READY FOR THE NEXT STORM

AI-Enabled Situational Awareness in Disaster Response

National Security Report

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Contents

Figures

Tables

Summary

Situational awareness during disaster response is critical as it enables the response community to rapidly and efficiently assist those in urgent need during the time-sensitive, acute phase of a disaster. New technologies can drastically improve the effectiveness of response operations: satellite imagery to quickly map the destructive path of a hurricane, social media tracking to identify communities of increased need, and computer modeling to predict the route of a wildfire to inform evacuations. The US government has prioritized implementation of artificial intelligence (AI) systems throughout the federal agencies, including those technologies that may assist in disaster response. In this report, we contribute a technological road map for delivering to the response community near- and more distant-future AI-enabled technologies that could aid in situational awareness during disasters. By exploring current and historical technology trends, successes, and difficulties, we envision the benefits and vulnerabilities that such new technologies could bring to disaster response. Given the complexities associated with both disasters and AI-enabled technologies, an integrated approach to development will be necessary to ensure that new technologies are both science driven and operationally feasible.

Situational Awareness in Disaster Response

On the morning of November 23, 2016, Great Smoky Mountains National Park (GSMNP) personnel discovered a small wildfire in the Chimney Tops area about 5.5 miles south of Gatlinburg, Tennessee, a city of close to four thousand people.[1] Believing the fire to not be severe, the GSMNP staff constructed a 410-acre containment area to control the spread and chose not to notify the Gatlinburg Fire Department of the situation. Over the next few days, the situation rapidly deteriorated because of weather conditions that favored growth of the wildfire, and by midday of the 28th, the Gatlinburg Fire Department, GSMNP, and the Sevier County Wildland Fire Task Force had boots on the ground fighting the blaze and serving evacuation notices to the Mynatt Park community. The high winds and dry conditions made the task a losing fight, and by 8 p.m., the fire had increased well over tenfold and had engulfed at least seven thousand acres. By 8:30 p.m., the Tennessee Emergency Management Agency (TEMA) made the decision to evacuate Gatlinburg.

TEMA intended to use an established public warning system to send text messages to all mobile devices in Gatlinburg. After the TEMA public information officer received the wording for the message in a phone conversation, they sought to verify the message before distribution, as was TEMA policy. In the time between the phone conversation and the message verification, power and cell phone connectivity was partially severed because of the wildfire, and the message was never verified or distributed. Fifteen agonizingly long minutes later, the National Weather Service made its own announcement using a more limited emergency alert system. In the absence of a widespread, electronic message, police, fire, and mass transit personnel began going door-to-door to serve evacuation notices, but this was a labor intensive and inefficient process. At 9:47 p.m., the National Weather Service made another announcement via radio and TV, but the message was too late in coming. By 10 p.m., only an hour and a half after the evacuation notice, three citizens of Gatlinburg and eleven people in Sevier County had perished in the firestorm. Two thousand five hundred buildings were damaged, and seventeen thousand acres burned. The failures that led to these avoidable deaths—inaccurate predictions of the fire spread, temporary breakdown of internal communications and connectivity systems, and inefficient means of contacting the public—all served to limit the situational awareness (SA) of the responding agencies and the public at large.

SA, as defined by Mica Endsley in her seminal 1988 work "Situation Awareness Global Assessment Technique (SAGAT)," is the "perception of the elements of the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future."[2] Proper decision-making in a complex emergency response scenario requires thorough SA of the threat, existing and potential damage, and available resources. Response decisions misinformed by incorrect or inadequate data can lead to preventable morbidity and mortality.

To simplify our terminology, the working use of the term "disaster" will encompass both disasters as defined by the Federal Emergency Management Agency (FEMA)—"an occurrence of a natural catastrophe, technological accident, or human-caused event that has resulted in severe property damage, deaths, and/or multiple injuries"[3]—and emergencies as defined under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act)—"any occasion or

[1] This section relies heavily on the information and analysis presented in Guthrie et al., *After Action Review*, published by ABSG Consulting on behalf of the City of Gatlinburg, Tennessee, and Sevier County, Tennessee. The report primarily focuses on the Chimney Tops 2 fire.

[2] Endsley, "Situation Awareness."

