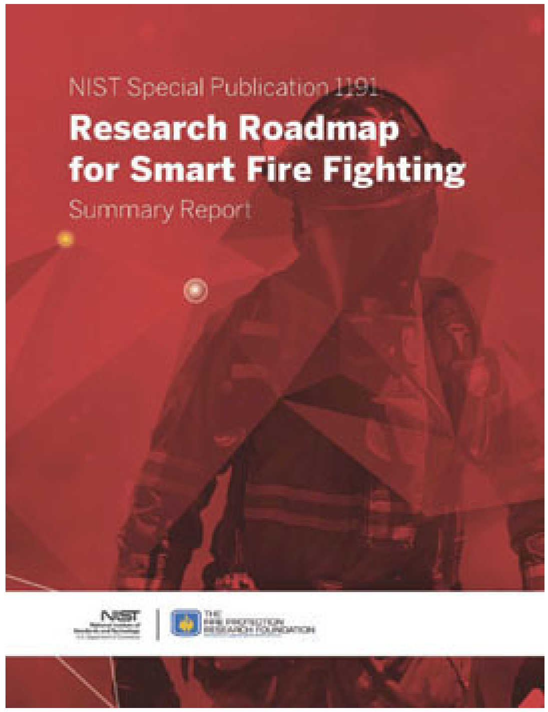
SMART FIRE FIGHTING

BY CASEY C. GRANT, PE, FSFPE

TECHNOLOGICAL INNOVATION is changing the world faster today ever before. The fire fighting profession is no exception, and today's emergency response community is entering an era where we are poised for great gains.

Fire fighting is inherently dangerous and has special, unique challenges. It often directly involves activities and events where actions determine whether someone lives or dies, including the civilians fire fighters protect and the fire fighters and other emergency responders themselves. The fireground, as any fire fighter will tell you, can be chaotic, with dynamically changing conditions that include rapid, difficult-to-predict challenges.



The concept of smart fire fighting is the story of how we're leveraging modern technological innovation to support more efficient and effective enhancements for the fire service and other emergency responders. Some of these advances are significant and show great promise for the future.

Certain aspects of this topic have already been addressed in the literature. However, the holistic and comprehensive basis for this specific topic was fundamentally established in the Research Roadmap for Smart Fire Fighting.[1] The discussion herein leans heavily on this earlier milestone work and the progress that's been made as technology continues to evolve.

The Roadmap provides a clear vision of the incredible opportunities based on harvesting new knowledge to make the tasks of fire fighters more effective and efficient, directly improving their safety and health. Situational awareness is an essential element of fire fighting. As stated by English philosopher Francis Bacon, "Knowledge is power," and smart fire fighting has the potential to provide fire fighters and other emergency responders with the knowledge needed to genuinely inform their decision- making and their activities.[2]

The Basics

Today, we are entering a new era: the industrial internet revolution. This is based on cyber physical systems (CPS), which are generally represented by tightly packaged, interwoven cyber and physical systems. These systems are based on recognizable patterns of integrated intelligence involving computational processes that interact with physical components.[4]

The industrial internet revolution is the merging of the industrial era's physical systems with the cyber systems of the internet revolution. One critical aspect of the explosive growth of CPS is the proliferation of sensors everywhere. We oft en hear in the mainstream media about the emerging world of the internet of things (IoT), which is now becoming referred to as the internet of everything (IoE). This is a key underpinning of current CPS trends.

Several focused activities support CPS. Perhaps most notable are various smart cities initiatives, such as the Smart Cities Council.[5] A strong example of this activity, and one that regularly includes fire fighting along with other applicable sectors, is the Global City Team Challenge hosted by the U.S. National Institute of Standards and Technology.[6]

An arguably over-used word in today's mainstream vocabulary is "smart" to describe clear advances of a particular activity over an established baseline. It is sometimes used in mainstream media and elsewhere to generally represent technological advances, and also as an acronym for goals such as "specific," "measurable," "assignable," "realistic," and "time-dependent" (or similar variations). Here, the focus is more consistent with the concepts of the smart cities initiatives. Specifically, this is the engagement with CPS to yield pervasive sensing, unparalleled analytical and computational capabilities, and real-time networked information to make the tasks of fire fighters more effective and efficient, resulting in direct improvement to their safety and health.

