who is using arc mapping, examine the reasons for or against its use and how it is being employed in the field. The research also attempted to identify

trends concerning training specific to arc mapping, a practitioner's length of service, and a correlation between using arc mapping and the private and public sectors. Finally, utilizing both a literature review and survey responses, the authors attempted to identify common areas of error to assist newer investigators with understanding this technique. In an effort to minimize the gaps identified above, we were able to use our existing data to extrapolate an approximate rate of error based on the responses collected.

Methods:

Procedure

We performed an exploratory, cross-sectional analysis to examine the association between demographic characteristics, training experience, and the use of arc mapping among a sample of fire science professionals located in the U.S. Both quantitative and qualitative responses were collected anonymously through the online survey platform SurveyMonkey. When identifying possible participants, the authors chose to use a convenience sample based on contacts acquired while working in the field of fire investigations. This sample included a variety of fire investigations related professionals such as public and private investigators, fire protection and electrical engineers, and fire officers. The methodology used in this study was submitted for ethics review and approved via an institutional review board.

Survey Instrument

The survey instrument was composed of 11 items. The survey collected demographic information (i.e., job classification and experience level), whether professionals had received training specific to arc mapping (yes versus no), whether the professionals use arc mapping during origin and cause investigations (yes versus no), and how valuable professionals felt arc mapping is in determining the origin and cause of fire (Likert scale ranging from 1 (*no value*) to 5 (*extremely valuable*). Further, participants were asked to rank factors (budget, time, comfort level, availability of an expert opinion such as an engineer, size of loss, the investigation being potentially criminal in nature, and the investigation being potentially civil in nature) based on the level of importance when making the decision to conduct arc mapping at a fire scene. Finally, the survey consisted of 4 open-ended questions. Professionals were asked; 1) whether they identified important variables related to the process of arc mapping, 2) whether they encountered an instance while conducting an arc study where the results falsely identified an area of origin, 3) whether they've developed any valuable best practices while conducting arc mapping, and 4) whether certain factors influence their decision to not use arc mapping.

Statistical Analyses

Statistical analyses were performed using IBM SPSS Statistics 24. Two chi-square tests of independence were conducted to examine the following RQs:

1. Is there an association between those that have received arc mapping training and the use of arc mapping during origin and cause investigations?

2. Is there an association between years working within the field of fire investigations and the use of arc mapping during origin and cause investigations?

   This analysis was selected due to the categorical nature of the independent and dependent variables. Contingency tables, containing the number of cases that fall into each combination of categories, were examined. Pearson chi-square statistic tests and the Likelihood Ratio (recommended with smaller samples) were used to assess whether the variables were independent. The level of significance was set at $\alpha = .05$. Effect sizes (Cramér's V) were also reported.

   In order to further explore the data, such as the perceived value in arc mapping, reasons for using arc mapping, and errors encountered by respondents, descriptive statistics (i.e., frequencies and percentages) were reported. Qualitative data was analyzed by coding the data according to key words and/or phrases identified in the participants' responses. Once the data was coded, recurring themes (i.e., opinions or beliefs) were categorized and reported in conjunction with the descriptive statistics.

Results:

The survey was distributed to a total of 98 professionals in the field of fire investigations or fire science. This included: 68 public sector fire investigators, 11 private investigators, 7 engineers, 9 educators, and 3 fire officers with an educational background in fire investigation. A total of 41 professionals chose to participate in the study, providing a 42% response rate. Sample characteristics are disaggregated and displayed in Table 1.

Table 1

Demographic characteristics among 41 professionals in the fields of fire investigation, fire science, and forensic science.

	Percent	*N*
Job Classification		
Fire Officer	5	2
Fire Protection Engineer	2	1
Forensic Chemist	2	1
Forensic Engineer	5	2
Lieutenant/Paramedic	2	1
Private Sector Fire Investigator	22	9
Public Sector Fire Investigator	61	25
Total	100	41
Experience		
Less than 1 year	2	1
1 – 5 years	34	14
6 – 10 years	22	9
11 – 15 years	12	5
16 – 20 years	7	3
20+ years	22	9
Total	100	41

Who is Using Arc Mapping?

