## ARTIFICIAL INTELLIGENCE – FIRE AND EXPLOSION INVESTIGATION © 2025

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## Abstract

This article examines the integration of Artificial Intelligence (AI) in fire investigation, highlighting its



potential to enhance investigative practices while emphasizing the need for caution. AI tools, such as Large Language Models (LLMs) and Retrieval-Augmented Generation (RAG), can aid in data analysis, hypothesis generation, and real-time monitoring, thereby enhancing the accuracy and efficiency of fire investigations. However, adopting AI raises legal and ethical concerns, including transparency, accuracy, and potential biases.

#### Figure 1 – Artificial Intelligence

The document discusses the roles of NFPA 921 and NFPA 1033 in guiding fire investigations, as well as the evolving use of AI in this field. Case studies illustrate the application of AI in real-world scenarios, demonstrating its benefits and limitations. The article emphasizes the importance of striking a balance between technological advancements and ethical standards to ensure reliable and credible outcomes in fire investigations.

## Keywords

Artificial Intelligence (AI), Fire Investigation, NFPA 921, NFPA 1033, Large Language Models (LLMs), Retrieval-Augmented Generation (RAG), Fire Dynamics Simulator (FDS), Predictive Modeling, Evidence Analysis, Fire Pattern Analysis, Ethical Considerations, Real-time Monitoring, Forensic Techniques, Fire Protection Systems, Digital Evidence, Predictive Analysis, Case Studies, Legal Standards, Expert Reports, Data Collection, Investigation Methodology, Fire Dynamics, Fire, Safety Engineering, AI Hallucination, Transparency, Bias, Ethical Standards

#### INTRODUCTION

This article explores the use of Artificial Intelligence (AI)  $^1$  in the fire and explosion investigation process, focusing on its application and potential impact on improving that process. While the evolving integration of AI offers new opportunities for reshaping our discipline, it is not without perils. Although it may potentially impact our methodology, opinions, and conclusions due to changing technology, human nature remains unchanged. That unchanging fact alone underscores the need for a measured approach that harnesses its potential power while emphasizing the importance of exercising caution in developing and applying this tool. While AI is gaining traction in fire investigations, its full acceptance will require continued development, regulation, and education, as is the case in any profession that utilizes its technology.

This paper is not intended to be a primer on Artificial Intelligence, does not aim to identify specific case matters or tools that incorporate it in the legal system, nor identify specific artificial intelligence tools, nor teach the reader how to apply those tools. Instead, it focuses on general ways fire investigators can and may use those tools. An excellent source for information on artificial intelligence in the legal profession is "Courts and Artificial Intelligence." <sup>2</sup> which explores AI in the legal system. "Artificial Intelligence: Now Being Employed in the Field of Law " also provides a comprehensive source that identifies specific cases in the legal system where AI is used, along with detailed examples of AI applications in various legal contexts, such as document reviews, forensic science, and sentencing analysis.



Currently, the courts consider both NFPA 921—Guide for Fire and Explosion Investigations (2024 ed.).<sup>3</sup> and NFPA 1033— Standard for Professional Qualifications<sup>4</sup> for Fire Investigators as standards of care in fire investigation, and fire investigators widely use both documents in their chosen profession. Technically, NFPA 921 а is guide (recommended), and NFPA 1033 is a standard (i.e., required when adopted by law).

#### Figure 2 – NFPA 921 and NFPA 1033

<sup>&</sup>lt;sup>1</sup> 1 Artificial intelligence (AI) refers to computer systems or tools capable of performing tasks that typically require human intelligence. In essence, AI aims to create computer systems that can perceive, learn, reason, and act in ways that mimic or surpass human cognitive abilities for specific tasks. The field continues to evolve rapidly, with ongoing debates about its current capabilities, future potential, and societal implications. AI is based on a combination of advanced algorithms, vast amounts of data, significant computing power, and various specialized techniques that together aim to replicate or surpass human cognitive functions.

<sup>&</sup>lt;sup>2</sup> A. D. (Dory) Reiling, 'Courts and Artificial Intelligence' (2020) 11(2) International Journal for Court Administration 8. DOI: <u>https://doi.org/10.36745/ijca.343</u>

 <sup>&</sup>lt;sup>3</sup> NFPA 921 – Guide for Fire and Explosion Investigations (2024 ed.) – National Fire Protection Association
 <sup>4</sup> NFPA 1033– Standard for Professional Qualification for Fire Investigators (2022 ed.) – National Fire Protection Association

The stated purpose of NFPA 921 has been and continues to be to improve the probability of reaching sound decisions. It does not, nor can it, guarantee that the outcome of every decision is sound. Over time, NFPA 921's recommendations have evolved to incorporate advances in methodology for determining the origin and cause of fires, as well as for collecting and managing physical evidence. Chapters have been added that focus on motor vehicle fires, wildfires, and appliances.

NFPA 921 was recently changed in 2024 to enhance its effectiveness and address evolving needs in fire and explosion investigations. It provides additional guidance on bias and expressions of certainty on conclusions, the impact of suppression activities, fire effects on electrical systems, and updates concerning fire patterns, arc mapping, and fire classification. These updates aim to improve the accuracy, reliability, and consistency of investigations and include the following:

- 1. Advancements Increase our understanding of fire dynamics, materials, and forensic techniques
- 2. *Feedback* Input from fire investigators, legal professionals, and other stakeholders.
- 3. *Requirements* Refer to legal proceedings and insurance claims.
- 4. *Clarity and Consistency* Clarifies concepts, provides additional guidance, and promotes investigation consistency.