Smart Fire Fighting Framework

The fire fighting profession encompasses a broad range of activities that go well beyond fighting a fire in a typical structure. Fire fighters respond to all emergencies, including medical events, vehicle crashes, wildl and fires, structural collapse, search and technical rescue, active shooters, maritime and aircraft rescue, as well as structural fire fighting.

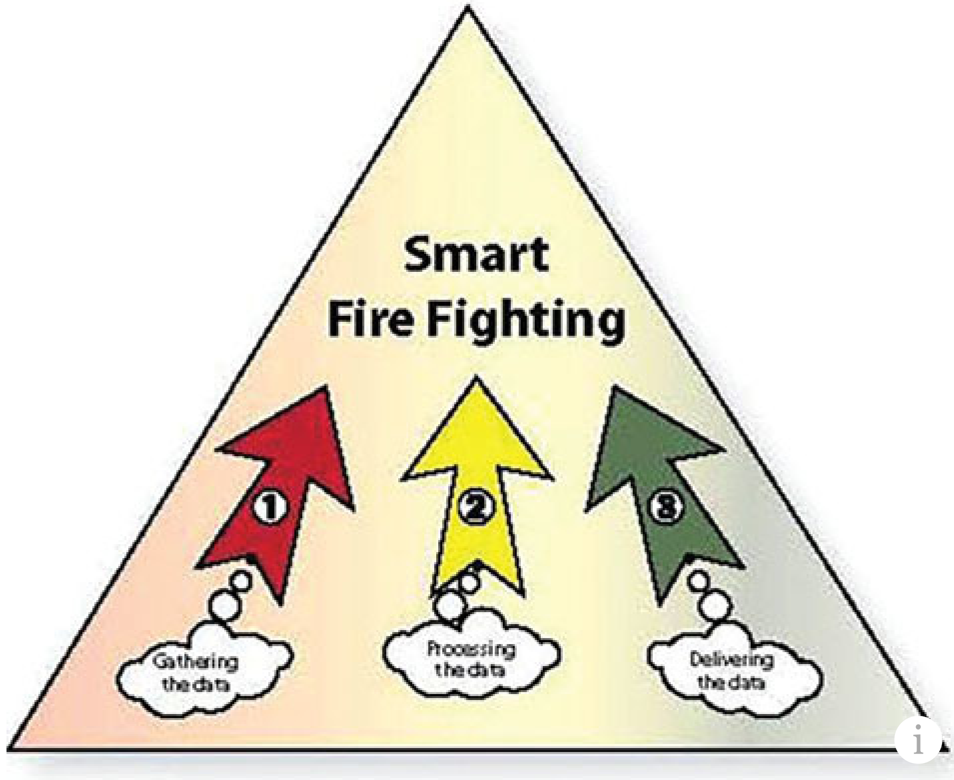
As we address smart fire fighting, we include all duties within their scope of responsibilities. All phases of their work are important, with focus on pre-event, during an event, and post-event. Time constraints are the greatest challenge during an event, while pre-event (prevention, education, pre-planning, etc.) and post-event (investigation, salvage, etc.) allow more time for actionable consideration.

Going forward, we can expect pre- and post-event focus areas to be the first to yield measurable and meaningful advances. These areas are also of special interest for fire protection engineers, who will have a key role in the design, installation, and maintenance of measures critical to support the fire service. This includes, for example, pre-planning information such as coordinated building systems in high-rises that realistically provide detailed information to incident commanders during a fire, as well as post-event information that provides rich activity detail based on the digital footprint (i.e., cloud-based status of all impacted components connected by the internet of things).