[3] FEMA, *SLG 101*.

instance for which, in the determination of the President, Federal assistance is needed to supplement State and local efforts and capabilities to save lives and to protect property and public health and safety, or to lessen or avert the threat of a catastrophe."[4] This definition allows us to contextualize the roles and responsibilities of FEMA, the Department of Defense, and the Department of Health and Human Services as well as other federal and state agencies essential to disaster response, especially responses to disasters officially declared by the president under the Stafford Act.[5] A full listing of those disasters informing our discussion can be found in Appendix C.

Roles and Responsibilities of the Government in Disaster Response

Disasters are demarcated by the different stages of the disaster life cycle: prevention, protection, mitigation, response, and recovery. Prevention, protection, and mitigation take place before the onset of a disaster, while recovery focuses on the long-term return to normal after a disaster strikes. The response phase, which is the focus of this work, begins the moment a disaster occurs. Per the National Response Framework (NRF),[6] response activities include any and all actions that save and protect lives, property, or the environment. As the NRF is nonspecific to the scale of the incident (and emphasizes that most incidents are strictly managed by local governments and entities), "response activities" can include actions ranging from neighbors delivering fuel to other members of their community to large-scale, multiagency and multistate search-and-rescue operations after catastrophic flooding. Generally, as the scale of a disaster increases, the scale of the response rises concurrently. Further, as an increasing number of responders and organizations become involved, the complexity of the response also increases, as does the need for and challenge in collecting complete and mutual SA.

An effective response necessitates coordination and collaboration to avoid duplication of effort or contradictory activities and to ensure the sharing of information and protocols. Response activities should be focused on similar priorities that leverage complementary, coordinated activities by involved entities to achieve the greatest possible return on effort. This is known as "unity of effort" and is particularly important in the acute stage of disasters when minute differences in response efficiency can drastically alter the magnitude of the loss of life or damage to property. The NRF, as well as the Department of Homeland Security's National Incident Management System (NIMS)[7] and Incident Command System (ICS),[8] increase the efficiency of a response through the use of administrative controls that establish common command structures and assign roles and responsibilities to different organizations. FEMA community lifelines[9] assist responding agencies by enumerating the services whose recovery should be prioritized in the acute

[4] Stafford Act, Pub. L. 93-288. The Stafford Act sets the relationship between the federal government and state and local governments with regard to disaster assistance. For a full definition, see Appendix A.

[5] While the team identified more than fourteen definitions of "disaster" during research for this report, because of the scope of this work, we chose to use a definition that would not categorize the 2008 financial crisis as a "disaster" because FEMA would not have been activated.

[6] DHS, *National Response Framework*. The NRF was mandated by the Homeland Security Act of 2002 after the attacks of 9/11 and the recognized need for a coordinated delivery of federal resources. For a full definition, see Appendix A.

[7] NIMS was developed by the Department of Homeland Security in 2004 in response to the Homeland Security Presidential Directive. For a full definition, see Appendix A.

[8] The ICS is a standardized management system that combines facilities, equipment, personnel, procedures, and communications operating within a common organizational structure. For a full definition, see Appendix A.

[9] FEMA community lifelines are those services that are indispensable to continuous operation of critical functions. For a full definition, see Appendix A.

stages of a response. These considerations are essential to setting up a response, but these publications do not go so far as dictating how each response should be administered. An all-hazards approach lays out the basic tenets needed to prepare for the majority of disasters, leaving the nuance of each disaster setting dependent on those involved. The response must be informed by an active understanding of the status of the disaster and activities on the ground, and for that, the coordinating body and response partners need to achieve SA.

The Need for a Full Picture

Collectively, four of the most destructive disasters in recent US history—Hurricanes Katrina, Harvey, and Maria and the Camp Fire that razed Paradise, California—killed over five thousand Americans and caused an estimated $350 billion in damages. Unfortunately, there is little chance that disasters such as these will cease in the coming decades. Recent studies suggest that disasters of all kinds, whether natural or not, have increased in frequency, severity, and complexity.[10] The factors leading to this increase in deaths and destruction include the escalating prevalence and intensity of critical weather events, the rising risks from emerging infectious diseases, and a global trend toward urbanization, which concentrates risk.[11] While accurate SA alone will not mitigate any of these disasters, it is a vital component of being able to properly respond to them, no matter the size.