NFPA 921 is a critical resource that informs the integration of emerging technologies and explains the crucial interplay with its sister document, NFPA 1033—Standard for Professional Qualifications for Fire Investigators. This document outlines the minimum job performance requirements for fire investigators, ensuring they possess the necessary knowledge and skills to determine the origin and cause of fires and explosions. Although NFPA 921 focuses on traditional investigative methodologies, neither it nor NFPA 1033 explicitly includes Artificial Intelligence or delves into its application to the fire investigative practices. This paper clarifies how Artificial Intelligence is currently integrated into fire investigation and is used by fire and explosion investigators to determine the origin and cause of fires.

# ARTIFICIAL INTELLIGENCE IN FIRE AND EXPLOSION INVESTIGATION



A cautionary tale, told in folklore and ubiquitous in popular culture, warns listeners of dangers and spreads awareness. In the story of the Trojan Horse, the Greeks constructed a giant wooden horse and concealed their presence within it. They offered it to the city of Troy as a gift. Once inside the city wall, the hidden soldiers emerged at night to open the gates for the rest of the Greek army, leading to the fall of Troy. Like most cautionary tales, the Trojan Horse warns of potential dangers but does not explain how they may be avoided.

#### Figure 3– Trojan Horse

Artificial intelligence (AI) refers to a computer or computer-controlled robot's ability to perform complex tasks historically only humans could do, such as reasoning, making decisions, or solving problems commonly associated with intelligent beings. Essentially, AI generally refers to the simulation of human intelligence in machines programmed to learn, think, and reason like humans. Concerning fire investigation, tasks that AI may aid investigators in include identifying and interpreting information that may help determine the origin and cause of a fire, testing whether an opinion or conclusion is consistent with the facts, evidence, and data, and reviewing reports.

Typically, AI systems are designed to perform tasks that require human intelligence, involving perception, reasoning, learning, and problem-solving. They use large language models (LLMs) stored in the cloud (i.e., online) and assessed by users employing tools such as Chatbots that emulate human language. AI tools can mimic human language, process enormous amounts of data, detect patterns, and assist investigators in making more informed decisions.

Artificial intelligence did not suddenly emerge; instead, it has developed over time and continues to evolve. Fuzzy logic <sup>5</sup> For example, fuzzy logic was first introduced in the 1960s and is a form of logic that deals with a type of reasoning that is approximate rather than fixed or exact. It allows values to be represented in degrees between true and false (0 or 1) rather than in a strictly binary way (either/or), helping to represent uncertainty and vagueness in real-world scenarios. Fuzzy logic enables a more nuanced approach to decision-making, particularly in systems where information is incomplete, uncertain, or unknown. Fuzzy logic has become a significant component of AI systems, especially in hybrid systems that can handle real-world problems more effectively. These systems aim to mimic human reasoning and address imprecision and uncertainty, rather than relying on either/or approaches.

Unlike computers that traditionally use binary systems of 0 or 1, either on or off, or true or false, fuzzy logic uses degrees of truth, sets clear boundaries, and incorporates rules and inferences to derive conclusions. For instance, in a smoke alarm, a rule might be "if the visibility is outside a particular range (i.e., higher), then turn on an alert." Smoke alarms incorporate artificial intelligence (AI) to enhance their effectiveness. Whereas they previously used physical sensors to detect the presence of smoke, they now employ more advanced algorithms and machine learning to analyze data in real-time, identifying early signs of fire and responding much quicker than conventional methods.

<sup>&</sup>lt;sup>5</sup> Fuzzy logic is a form of many-valued logic that allows for reasoning based on "degrees of truth" rather than the usual "true or false" (1 or 0) Boolean logic that computers are traditionally based on. Fuzzy logic provides a way to arrive at definite conclusions based on vague, ambiguous, imprecise, noisy, or missing input information. It's particularly useful in scenarios where human-like reasoning is needed or where precise mathematical models are difficult to construct.

In fire investigation, AI retrieves information from large language models using evolving tools rather than manual online searches. RAG <sup>6</sup> helps fire investigators solve the puzzle more effectively by combining real-time data with advanced AI analysis. Information is first retrieved from the cloud from large language models (LLMs). Then, the augmented context is modified by RAG and used to generate hypotheses, suggest possible causes, and recommend further investigative steps based on the original data and the retrieved information.

RAG can effectively extend the capabilities and knowledge contained within LLMs and optimize LLMs through training, allowing LLMs to remain accurate and up-to-date and minimizing AI hallucinations <sup>7</sup>. RAG also enables large organizations to develop systems (and knowledge) specific to their discipline (e.g., fires and fire investigation). If an organization is concerned about uploading personal information to the internet (e.g., information privacy), AI tools exist that allow investigators to download large language models (LLMs) and store and assess them locally to isolate them from online systems that any user may have access to.

**Retrieval Augmented Generation (RAG)** is an advanced AI technique that embraces the capabilities of large language models (LLMs), which are the basis for most Artificial Intelligence. While AI is not replacing traditional fire investigation methods, it is being used to augment and enhance the work of human investigators. RAG can apply AI more precisely to fire



investigation, providing fire investigators with external retrieval and local content developed and based locally and in-house. In the context of fire investigation, RAG can be a powerful tool to enhance the analysis. It can be leveraged to reach quicker and

more accurate findings regarding the potential origin and cause of fires.

## Figure 4 RAG Process

<sup>&</sup>lt;sup>6</sup> Retrieval-Augmented Generation (RAG) is an AI framework designed to improve the quality and accuracy of responses generated by large language models (LLMs) by training and grounding them on external sources of knowledge. RAG enhances LLMs by dynamically incorporating external knowledge, leading to more accurate, current, and trustworthy AI-generated responses across various applications.

<sup>&</sup>lt;sup>7</sup> AI Hallucination - An AI hallucination occurs when an artificial intelligence system, such as a large language model (LLM) or computer vision tool, generates false and misleading output.

An example of RAG-generated AI output for a fire investigator working on a warehouse fire case.

Example of using RAG in fire investigation.