As shown in the contingency table (Table 2), 29 out of 41 professionals (71%) use or consider using arc mapping during origin and cause investigations. Twenty-four out of these 29 professionals (83%) have received training specific to arc mapping outside of what is included in the entry level fire investigator certification (NFPA 1033 or equivalent). A total of 12 professionals stated they did not use arc mapping during origin and cause investigations (29%). Nine out of these 12 professionals (75%) stated they have not received additional arc mapping training. There was a significant association between those that had received additional arc mapping training and professionals that use or consider using arc mapping, $\chi 2\ (1) = 12.59$, $p < .001$. Additionally, the Likelihood Ratio test statistic was 12.49 ($p < .001$) and Fisher's Exact test was $p < .01$. Cramér's V (φc) statistic was .55 out of a possible maximum of 1 representing a medium association between those that have received arc mapping training and utilizing arc mapping in the field. Given this analysis consisted of a 2 X 2 contingency table, we calculated an odds ratio for further interpretability. Based on the odds ratio, the odds of using or considering using arc mapping were 14.29 times higher if the professionals had received training compared to if they had not received training.

Table 2

Arc mapping training by arc mapping usage crosstabulation

		Uses or Considers Using Arc Mapping During Origin and Cause Investigations		
Arc Mapping Training		No	Yes	Total
	No Training	9 (22%)	5 (12%)	14 (34%)
	Training	3 (7%)	24 (59%)	27 (66%)
Total		12 (29%)	29 (71%)	41 (100%)

Note: % of the total for each category is presented in parentheses.

As shown in Table 3, out of the 29 professionals that use or consider using arc mapping during origin and cause investigations, those that had 6 – 10 (24%) and > 20 years of experience (31%) were most likely to use the technique compared to other subcategories. Interestingly, a larger proportion of professionals working in the field of fire investigations for 1 – 5 years (21%) reported they are more likely to use or consider using arc mapping than professionals working in the field for 11 – 15 (10%) and 16 – 20 years (10%). There was a borderline statistically significant (i.e., $p = .049$) association between professional experience and professionals that use or consider using arc mapping, $\chi 2\ (1) = 11.13$, $p = .049$. However, the Likelihood Ratio test statistic (14.19) indicated a statistically significant association between the two variables ($p < .05$). Cramér's V (φc) statistic was .52 out of a possible maximum of 1 representing a medium association between professional experience and the use of arc mapping.

Table 3

Professional experience by arc mapping usage crosstabulation

		Uses or Considers Using Arc Mapping During Origin and Cause Investigations		
Professional Experience		No	Yes	Total
	< 1 year	0 (0%)	1 (2%)	1 (2%)
	1 – 5 years	8 (20%)	6 (15%)	14 (34%)
	6 – 10 years	2 (5%)	7 (17%)	9 (22%)
	11 – 15 years	2 (5%)	3 (7%)	5 (12%)
	16 – 20 years	0 (0%)	3 (7%)	3 (7%)
	20+ years	0 (0%)	9 (22%)	9 (22%)
Total		12 (29%)	29 (71%)	41 (100%)

Note: % of the total for each category is presented in parentheses.

Further, results indicated that investigators in the private sector are more likely to utilize arc mapping. Of the 9 private investigators responding to the survey, all indicated that they use or consider using arc mapping during an origin and cause investigation. In contrast, only 60% of the public sector investigators responded that they routinely use this method.

Perceived Value of Arc Mapping

Professionals were asked to denote arc mapping's value on a scale of 1 (*no value*) to 5 (*extremely valuable*). Of the 29 respondents who considered using arc mapping, 25 of them provided a response. Overall, 24% of these responses indicated arc mapping is extremely valuable, 20% that it is very valuable, and 52% indicated it is somewhat valuable. Only one respondent indicated that they do not find value in arc mapping.