On a structural fire fighting scene, a typical smart fire response would be the result of integrating smart dispatch, fire-smart buildings and infrastructure, smart fire apparatus and equipment, and smart fire fighter personal equipment. Much of this technology and information already exists in varying levels, though it lacks even basic levels of integration to derive optimum value for effective use by fire fighters.

The lifeblood of smart fire fighting is data derived from the CPS environment. Everything about smart fire fighting revolves around and is enabled by three primary realms of focus: gathering data, processing data, and delivering data.

1. **Gathering data requires sensors that collect and harness the data**. With the proliferation of the IoT, our world today is becoming increasingly sensor-rich, and this continues to quickly become the least of the challenges. The bigger question is what we will be doing with this data.
2. **Processing data is sometimes relatively straightforward (e.g., comparison of spreadsheets); conversely, at other times, it can be very complex (e.g., real-time fire modelling)**. Ultimately, this is the process that makes the data useable and relevant.
3. **Delivering data, also referred to as targeted decision-making, is arguably the most underappreciated component of the smart fire fighting ecosystem**. It is essential to process the data and deliver it to those who need it, the way they need it, when they need it, and nothing more. In the time-critical environment of the fireground, it’s paramount that fire fighters are not overloaded with superfluous details. The final communication must be simple, precise, and relevant to be of value. Targeted decision-making is an essential characteristic of smart fire fighting. At best, drowning in data accomplishes nothing; at worst, it is a dangerous distraction that can compromise safety and effectiveness.



Analyzing the Data Is the Key

Enabling smart fire fighting is dependent on gathering and processing data, and in today's world, we are increasingly inundated with massive amounts of data coming at us from all directions. Today, we are in a sea of data, and the IoT is sharply increasing it every day. What will we do with this data? How will we refine and process it and utilize it for targeted decision-making for the fire service?

In truth, it's not this incredible abundance of data that enables great things for today's fire service. The ultimate key is the analysis of this data. A helpful analogy is the concept that "data is the new oil." This concept found its way into the mainstream media in 2006; all fingers pointed to Clive Humby, who stated: *"Data is the new oil. It's valuable, but if unrefined it cannot really be used. It has to be changed into gas, plastic, chemicals, etc., to create a valuable entity that drives profitable activity; so must data be broken down, analyzed for it to have value."*[9]

Oil is a fundamental building block of our modern civilized world. The existing commodity of oil and the new commodity of data have striking parallels. We actively address the safe and proper identification, collection, containment, management, transport, use, and ultimate disposal of both. Interestingly, fire protection is a crucial support activity to assure the safety of oil, and similar crucial support activities assure the safety of data (e.g., cybersecurity).

It’s easy to check the validity of Humby’s analogy by reviewing the market capitalization of the world’s largest public companies within the last decade. Table 1 compares two years: 2011 and 2019. In 2011, six of the top 10 largest companies were oil giants; only two were technology companies. By 2019, this had flipped: Seven of the world’s top 10 largest companies are now technology giants; only one oil company remains on the list. Further, the tech giants dwarf the rest of the field. Figuratively and literally, data is the new oil.

The advances being made in support of smart fire fighting are not always independent, innovative activities, and in some cases, they are sweeping significant changes to the overall infrastructure. One of the most prominent is the FirstNet initiative, which is formally known as the First Responder Network Authority under the National Telecommunications and Information Administration (NTIA) and a part of the U.S. Department of Commerce.