- 1. Information Retrieval: The AI system retrieves data from previous fire cases involving warehouses, scientific studies on fire spread, information about the materials commonly stored in warehouses, data on how certain materials might react in a fire, and requirements and guidelines from applicable codes and standards.
- 2. Augmentation: This information includes detailed reports on similar fires and can be generated and stored locally and isolated from the cloud. It may also contain specific information about the actual fire being investigated.
- 3. Generation The AI model utilizes the augmented context to generate potential hypotheses, suggest possible causes, and recommend additional investigative steps based on the original data and the retrieved information. AI might, for example, develop the following possible solution. "Based on patterns, a likely cause might be related to an electrical fault. (e.g., regular inspections, proper use of extension cords, maintenance, unplugging when not used, fire-rated fixtures, training, awareness, violation of applicable codes or standards).



**Real-time Monitoring** - AI can be integrated with sensors and monitoring devices, allowing for real-time assessment of fire-prone areas. AI algorithms can analyze environmental conditions, detect anomalies, and alert authorities to potential fire risks, enabling swift intervention. The integration of AI into the fire service brings about significant efficiency improvements.

Artificial intelligence can help respond to and assess a fire scene, making informed decisions about extinguishing the fire and limiting its spread and damage. It can provide critical insights, improve safety, and enhance response capabilities. It is currently used in flashover prediction, data interpretation, on-scene data collection, and real-time traffic analytics. Artificial intelligence data can be used to assess building and fire conditions.

Figure 5– Using Artificial Intelligence in the Fire Service

Artificial intelligence (AI) is currently integrated into fire protection technology and utilized in various ways for fire prevention, detection, and investigation. Smoke and heat detector devices

and components of fire protection systems use AI to function and analyze data, enabling the design, placement, and collection of data from these devices to detect smoke and flames, identify patterns, and inform decisions about the presence of fire or smoke. The combination of AI and Internet of Things (IoT) devices, such as smart smoke detectors and temperature sensors, provides investigators with real-time and historical data that can be analyzed to understand fire incidents better.

With cameras and video, AI can measure, record, and capture events related to fires and explosions. Fire investigators can analyze the data collected by these devices to identify essential information about the origin and cause of the incident, creating timelines that tie benchmark events (e.g., when a fire is detected or discovered, when a fire is reported, how long it takes the fire department to respond, etc.) to responsibility.

**Evidence** Analysis —AI-powered equipment detects and analyzes debris and artifacts collected from fire and explosion scenes and processes data from hydrocarbon detectors, CT scans, and GC-MS (Gas Chromatography-Mass Spectrometry) devices. This helps investigators identify specific substances or chemicals at the scene and determine whether they are material or relevant to the fire or explosion.

Digital evidence analysis is crucial in forensic investigations, and AI technologies facilitate rapid and precise analysis of evidence collected from fire scenes. Whether identifying accelerants, analyzing burn patterns, or categorizing fire-related artifacts, AI enhances the speed and accuracy of evidence interpretation. It can encompass various data sources, such as emails, social media, financial transactions, and surveillance footage. AI algorithms play a crucial role in collecting and analyzing data on fire incidents, including details such as fire spread patterns, ignition sources, and environmental conditions, thereby revealing relevant patterns and insights. AI excels at identifying similarities, inconsistencies, outliers, and other suspicious activities, enabling investigators to connect the dots and build strong cases. By leveraging AI-powered forensic tools, investigators can efficiently manage the growing complexity and volume of digital evidence.

*Fire Pattern Analysis* - AI algorithms play a crucial role in deciphering complex fire patterns. By processing images and data from fire scenes, AI systems can identify distinctive patterns that may elude the human eye, aiding investigators in reconstructing the sequence of events leading up to a fire. These tools can process information such as burn patterns, heat distribution, and the presence of accelerants to help identify the point of origin and the most likely cause of a fire.

Advanced AI systems, particularly those using computer vision and Convolutional Neural Networks, are being employed to process images from fire scenes. Courts generally require either the original raw image or verification of the same image or video because AI-generated or enhanced/altered images can be used as evidence in reports to convince others (e.g., experts, attorneys, or a judge and jury) to interpret evidence differently. Fortunately, the metadata is recorded when fire and explosion investigators create or collect images that cannot be modified or erased from the original raw data, assuming it is still available for examination.

AI algorithms identify patterns, anomalies, and connections, uncovering hidden insights that might otherwise remain concealed. These AI-powered investigation techniques optimize time, boosting

efficiency and effectiveness. AI's ability to manage repetitive and mundane tasks allows investigators to dedicate more time to critical thinking and problem-solving, resulting in faster and more accurate investigation outcomes. Artificial intelligence has transformed hypothesis generation, decision-making, and strategy development in fire and explosion investigations.

**Reconstruction of Fire Events** - AI systems can integrate diverse datasets, including weather conditions, building structures, and witness statements, to reconstruct the sequence of events leading to a fire. This holistic approach enables a more comprehensive analysis of fire incidents by considering multiple variables simultaneously.

**Predictive** Analysis - Machine Learning algorithms can be trained on historical fire data to develop predictive models that simulate reality. These models help anticipate potential fire hazards, assess the risk of specific scenarios, and enable proactive design, prevention, and investigation measures. Predictive analysis is a powerful technique that uses modeling and simulation to simulate the origin and cause of fires, test different hypotheses, and determine whether a specific hypothesis is consistent with facts and evidence and corresponds with accepted and known principles of fire science. Trained and validated predictive models can be deployed in training as models to teach the basic principles of fire science and fire dynamics or, in specific cases, to simulate actual fires and their consequences. The latter can be used to test different fire scenarios, evaluate the effectiveness of prevention strategies, or improve the accuracy of investigations.

The modern investigation of fire has evolved from an informal and simplistic approach to understanding the elements of the fire triangle (e.g., heat, fuel, oxygen) and fire tetrahedron (which includes a reaction between its components) to one of analyzing fire using a System Approach based on a more complex science-based methodology (i.e., the scientific method adopted and described in NFPA 921).