What is considered complete or necessary SA varies significantly depending on the specific disaster, location, and responders involved. Firefighters need information about fire dynamics and weather conditions to combat a wildfire; conversely, there is no evidence that weather tracking and climate models could help scientists understand or mitigate the spread of SARS-CoV-2.[12] Some needs can be shared—understanding evacuation bottlenecks and congestion in the face of an impending hurricane, flood, tsunami, or wildfire can enable authorities to move communities to places of safety more quickly. Because the federal government may be asked to assist communities in any state or territory, it is prudent for FEMA and other federal agencies involved in disaster response[13] to have access to diverse tools that could aid in SA for any major disaster across the country.

Realizing a Place for Artificial Intelligence in Disaster Response

Executive Order 13859 directs federal government agencies to bolster their use of artificial intelligence (AI) technologies through investment in research and development, training, and collaboration.[14] This mandate was released in February 2019 and is commonly referred to as the American AI Initiative. For some agencies, this initiative has meant continued work in the field of AI, whereas other areas of the federal government have found that their operational space contains few existing AI technologies. Though this order does not mandate research to confirm which technological areas may see the greatest benefits from AI, the federal push for its

10 Than, "Scientists."

11 Easterling et al., "Climate Extremes"; Jolly et al., "Climate-Induced Variations"; Jones et al., "Global Trends in Emerging Infectious Diseases"; Mazdiyasni and AghaKouchak, "Substantial Increase in Concurrent Droughts"; and UN Department of Economic and Social Affairs, *World Urbanization Prospects*.

12 Jolly and Freeborn, "Towards Improving Wildland Firefighter Situational Awareness," 574; and Lipsitch, "Seasonality of SARS-CoV-2."

13 Though FEMA, housed under the Department of Homeland Security, is the lead agency for emergency management, other federal agencies that are frequently called upon for disaster response include the Department of Veteran Affairs, Centers for Disease Control and Prevention, Office of the Assistant Secretary for Preparedness and Response, National Weather Service, National Science Foundation, and Department of Defense. Other agencies can provide supplemental assistance as needed and appropriate under the Stafford Act.

14 Executive Office of the President, *Maintaining American Leadership*.

expansive incorporation motivates a closer look at how AI may be of use for SA in disaster response.

AI and machine learning (ML) capabilities have demonstrated effectiveness in many arenas, especially in the development of tools that can intelligently sort through large amounts of data to draw conclusions much faster than a human can. Given that one of the most common refrains from disaster responders is fundamentally "too much data, not enough time," AI/ML solutions are appealing to the response community.[15] However, AI/ML solutions have shown unexpected consequences that highlight the need to operationalize AI wisely and thoughtfully and only after careful verification and validation of the tool and associated policies.[16]

Consider the following cautionary example of AI being adopted without proper consideration. A start-up company called OneConcern deployed AI algorithms based on water flow information to predict areas of increased risk and need during a flood. The usability and friendly design of OneConcern's user interface made it an attractive tool for responders seeking SA to set geographic priorities. However, as this tool was further field tested and implemented, it became clear that the limited training data used to develop the model overrelied on the importance of residential density and significantly underestimated risk in commercial areas. These miscalculated predictions could have put lives at risk if any of those areas had been in unrecognized danger and could have resulted in wasted resources if responders had prioritized other locations.[17] While it does not appear that OneConcern's data problems caused significant harm during the time the tool was deployed, it is one example of how insufficiently validated AI/ML tools may have unforeseen costs.

[15] Compiled notes from personal interviews conducted with disaster-response professionals.

[16] Osoba and Welser, *Intelligence in Our Image.*

[17] Fink, "This High-Tech Solution."

As the federal government further embraces the use of AI in all applicable sectors, it is worth exploring what the near, medium, and distant future of disaster response will look like as novel technologies are implemented. In developing a road map for technological advancement, we aim to answer the following questions:

- What technology is available for SA?
- What AI/ML technological development is achievable in the short, medium, and long terms?
- What organizational and practical impediments may exist that would make it difficult to adopt AI-enabled technologies, and how could they be overcome?

In this report, we describe a vision for the future of technology integration to achieve SA in disasters that is informed by a systematic review of published literature as well as postdisaster after-action reports (AARs), interviews with US government personnel at both the local and federal levels, and focus groups with AI and technology subject-matter experts (SMEs). Structured brainstorming sessions within the focus groups provided comprehension of the near and far future of technology in this field as well as proposed novel technologies to fill the identified gaps in SA technology. A combined understanding of the current and future limits of technology for SA, consideration for the in-the-field needs of disaster-response personnel, and SME input were leveraged to produce an envisioned future to better contextualize these technologies.