We further disaggregated responses according to training and level of experience to determine if such factors influenced perceived value in arc mapping. Of the 25 respondents, 21 indicated they had received training and 4 indicated they had not received training. As seen in Figure 1a the majority, both those that had received training (48%) and those that had not received training (75%), considered arc mapping to be somewhat valuable. As shown in Figure 1b, responses were disaggregated according to the length of time working in the field of fire investigations. To obtain a more balanced design, we collapsed adjacent categories; For example, respondents indicating they had < 1 year of experience were combined with those indicating they had 1 - 5 years of experience, etc. Again, the majority, across all three categories, perceived arc mapping as somewhat valuable. Interestingly, the respondent that perceived arc mapping as not valuable had both received training specific to arc mapping and had been working in the field of fire investigations 16 to 20+ years.

Reasons for Using Arc Mapping

Survey data was also used to examine if investigators were using arc mapping to predominantly prove or disprove a hypothesis. Of the 24 responding investigators, 70.9% indicated they use this technique equally when testing hypotheses. Conversely, 25% indicated they used arc mapping to support their hypotheses, and only 4.1% used it solely to negate a hypothesis.

Two dominant trends appeared in the qualitative data regarding aversion to the use of arc mapping. First, those with less training and experience were less likely to utilize the technique. Second, the increased amount of time and necessary resources needed to conduct arc mapping deterred individuals from using the technique. Thirty-three percent of the professionals cited this as cause for not using arc mapping. Similarly, 25% of the 12 investigators responding to this question indicated they do not conduct arc mapping because the insurance companies will do so. Interestingly, while financial resources and time restraints are mentioned most frequently, only one respondent indicated the lack of access to specialized experts, such as electrical engineers, factored into their decision.

Known Rate of Error

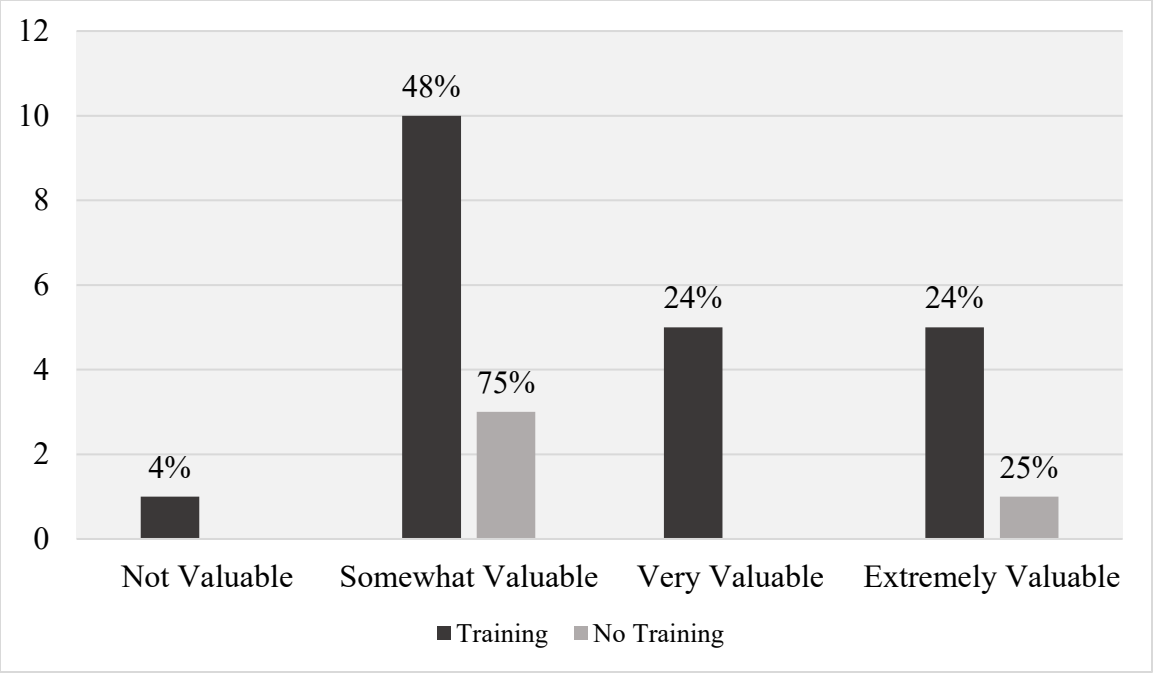
Of the 18 professionals that responded to this portion of the qualitative section, 14 (78%) indicated that they had not received a false area of origin when using arc mapping. The information in the following section was provided by the 4 (22%) investigators reporting known errors.