More recently, fire investigators have adopted a systems approach to fire investigation and used it to perform a more formal fire dynamics analysis, which NFPA 921 describes as the underlying



A Systems Approach to Fire Investigation

Figure 6– Systems Approach to Fire Investigation

basis for determining the origin, cause, development, responsibility, and, when required, failure analysis of a fire or explosion. The Systems Approach to forensic fire investigation includes human, building, fire, and environmental factors. It is a comprehensive approach to understanding how and when a fire occurred, as well as who or what was responsible for causing it. All of these elements are crucial for fire investigation and fire analysis.

The 2017 ed. of NFPA 921 includes mathematical tools, or fire modeling, which can help to *simulate* fire dynamics, predict fire behavior, and validate hypotheses about the origin and cause of fires.

Fire Dynamics Simulator (FDS), developed by the National Institute of Standards and Technology (NIST) in the late 1990s and based on mathematical modeling, is likely to be used by fire investigators or encountered by them in the legal process if their opinions are challenged. Its initial goal was to simulate the movement of fire and smoke in complex structures and provide valuable insights for fire safety engineering, supporting design purposes. Because it was developed using taxpayer money, it is in the public domain and may be downloaded for free, along with its complete documentation, from the NIST website.



Originally developed and used by Fire Protection Engineers with the assistance of applied mathematicians, since its inception, the fire investigation community has adopted the Fire Dynamics Simulator (FDS) to reconstruct fires. This is partly because of its continued development and use by the fire prevention profession.

Figure 7– Predictive Analysis (Simulation)

Despite its complexity, FDS can be obtained, learned, and applied without understanding its underlying equations so long as it is used within its limitations and restrictions. The courts and legal system have allowed the use of FDS in fire investigation cases, recognizing it as a reliable tool for reconstructing fire scenarios and understanding fire dynamics. However, its acceptance can vary depending on the jurisdiction and specific circumstances of each case. Effectively, FDS can test various hypotheses but not directly establish a fire's origin or cause. It also operates within the subsonic range and is generally unsuitable for simulating either the chemistry or physics of explosions.

AI can be integrated with FDS to enhance its capabilities, including:

*Predictive Analysis* – AI algorithms can analyze historical data to predict potential fire scenarios, thereby improving fire safety designs and emergency response plans.

*Optimization* – AI can optimize the parameters used in FDS simulation, such as ventilation conditions and material properties, to achieve more accurate and efficient results.

*Real-Time Monitoring* – AO can monitor real-time sensor data and dynamically adjust simulation parameters, providing more accurate and timely predictions.

*Automated Design* – AI can assist in automating the design process by suggesting optimal fire safety measures based on simulation results, reducing human error, and saving time.

The input file for the Fire Dynamics Simulator can be configured to produce the desired results. The user needs only to specify the necessary parameters (e.g., the geometry of the space, material properties, heat release rates, ventilation conditions, etc.), configure the output requests to capture the desired data, and execute the simulation to ensure they meet the desired objectives. By carefully setting up the input file and running the simulation, you can obtain the specific outputs needed for a safety analysis. Herein lies the rub.

By meticulously confirming the input elements, you can steer the FDS (or any simulation) to yield the desired outcomes. If you are a fire investigator, observed data may be used to infer the conditions or parameters that produced those observations (Inverse Modeling). Essentially, it is like running the simulation in reverse. You start with the output and work backward to determine the input parameters that led to that output.

This approach is beneficial in fire investigations where data from a real fire is available, and the goal is to determine the likely conditions that caused the observed damage. By using inverse modeling, you can estimate the fire's origin, growth rate, and other crucial factors.

For further information about computer fire modeling or FDS, the reader of this paper is referred to "Computer Modeling and the Law: Application to Forensic Fire Engineering Investigations," which discusses the use of computer fire modeling in forensic fire investigations and legal proceedings and its purposes, legal challenges, expert testimony, and professional standards.<sup>8</sup>

Fire investigators are likely to use Artificial Intelligence tools to research the thermophysical properties of materials used in FDS input and base their hypotheses concerning the fire's origin on its output, predicted tenability conditions, and the response of various fire protection components (e.g., smoke alarms, heat detectors, sprinkler heads).

<sup>&</sup>lt;sup>8</sup> David J. Icove, PhD, PE, Thomas R. May, MS, JD, Computer Fire Modeling and the Law: Application to Forensic Fire Engineering Investigations, Journal of National Academy of Forensic Engineer, Vol. 38 No. 1 July 2021, PP 77-90

**Research, Reports, and Testimony** – Perhaps the most significant potential impact of Artificial Intelligence on fire investigation is its application in finding and verifying the information and content of reports a fire investigator chooses to place in reports. Despite their



crucial importance, less attention is paid to reports than to the investigation itself, as conducted by its author and reader. Fire investigators and others should remember that reports are only the visible portion of the process in fire and explosion investigations. The most critical documentary evidence is the facts and evidence developed and documented during the investigation that may not be included in the report. Metaphorically, a report is just the tip of the iceberg. The investigation lies in the watery depths below it and is often submerged, hidden, and never brought to light.

NFPA 1033 requires fire investigators to conduct investigations and report their findings accurately, reflecting the facts, data, and scientific principles on which the investigator relied. It is vital that reports and testimony are the product of reliable properties and methods and that the expert applies verifiable

principles and techniques to the facts of the case.

Figure 8– Reports are only the visible part of the iceberg.

Fire and explosion investigations and documentation are lengthy and complex, and the specific processes resulting from a report are not necessarily efficient or cost-effective. Authoring reports based on the analysis of a documented investigation involves time and money in the real world. Accordingly, considerable effort has been invested in developing methods to investigate a scene and generate reports more efficiently. AI streamlines time-consuming tasks, such as data collection, analysis, and report generation, through automation. By automating these processes, users can focus on tasks of higher value.