FirstNet is an independent authority established by the United States Congress in 2012 with a mission to develop, build, and operate the nationwide broadband network that equips first responders to save lives and protect U.S. communities.[[11]] FirstNet uses a significant portion of the radio spectrum that is now dedicated to first responders, but is leased out for use during non-emergency conditions in a public/private partnership with a telecommunication partner (awarded to AT&T through a public auction). Once an emergency occurs, all other users of the dedicated spectrum are pushed aside, and priority is given to first responders. When fully functional, First- Net will provide a nationwide, interoperable, broadband network for all emergency response professionals and provide the ability to transmit and receive voice communications in several ways: push-to-talk functionality; group-call (one-to-many) capability; direct-mode (i.e., peer-to-peer or talk-around); full-duplex voice (like a traditional phone call); and voice with caller identification (ID).[[12]]

Rank	2011 (as of March 31)	2019 (as of March 31)
1	Exxon Mobil—$417B	Microsoft—$904B
2	PetroChina—$326B	Apple—$895B
3	Apple Inc.—$321B	Amazon—$874B
4	ICBC—$251B	Alphabet (Google)—$818B
5	Petrobras—$247B	Berkshire Hathaway—$493B
6	BHP Billiton—$247B	Facebook—$475B
7	China Construction Bank—$232B	Alibaba Group—$472B
8	Royal Dutch Shell—$226B	Tencent—$440B
9	Chevron Corporation—$215B	Johnson & Johnson—$372B
10	Microsoft—$213B	Exxon Mobil—$342B

TABLE 1. Top 10 Public Corporations Based on Market Capitalization in 2011 and 2019[10]

Early Demonstrations of Smart Fire Fighting

In terms of smart fire fighting applications, the Research Roadmap provides a set of ten emergency/safety scenarios of tangible case study emergencies that served as examples of applying CPS to enable smart fire fighting. Their purpose was to stimulate consideration of possible data and information and to clarify both near-term and long-term deliverables. These scenarios included:

1. A wildland urban interface (WUI) fire with evacuation of a retirement community
2. A wind-driven residential structure fire
3. A wind-driven high-rise apartment fire
4. A vehicle crash (EV) with entrapment

5. A train derailment with fire and toxic hazmat
6. A highly challenging warehouse
7. A night-club code compliance
8. A tornado
9. A terrorist event with large-scale EMS efforts
10. An elevator rescue due to a metro city power failure[[13]]

A vivid example of the challenges of enabling data in support of smart fire fighting was illustrated by the Las Vegas Mandalay Bay Shooting in October 2017 that resulted in 59 fatalities and 851 injuries.[[14]] It exemplifies the emergency response to a mass casualty event, consistent with #9. It is of particular interest because it occurred at a modern facility already bristling with a wide spectrum of data gathering sensors, and it dramatically impacted all emergency response. A critical question was how emergency responders, including incident command, were able to use any of the harvested data to address this dynamic and rapidly unfolding situation, where every second was precious for those who lived and those who died.

Common Terms in the Data Science Field

THE DATA SCIENCE WORLD has not yet achieved a universally recognized glossary of key terms. These have been and continue to rapidly evolve in recent years. Searches for these definitions result in seemingly endless variations from numerous credible sources. The following definitions are offered for sake of discussion and to offer additional guidance, recognizing the on-going fluidity of these terms.

- **Application programming interface (API)**. An approach that provides users with a set of functions used to interact with and deploy the features of a specific application or service.[c]
- **Artificial intelligence (AI)**. The ability of machines to mimic cognitive functions and capabilities of human brains to learn and solve problems.[d]
- **Augmented intelligence**. An approach that uses data produced by a computer that is superimposed to the real world.[b]
- **Big data**. The information asset characterized by such a high volume, velocity, and variety to require specific technology and analytical methods for its transformation into value.[a]
- **Data mining**. A process data scientists employ to find usable models and insights in data sets. They use numerous techniques to accomplish this task such as regression, classification, cluster analysis, and outlier analysis.[c]
- **Data science**. A field of science that works with and analyzes large amounts of data to provide meaningful information that can be used to make decisions and solve problems. Data science includes work in computation, statistics, analytics, data mining, and programming.[c]
- **Deep learning**. An artificial intelligence function that imitates the workings of the human brain in processing data and creating patterns for use in decision making.[e]
- **Machine learning**. The computational process wherein a machine learns and adjusts its behaviors based on feedback from data. Usually manifesting as an

adaptable algorithm, machine learning helps computers predict outcomes without explicit human input.[c]

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The Mandalay Bay event severely impacted all three branches of emergency response (fire, EMS, and law enforcement) as they attempted to fulfill their duties during this rapidly changing emergency. Yet like any event, lots of real-time data was being captured from building systems, transportation systems, individual personal devices, emergency response equipment, satellites, social media, and numerous other sources. The facility had a robust and sophisticated security system because of the nature of the occupancy. Where is the critical information going and who is getting it? Is it being securely and reliably delivered to those who need it?