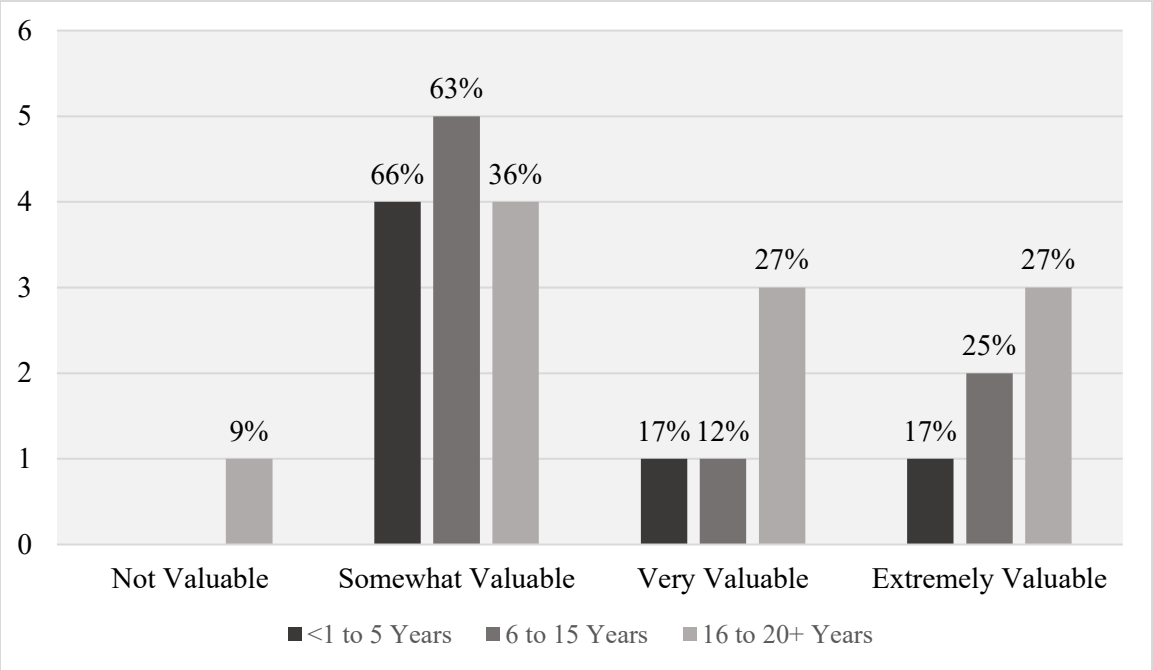
In order to minimize future errors through better understanding of the process of arc mapping, we attempted to compile a list of causes for errors listed by respondents. Several factors were identified by participants in the survey. Generally, the causes revolved around a misinterpretation or over-exaggeration of other information present.

Similarly, the presence of additional storage or pathways of electricity such as backup generators, uninterruptible power supplies, or vehicle batteries was suggested. These factors revolve around the issue of the back feeding of electricity, which is addressed in both NFPA 921's discussion of arc mapping[2] and Babrauskas's article *Arc Mapping: A Critical Review*.[6] Additional examples provided were the presence of previous electrical damage prior to the fire, exposure damage to the electrical conductors because of the fire, and multiple active circuits that were present in a rapidly progressing fire.

Figure 1a and 1b

Perceived value in arc mapping disaggregated by those that 1) have received arc mapping training versus those that have not and 2) according to the length of time working in the field of fire investigations





Discussion:

While conducting this research, it was observed that the consideration for using arc mapping was approximately 14 times greater among those that have additional training. Similarly, a direct relationship between the use of arc mapping and the availability of resources was observed. Finally, a theoretical rate of error was able to be compiled from the data gathered.