Researching data and producing and reviewing reports that meet standards and legal requirements and are consistent with the facts and evidence is a process that AI excels at. AI-powered analytics already drill down into databases and documents and auto-produce easy-to-understand written reports that unearth insights about trends or patterns that otherwise may never have seen the light of day.

Although AI currently powers search engines used by fire and explosion investigators, which can process data, provide relevant information related to fire investigation techniques, and generate reports, the question remains: to what degree does artificial intelligence affect the actual substance of a fire investigator's report, not just its appearance or form?

Any application that scrutinizes your writing to improve clarity, spelling, composition, grammar, and word choice also affects a report's meaning. In other words, the selection of words and use of language affect not only the appearance of the expert's report but also its logic.

Currently, templates are the most popular and common method by which larger organizations approach the generation of reports and their review. This method typically involves an organization-wide acceptance of a specific format with internal references that comply with external protocols and standards (e.g., NFPA 921, NFPA 1033, ASTM). Essentially, it is a quality control approach that ensures the content and format of reports are reviewed before publication or release. The strategy is implemented through internal technical and administrative reviews. Organizations may adopt templates from external 3<sup>rd</sup> party sources and incorporate them with their branding.

Templates can automate the generation of reports by combining data extracted from the scene with the accepted internal format of the report. Using a template guarantees uniformity throughout the organization and saves money and time. The template technique may be replaced or supplemented with an 'active document' approach that combines data extracted automatically, instantaneously, and remotely from the scene with the accepted internal format to produce a finished report.

Most reports contain a disclosure clause that attempts to certify their accuracy by stating they comply with professional guidelines or legal requirements. For example, an origin and cause report may contain a clause that the investigation that the report relies on, and its conclusions, are cited and comply with NFPA 921at least at the time it was written and that new information that was not known at the time the report was prepared may alter or change those opinions requiring further investigation and a new report to change or supplement its findings.

Because it is currently difficult to specify the sources from which artificial intelligence information was obtained or even detect whether it was used or relied on in a report, the question arises about whether or not it should even be cited. For example, it is likely that most investigators use an AI-based application that checks their spelling, composition, and grammar, yet does not disclose this fact. One way to deal with the disclosure of AI in a report is to include a disclosure in every report where it is used.

One way to claim the accuracy of a report is through a *disclosure* clause placed in the report. Sometimes, the two are confused and combined. It is not the purpose or intent of this paper to recommend that either be included, only to explain their differences and general purpose. A disclosure is more about transparency. A *disclaimer* is more about protection and attempts to limit responsibility. Disclaimers open up what is included. Disclaimers set boundaries around the information that is provided. Neither guarantees the investigator's opinions and conclusions regarding the facts and evidence (hypothesis) are reliable and accurate, nor protects them from liability or the consequences of being wrong. Usually, either one or the other, or both, are placed in reports. Neither a disclosure nor a declaimer cause is required by NFPA 921, NFPA 1033, or the courts; however, some organizations or clients require them in reports.

The following disclaimer and disclosure examples are included for illustration only. The author of this paper does not suggest or recommend that either be incorporated into a report. The best way to verify a report's content, conclusions, or findings is by fact-checking its sources, identifying

peer-reviewed data, and identifying errors in its logic or calculations. This is particularly important if AI is used to generate the report.

#### Disclaimer Example

"This report (including any enclosures and attachments) has been prepared for the exclusive use and benefit of the addressee(s) and solely for the purpose for which it is provided. Unless we provide express prior written consent, no part of this report should be reproduced, distributed, or communicated to any third party. We do not accept any liability if this report is used for an alternative purpose from that for which it is intended, nor to any third party regarding this report."

#### AI Disclosure Example

"This report incorporates AI-assisted analysis tools. While AI has contributed to the preparation of this report, all AI-generated content has been thoroughly reviewed and verified to ensure its accuracy and relevance. The conclusions and recommendations presented herein are based on a combination of AI-assisted analysis and the professional opinion(s) of the undersigned author(s)."

AI tools are already used to research definitions and issues related to the origin, cause, and responsibility for fires and explosions. These tools can extract questions from documents (reports and depositions) and create summaries of depositions used in legal proceedings, pinpoint sources of information, or highlight inconsistencies or errors in logic, ensuring that our legal processes are thorough and efficient.



AI tools can determine whether a guide's methodology or standard's requirement was met, prepare for deposition testimony, and find a list of prospective questions that an opposing expert could ask during their examination. These questions may be based on the content and conclusion of the expert's report, but also on that expert's qualifications, past reports, or testimony history.

Figure 9– Courtroom Testimony

While AI can improve the efficiency and accuracy of investigations and reports, it does not replace the need for human expertise and input. What is certain is that it, along with other tools, requires human input for analysis and narrative. Likely, artificial intelligence may eventually replace technical and administrative review of reports if for no other reason than it already has, or will become, more efficient and cost-effective. Expect Artificial Intelligence in any report regarding fires or explosions you receive, certainly in form or appearance, and progressively in substance (e.g., opinions and conclusions).

Rule 26 of the Federal Rules of Civil Procedure outlines the current guidelines for expert witnesses in federal court and can be downloaded from the United States Courts website at <u>www.uscourts.gov</u>. While some states accept and implement the federal standard, every report should be considered an expert report, regardless of whether it is in the federal system.<sup>9</sup>

<sup>&</sup>lt;sup>9</sup> The guidelines for expert witnesses in federal court are primarily outlined in Rule 26 of the Federal Rules of Civil Procedure, which can be downloaded from the United States Courts website at <u>www.uscourts.gov</u>. While some states accept and implement the federal standard, every report should be considered an expert report, regardless of whether it is in the federal system.