A key term used by fire service incident commanders is “sizeup,” which attempts to take into account all the variables and characteristics of the emergency to support informed decisions. In events like the Mandalay Bay shooting, size-up is obviously a challenge, and the goal is to harness the information that will enable the best possible actions. The potential benefits are significant, but the complexities of gathering, processing, and delivering the data with real-time exchange of changing data sets are likewise significant. To address the need for emergency responder size-up at Mandalay Bay, knowing that there was a single shooter and knowing the location of that shooter was absolutely critical information to the on-site emergency responders. Even post-event was significantly challenged with, for example, the lack of secure and proper channels to share key information from medical personnel who were collectively gathering critical victim information that was providing important clarifications for totally securing the scene.

In addition to size-up, situational awareness on the fireground is paramount and often a key issue with a line-of-duty death (LODD) event. Since the situation and conditions of the fire scene are continually changing, it is common to lack critical information that is needed to make optimal decisions regarding the status of the structure's stability, the health and status of the firefighters, the location of victims, the changing fire conditions, etc.

A research project led by the University of New Mexico in collaboration with the Fire Protection Research Foundation is addressing these issues by exploring novel use cases for sensors to improve the safety of firefighters on the fireground.[15] Funding for this effort is through a multi-year grant from the National Science Foundation. The goal of this research project is to make fundamental technical and algorithmic advances within the context of connected and smart cyber fire fighting using artificial intelligence and machine learning to provide direct benefits to fire fighters and incident commanders. (*Editor's Note: See sidebar above for definitions of certain data science terms.*)

This project addresses five key topic areas and provides vivid examples of applying computer and data science in direct support of improving fire fighter safety:

1. **Fireground PAN/LAN Data Communication System**. Establish a practical personal area network (PAN) using a PPE sensor network and a local area network (LAN) involving a fireground local area data communication system, using a mesh structure based in Wi-Fi communications but extended to other communication methods.
2. **Fireground Sound Discrimination**. Capture and identify critical fireground sounds (e.g., PASS device or Mayday) and discriminate and filter these sounds from other fireground noise using algorithms supported by machine learning to implement specific fireground actions.

3. **Fire Fighter Exhaustion Prediction**. Capture, identify, and process speech features through the central computer to determine the level of stress and exhaustion of the fire fighter. Combined with respiration estimation procedures, this data will be used for actionable measures, such as estimation of remaining quantities of available SCBA air, or as a supplement to other physiological indicators.

4. **Human/Object/Event Recognition with Thermal Imaging**. Algorithms will identify specific target entities using thermal imaging, and with support from machine learning, will be transformed into knowledge-based actions for fire fighters.

5. **Navigational Image Search Techniques**. Adapt algorithms that utilize imaging techniques and are supported by machine learning to support fire fighter locator navigation and ultimately benefit key fireground activities dependent on locator technology, such as search and rescue or rapid intervention team (RIT).

Challenges and Next Steps

We are in our infancy with smart fire fighting, but based on the preliminary gains, we can see great potential. Going forward, we can use the summary observations from the Research Roadmap for Smart Fire Fighting as a guide. The Roadmap’s research priorities are based on key elements that have been distilled from a variety of sources collected throughout the overall effort. The recommendations to address perceived research gaps and solution approaches have been separated based on common features into four primary categories: Standardization; Developmental Gaps; Broad Conceptual Gaps; and Solution Approaches. An overview of these key elements and associated research gaps and solution approaches is illustrated in Figure 3.