Who is Using Arc Mapping?

The relationship between willingness to apply arc mapping to a fire investigation and training in the use of the technique can be seen in the ATF's Arc Mapping as a Tool for Fire Investigations wherein the authors wrote, "In order to properly apply arc mapping in fire investigations, the investigator must have a strong knowledge of electricity, building construction, fire dynamics, and wiring practices." [8] This statement supports the relationship between training and the consideration for arc mapping identified in the present study. Furthermore, it suggests additional training in these disciplines would strengthen an investigator's knowledge of the arc mapping process.

The need for recurring training can also be seen in the Recommendations Section of ATF's *Visual Characteristics of Fire Melting on Copper Conductors* when the authors comment that "practice and training are the best ways to become proficient at identifying the difference between fire and arc melting." [11] Likewise, when discussing arc mapping and a fire investigator's ability to properly identify electrical artifacts, Icove et.al state, "The skill set is a combination of background, training, and experience." [15]

How is Arc Mapping Being Used?

In the article *A Methodology for the Examination of an Electrical System by Fire Investigators and Engineers*, Cameron Novak states, "Arc mapping is a tool to test a hypothesis…"[3] This led the researchers to investigate if this technique was predominantly used to prove or disprove a possible origin and cause determination. The quantitative data demonstrated that arc mapping is used equally to prove and disprove hypotheses.

During analysis of the qualitative data collected in the present study, several practitioners stressed that they do not use arc mapping solely to test a hypothesis and that it is simply an additional investigative tool. Novak also acknowledges that this technique is one source of data and should not be used alone. [3]

Additional information on the use of arc mapping was offered by Mr. Jeremy Neagle, an electrical engineer with the ATF, during his December 2020 presentation *Basic Electricity, Electrical Appliances, and Arc Mapping*.[7] In this lecture he presented three ways to use the information gained during arc mapping, which include developing an area of origin, establishing a timeline, and testing various hypotheses during an origin and cause investigation. Mr. Neagle continued to discuss how arc site identification has led to establishing a working timeline and later an area of origin after occupants reported removing power to the structure.[7] Similar

explanations of how arc mapping is used can be seen in Novak's article when he discusses using this process to determine a fire's origin, direction, or sequence of events.[4]

Reasons for Not Using Arc Mapping

As discussed above, trends for not using arc mapping include practitioners with less training and experience and the increased amount of time and resources necessary to complete this task. We hypothesize that the second observation correlates with the increased frequency of consideration in the private sector, as these investigators generally have greater access to resources and a more flexible timeline. This is supported by the respondents who indicated they do not conduct arc mapping because the insurance companies will do so.

Errors Encountered by Respondents:

One practitioner's response indicated that inexperience with arc mapping was a cause for error. This statement combined with the trends regarding additional training and experience support the hypothesis that a lack of familiarity with the technique, and associated procedures, may contribute to inaccuracies during arc mapping. Investigator's inexperience also appears in the Lincoln Memorial University Law Review article when the authors identify "errors due to deficient practitioner training and experience."[14]

The misinterpretation or over exaggeration of data was another common theme for cause of practitioner error. This theme is also suggested in May and Icove's article when they list "exaggerated inferences from the available data" as one of the six pitfalls for relying on the findings of arc mapping as part of expert testimony.[14] One example from survey responses involved the misinterpretation or lack of consideration of fuel loads and ventilation patterns. These factors were also discussed in the article by Carey and Nic Daeid,[13] the ATF's 2017 technical bulletin,[8] and Wheeler's 2015 article *Arc Mapping: Things to Consider*.[9]

Similarly, Icove et al. discuss the "failure to adequately account for potential methodological flaws" as a pitfall to arc mapping.[15] Chapter 4 of NFPA 921 defines the scientific method as the basic methodology for conducting fire investigations. While not specific to arc mapping, the utilization of this method, combined with adequate knowledge, skills, and training, should minimize the frequency of criticisms on this basis. Additionally, Section 6.3.21.10 of NFPA 921 provides investigators with an overview of the arc mapping process to foster consensus among practitioners on the method(s) applied during fire investigations.[2]