The Federal Plain Language Guidelines <sup>10</sup>, promulgated as law in 2010, helps federal agencies write documents clearly and understandably, so that users can easily find, understand, and use the information they need. These guidelines can also be valuable for expert witnesses investigating and writing reports concerning the origin, cause, and responsibility of fires and explosions. They help them understand their audience, organize the report, apply sound writing principles, and test the document's effectiveness in reaching its intended audience.

While AI solves many of the difficult choices in establishing whether a particular methodology (NFPA-921) or requirement (NFPA 1033) has been consulted and adhered to, it currently falls short of meeting existing legal requirements regarding its content. Regardless of whether AI is used in preparing a report, the author of a report must testify under oath to its content and conclusions and identify all sources of information on which they consulted or relied. However, it is cost-effective, overcomes writer's block, creates content faster than people, and is economical.

AI report generators can quickly transform raw data or text into visually appealing and wellstructured reports, making the author's work appear more polished and professional. Some AI tools can perform complex data analysis and identify trends that may not be immediately apparent to the human author, leading to deeper insights into the report and leaving the reader mistakenly believing the author possesses more knowledge than they do. The bottom line is that truth in the legal system is ultimately determined by a jury's vote based on their assessment of the facts and evidence presented to them.

While AI can process and present information, it does not replace the author's original ideas, critical thinking, or domain expertise. Artificial intelligence tools frequently misrepresent, do not fully explain the facts, or are subject to being used by those with a vested interest in the outcome of a legal proceeding. Technology may change, but human nature does not. Because of this, in some cases, AI can disguise incompetence and allow bias to enter the system, sometimes unintentionally and undetected. Authors must critically evaluate AI-generated content to ensure it aligns with their intended message and professional standards. The author remains accountable for the report's content, including any AI-generated portions. AI tools cannot be held responsible for the work or potential errors.

## Case Studies

Several case studies highlight the potential of AI in fire investigations and its potential contributions to them.

## Case Study 1

A local LPG vendor delivered and filled several forklift cylinders inside a customer's building. At least three cylinders were overfilled, and the delivery technician was bleeding them using the bleed valve on the cylinders. The vapors from the cylinders ignited, injuring the technician and causing damage to the customer's building and property.

<sup>&</sup>lt;sup>10</sup> Plain Language Guidelines <u>http://www.plainlanguage.gov/media/FederalPLguidelines.pdf</u>



Figure 10- Location where the fire occurred, the delivery truck, and the portable washer

The technician immediately removed the delivery truck from the building during the event, and its exact location could not be determined. A thorough scene investigation was conducted, and the local fire department secured the cylinders. The initial investigation by the local fire department revealed that a portable washer located in the same space was off at the time of the incident and had not been used for over an hour before the event. Subsequent investigation of the scene revealed multiple competent ignition sources were present at the event's time (e.g., the delivery truck, static electricity, fluorescent lighting, air compressor, etc.)

An expert retained by the delivery company used a fire model, Fire Dynamics Simulator (FDS), to simulate release and determined that given the circulation within the building due to the weather conditions outside the building at the time of the event, the vapors released from the cylinders could not have reached their lower flammable range in the area where the delivery truck was parked and left running. Instead, the pilot flame of the portable washer, which was installed inside the service bay and belonged to the delivery customer, was the ignition source for the released gas. The expert failed to produce any documents about the simulation, including a Sensitivity Analysis.

A search using Artificial Intelligence tools revealed that the release of propane from a pressurized LPG cylinder is beyond the limitation of FDS, nor could it accurately simulate the release or predict the explosive concentration of the gas in the immediate area over time. These limitations were confirmed through the model's documentation and with the developers, and the model was rerun to obtain different results.

#### Case Study 2

A second case study examines a restaurant kitchen's extinguishing system that malfunctioned during a fire, either failing to extinguish the fire or allowing it to spread. A thorough scene investigation was conducted, and the fire protection system components and the appliance they protected were collected.



Examination of the fire protection system records revealed that the last inspection of the system occurred less than one month before the fire, but that the system had been inspected regularly. During a lab examination of the collected evidence, the fire investigator found grease on the canister seal of the extinguishing agent. Crystallization was observed in the remaining liquid extinguishing agent after opening the extinguishing canister.

The observations led the investigator to utilize AI to search for and confirm that NFPA 96 - Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations - requires system components to be inspected at least once every six months.

#### Figure 11 – Cannister seal and crystallization of contents

The investigator's AI research also revealed that the crystallization of the extinguishing agent could be due to changes in temperature or contamination of the agent. The fire investigator confirmed with the manufacturer that canisters are not opened during routine inspections to confirm the presence of an extinguishing agent and that technicians perform a visual inspection and check for the system's proper operation instead.

Further investigation verified the components' inspection cycle and grease throughout the system, which allowed moisture to enter the extinguishing agent, causing the crystallization. Laboratory testing of the remaining extinguishing agent, which included a comparison with a control sample from the manufacturer, revealed a typical composition of the agent except for a high moisture content.

Combined with traditional investigative tools, the investigator utilized AI tools to collect data, focus the investigation, identify the necessary expertise to determine the cause of the fire, and write a report that would withstand reasonable examination by others. Ultimately, the fire investigator concluded that, despite being inspected as reflected in the provided documentation, the system's operation was either not properly checked or tested, and it failed to extinguish the fire, allowing it to spread.

#### Case Study 3

A third case study involved a natural gas line supplying gas to a range in an unoccupied apartment that leaked before being discovered and responded to by the fire department the following morning. An explosion occurred after firefighters entered the apartment, followed by a fire that further damaged the apartment and building. The firefighters and others were injured. The building was demolished for safety and health reasons before a full investigation of the incident could be conducted.

Aside from other issues concerning applicable regulations and standards relating to the installation, operation, inspection, and maintenance of natural gas systems, as well as proper protocols in responding to such incidents, a key technical question is "What was the natural gas concentration inside the apartment when the fire department opened the door and entered it?"