We are on the cusp of a new era — one that is based on the data revolution. We look forward to maximizing the use of this commodity in new and hard-to-imagine ways to ultimately make our world a better place.

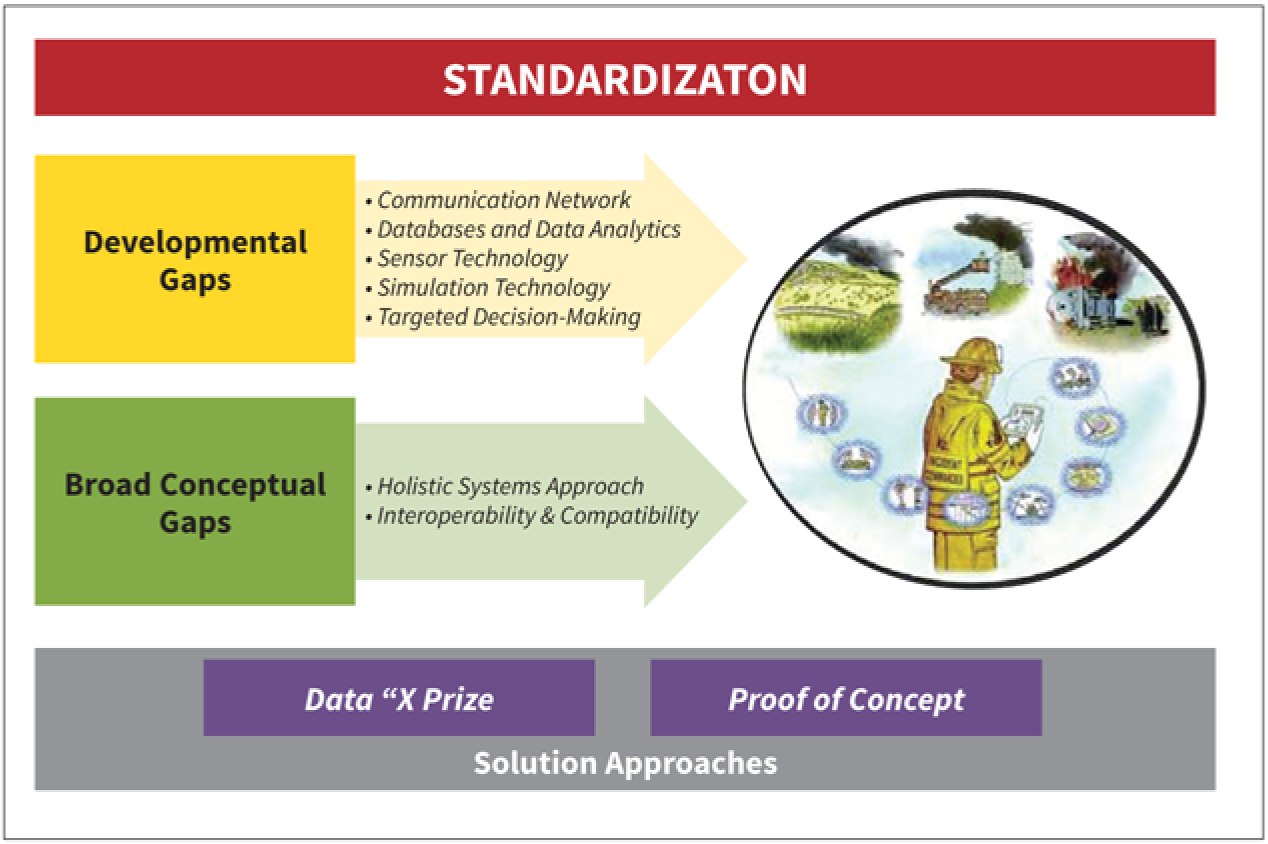

FIGURE 3. Research Priorities for Smart Fire Fighting [16]

CASEY C. GRANT, PE, FSFPE *is with the Fire Protection Research Foundation*.

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