During their discussion of expert testimony admissibility, May and Icove also suggest errors occur during the identification of electrical artifacts.[14] While NFPA 921 does not require experts to conduct arc mapping, it does discuss the use of electrical engineers and metallurgists to assist fire investigators with this process. The Guide for Fire and Explosion Investigations then continues to demonstrate how engineers can be used to perform difficult calculations and metallurgists can assist with scientifically confirming arc site identification but are not required to do so.[2] Furthermore, several documents exist to assist fire investigators with eliminating errors due to identification.[2, 4, 5, 7, 11, 12]

Limitations and Future Research

This research utilized a convenience sample based upon the author's contacts within the industry and thus surveyed a disproportionate amount of public sector fire investigators. The author acknowledges this data was not subject to rigorous statistical procedures due to the small sample size and thus only limited generalizations can be made. This study is exploratory in nature and intended to uncover areas of future research. Future research could include the expansion of the study to consist of a research group more representative and proportional to the entire industry, a more extensive compilation of methods to aid in arc mapping, and additional live fire experiments to test these practices and further delve into the accuracy of arc mapping.

References

1. National Fire Protection Association (NFPA). *NFPA 921: Guide for fire and explosion investigations 2001*. Quincy, MA: National Fire Protection Association; 2001.

2. National Fire Protection Association (NFPA). *NFPA 921: Guide for fire and explosion investigations 2021*. Quincy, MA: National Fire Protection Association; 2020.

3. Novak; C. A methodology for the examination of an electrical system by fire investigators and engineers. *Fire & Arson Investigator*. April 2020; 70(4), 30-37.

4. Novak C. A methodology for the identification and interpretation of damage on electrical wiring. *Fire & Arson Investigator.* July 2020; 71(1): 22-30.

5. Franzi K, Novak C, Keller M. Comparison of heat impinged conductors. *Fire & Arson Investigator.* April 2021; 71(4), 12-18.

6. Babrauskas V. Arc mapping: A critical review. *Fire Technology*, 54: 749-780.

7. Neagle; J. Basic electricity, electrical appliances, and arc mapping. Fairfax County Fire Investigations Section continuing education Fairfax VA. December 15, 2020.

8. *Arc Mapping as a Tool for Fire Investigations.* Ammendale, MD: Bureau of Alcohol Tobacco Firearms and Explosives (ATF) Fire Research Laboratory; 2017. ATFFRL-TB-170001.

9. Wheeler DM. Arc mapping things to consider. *Fire & Arson Investigator*. July 2015; 66(1); 17-23.

10. Roby R, McAllister J. *Forensic investigation techniques for inspecting electrical conductors involved in fire.* Columbia, MD: National Institute of Justice; 2012.

11. *Visual Characteristics of Fire Melting on Copper Conductors.* Ammendale, MD: Bureau of Alcohol Tobacco Firearms and Explosives (ATF) Fire Research Laboratory; 2012. Technical Bulletin 001.

12. Babrauskas V. *Distinguishing melt globules from arc beads.* NFPA 921-2014 Committee first draft proposal; 2012.

13. Carey N, Nic Daeid N. Arc mapping research – a clarification. *Fire & Arson Investigator.* October 2020; 71(2): 30-34.

14. May; TR, Icove; DJ. Arc mapping methodologies & the pursuit of magical globules, notches, & beads: A bridge too far to establish fire origin?. *Lincoln Memorial University Law Review*; 2020; *7*(2): 37-77.

15. Icove DJ, Buc EC, Goodson ME, May TR. State of the arc (mapping). *Journal of the National Academy of Forensic Engineers.* June 2021; *38*(1), 63-75. DOI: 10.51501/jotnafe.v38i1.127

16. Gorbett GE, Chapdelaine W. *Scientific Method - use, application, and gap analysis for origin and cause determination.* 2014 Symposium on Fire Investigation Science and Technology. 2014.