Figure 11 – Aerial View of the building and apartment where the explosion occurred.

Using Artificial Intelligence tools, we can model the gas concentration using a differential equation that accounts for the gas inflow and the air exchange rate. This is a linear first-order differential equation. We can solve it with the initial condition C(0) = 0. By performing the calculations, we can plot the gas concentration over time and determine the gas concentration

Let us define the variables:

- • V: Volume of the apartment in cubic feet.
- • Q: Rate of gas leakage in SCFH.
- •  $\lambda$ : Air exchange rate in exchanges per hour.
- • C(t): Gas concentration at time t in SCF per cubic foot (SCF/ft<sup>3</sup>).
- The volume V of the apartment is given by:
- V = Area × Ceiling Height
- The rate of change of the gas concentration C(t) inside the apartment can be modeled by

- the following differential equation:
- $d C (t) / d t = Q/V \lambda C (t)$

To calculate the gas concentration inside the apartment over time, we need to consider the following factors:

- 1. Volume of the Apartment: The volume can be calculated using the area and ceiling height. The apartment's dimensions were 525 square feet and 8-foot ceilings.
- 2. Gas Leakage Rate: Given in Standard Cubic Feet per Hour (SCFH). Laboratory testing of the range and severed flexible line recovered from the debris after the demolition indicated natural gas flowed freely into the apartment at a rate of 330 SCFH at a pressure of 5 in. WC.
- 3. Air Exchange Rate: The rate at which air is replaced in the apartment. It has an air exchange rate of 0.35 air exchanges per hour.

Additional Artificial Intelligence description - "Now, let's compare this to the flammable limits of natural gas: According to the search results."

These percentages are the Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL), respectively. The calculated concentration of 21.97 % exceeds the upper flammable limit of natural gas. The gas concentration is above the Upper Explosive Limit (UEL) of approximately 17%.

1. The Lower Explosive Limit (LEL) remains at about 4.4%.

It is crucial to note that this situation is hazardous:

- 1. The concentration is above the UEL, which means changes in ventilation or gas dispersion could bring it back into the explosive range.
- 2. Any area with a concentration between 4.4% and 17% would be at risk of explosion if an ignition source is present.
- 3. This calculation assumes perfect mixing, which is unlikely in real-world scenarios and does not account for mechanical ventilation. There could be pockets of higher or lower concentrations throughout the apartment.

In a real-world scenario, this situation would require immediate evacuation and professional intervention before reaching this concentration. Any detectable natural gas leak should be treated as an emergency requiring immediate action.

AI can generate code snippets, functions, and even entire programs based on natural language prompts or specifications. Tools like GitHub Copilot, Amazon Code Whisperer, and OpenAI Codex can suggest code completions in real time, translate natural language descriptions into code, and assist with various programming languages. These tools utilize large language models trained on vast amounts of code to provide context-aware suggestions, often accelerating the development process.

For example, based on the previous solution suggested by artificial intelligence, the investigator might code an Excel spreadsheet to calculate the gas concentration within the apartment over time

at a given leak rate and air exchange, thereby determining what the gas concentration would be at a specified elapsed time.

The investigator might also go further by using an AI tool that accepts user input to program an application that:

- A. Allows the user to select either Natural Gas or Propane (based on its LFL and UFL)
- B. Calculates the gas concentration inside a closed compartment of a given volume, air exchange rate, and leakage rate, for an elapsed time.
- C. Creates a chart that visually shows the data that is calculated.
- D. Shows the effect of opening the door of the compartment on the gas concentration inside the compartment
- E. Information regarding the assumption, formulas, or equations used for the calculation(s) or other relevant or material data might be displayed as data to help the user choose the input and understand its output.

The source of the values used for the calculation(s) should be referenced for independent evaluation and, if needed, duplication. For more precise calculations, you would need to know the actual dimensions of the apartment, the airflow rate of its mechanical ventilation systems, the infiltration rate of the building envelope, and the local climate conditions that existed at the time of the incident. The program's output might look like this.

pre	riew-gasmik-calculator.lovable.app / index v 🛛 🖄 📮 😋 🗘	) Select
Color the area in the chart below the LFL as Light Green	Gas Concentration Calculator	
Verable		- 1
Fill moonly the ConcentrationChart component to add a light green area below the LFL line. Since this file is over 200 lines, I'll also refactor it into smaller components.	Input Parameters         Gas Concentration Over Time           Gas Type         Time to reach UFL 072 hours	
<> Edit #92 • Color chart area below LFL > Click to view code	Natural Gas Time to reach UFL 570 hours Time to reach UFL 570 hours Time to reach UFL 570 hours Time to reach or upin 478-111 1398	- 1
The chart now shows a light green area below the LFL line, and the component has been reflectored into smaller, more manageable pieces. The ChartAreas component handles the control areas, while ChartLines handles the reference lines and main concentration line.	Gas Properties         UPG           Natural Gas         UPG           Odor Threshold: 0001%         Odor Threshold: 0005%           UFL: 44%         UFL: 21%           Stockhomenet: 53%         Stockhomenet: 4%           UFL: 17%         UFL: 95%	
Restored #89 Add ACH value with door open	Dimensions of Compartment Reset Dimensions	
display on the chart information about how many minutes after the door is opened it takes for the gas concentration to drop	Length (feet) Width (feet) Height (feet)	
below the UFL.	30 20 8 4.0	- 1
Vertex ve	Volume (cubic feet)	- 1
I'll help add information about the time it takes for gas concentration to drop below UFL after opening the door. Since this requires modifying the ConcentrationChart	4800 0 1 2 3 4 5 6 7 8 9 10 11 12 Bapted Time (Hours)	
component, I'll also refactor it into smaller components.	Initial Air Exchange Rate (ACH) Reset Air Exchange Rates Print Chart	- 1
Click to view code	0.35	
The chart now shows how many minutes it takes for the gas concentration to drop	Air Exchange Rate After Door Opens (ACH)	- 1
below UFL after the door is opened, and the code has been refactored into smaller, more manageable components.	1	- 1
Let the user inout the air exchange rate after opening the door	Typical Air Eachange Rates (AC-0):           - Relidences: 63 - 15 AC-14           - Apartments: 03 - 15 AC-14           - With door genes 10 - 2-5 AC-14	
or the apartment.	Leak Rate (SCFH) Reset Leak Rate	
Vertex Covable	330	
I'll help modify the code to allow users to input the air exchange rate after opening the door, while maintaining all existing functionality.	SCFH = Standard Cubic Feet per Hour	
<>> Edit #94 • Add user input for air exchange rate > Click to view code	Elapsed Time (minutes) 660	

• In addition to the issue(s) or question(s) that the client seeks and asks, the solution(s) suggested by AI may identify other problems or questions that are important and need to be addressed to evaluate the incident thoroughly.

- For example:
- At what point would it be reasonable to assume the leak would be detected?
- What would the impact of the firefighters actually be by opening the apartment door on the natural gas concentration inside?
- What regulations and standards are related or applicable that might apply to the suggested solutions or issues?

The right question is often as important as the correct answer!

### THE FUTURE

Artificial intelligence (AI) has become increasingly prevalent in various aspects of our lives, offering significant benefits and potential drawbacks in our daily lives and fire and explosion investigations. As we continue integrating AI into multiple facets of our profession, we must carefully consider its pros and cons and strive for a balanced approach that maximizes the benefits while mitigating the risks. In particular, investigators must understand the algorithms they deploy and be cautious of potential biases in data that might impact the accuracy of their predictions or findings.

In conclusion, while AI offers numerous benefits in terms of efficiency, accuracy, and capabilities that surpass human limitations, it also presents challenges related to job displacement, privacy concerns, and the potential erosion of human skills. As we continue to integrate AI into various aspects of our lives, we must carefully consider these pros and cons and strive for a balanced approach that maximizes the benefits while mitigating the risks.

The fire investigator must remember that technology will change, but human nature will not. Reality is likely to be more complex than is currently imagined. Truth always turns out stranger than fiction. The laws of nature say you get nothing for free. AI is already here to stay, and investigators can view it as either a threat or an opportunity.

AI is a tool and a potential ally in the pursuit of truth. As fire investigators embrace its advancements, they must move forward carefully, acknowledging the challenges and ethical considerations. Regardless, their actions, opinions, and findings must remain truthful, documentable, and verifiable to be credible and acceptable both socially and legally. Fire and explosion investigators must be familiar with and apply accepted principles outlined in guidelines and standards recognized within their discipline, as well as the requirements of the legal system.

While precision and reliability are paramount in fire investigation to determine the origin, cause, and responsibility for fires, aligning AI with industry, legal, and ethical standards is equally important. The guidelines and standards relating to fire investigation must not only recognize but also incorporate AI into their structure and clarify the framework of its application to their work. Currently, neither NFPA 921 nor NFPA 1033 does.

Ultimately, we would be best served by realizing that we alone are responsible for our actions, that "doing wrong that good may come of it is never right, and that we must act right, whatever the consequence."

## References

In addition to those referenced in this paper's footnotes, the following papers, books, materials, or websites were consulted, read, or evaluated. They may be used as resources for understanding and applying Artificial Intelligence tools to fire and explosion investigations.

- 1. Future of Fire Investigation: AI and Machine Learning, <u>"Unveiling the Future: Harnessing AI and Machine Learning in Fire Investigation" Ohio Arson School</u>
- 2. Natural Language Processing (NLP) Tools, Enhancing Firefighting Techniques with AI, Enhancing Firefighting Techniques with AIA
- 3. The AIDED Project utilizes AI for detecting explosive devices. <u>https://www.spaceapplications.com</u>
- 4. InfoBeyond Project Awarded contract to develop AI Technology for Advanced Fire Ignition Video Analysis, <u>http://infobeyondtech.com/news/fire-investigation</u>
- 5. Artificial Intelligence in Forensic Science, CRC Press, 2024, Edited by Saini, Sonone, Sankhla, and Kumar
- 6. Grammarly is an AI-powered writing assistant that helps writers improve their writing across various platforms and devices. It may be used to check for and correct spelling, punctuation, word choice, and style. It also checks for potential plagiarism and the use of AI in documents. <u>www.grammarly.com</u>.
- 7. Perplexity serves as a central hub for generative AI tools that aim to make advanced AI capabilities more accessible. The application streamlines the workflow for efficiency and addresses privacy concerns associated with generative AI tools. https://www.perplexity.ai
- 8. Microsoft Copilot is an AI-powered assistant that integrates with Windows and various Microsoft applications and services to enhance user productivity and efficiency. COPILOT is deeply integrated into the Microsoft ecosystem, which can limit users who want and need unlimited access to the broader resources of AI. <u>www.microsoft.com</u>
- 9. Artificial Intelligence and Fire Investigation: This course is designed to provide fire investigators with an understanding of how Artificial Intelligence (AI) and Large Language Models (LLMs) can be integrated into fire investigation processes, with a focus on enhancing the quality and efficiency of expert report writing. Participants will gain insights into the transformative potential of AI technologies in analyzing fire scenes, reconstructing events, and generating precise and detailed reports that align with industry standards such as NFPA 921 and NFPA 1033. www.cfitrainer.net
- 10. Language, Logic, and Reports, Joseph M. Ellington, www.aifirelogix.com
- 11. Fire Dynamics Simulator (FDS) A Fire Investigation Tool, Joseph M. Ellington, <u>www.aifirelogix.com</u>
- 12. <u>www.aifirelogix.com</u> A website dedicated to fire modeling and artificial intelligence applications to fire and explosion investigation and litigation.