Developing a Road Map

To develop an informed and feasible road map and envisioned future, we first took stock of the current state of the science in technology integration for SA and disasters. We conducted a systematic literature review of the state of technology to enable SA in disaster response.[18] Briefly, this review

[18] Kedia et al., "Technologies Enabling Situational Awareness."

spanned academic literature related to technology and SA in disaster response and AARs from several large-scale disasters. Additionally, the team conducted interviews with current and former local, state, regional, and US government officials in the disaster-response field. The team identified all technologies and technology capability gaps addressed in each source and organized the data into primary categories.

In performing the literature review, we recognized that solely focusing on the gaps in technology development and production was insufficient to address all the relevant factors that resulted in SA difficulties during disaster response. An overreliance on technological solutions could also lead to vulnerabilities in the response. For example, investing in novel computer programs would prove ineffective if continued power outages and a lack of back-up power at a disaster site render computers useless. To better understand common difficulties surrounding technology gaps, we leveraged published AARs to identify lessons learned that relate to SA capabilities. These were categorized into doctrine, organization, training, materiel, learning, personnel, and facilities (DOTmLPF) failures, though a complete DOTmLPF analysis was not conducted because of time constraints.

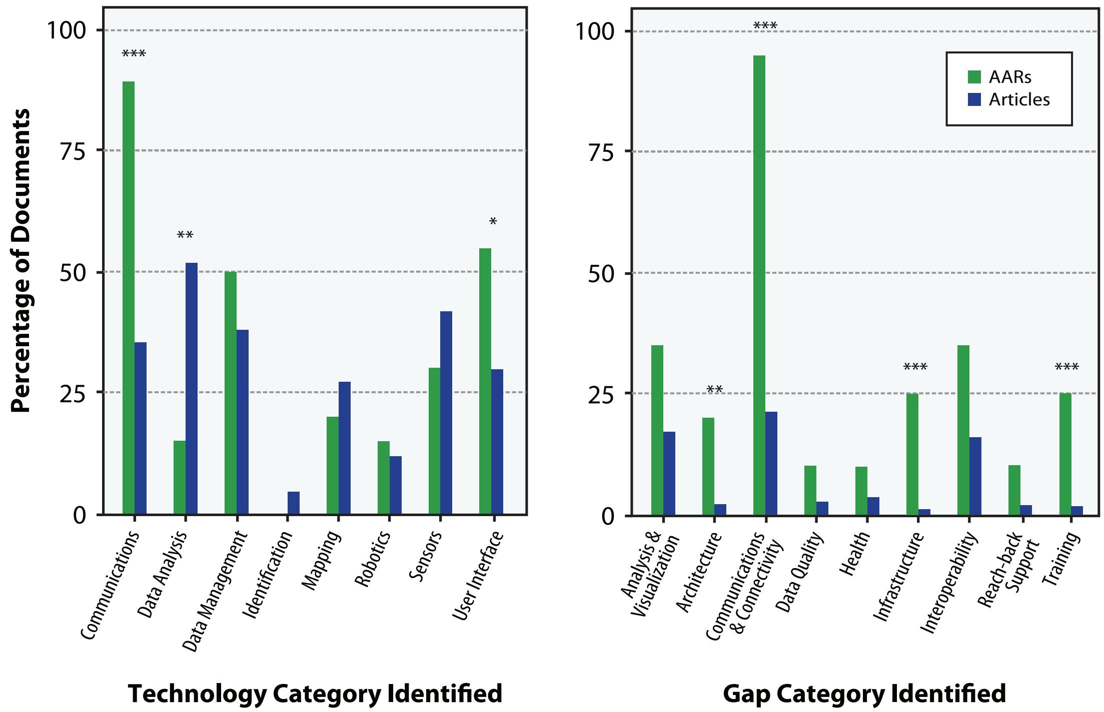
Drawing on a grounded understanding of the current technology gained through the literature and interviews, we then sought AI/ML and national security expert input to understand future technological directions and associated implementation challenges. The participants of the AI/ML SME focus groups were asked to propose AI-enabled technologies based on their experience and knowledge of AI/ML. They categorized their brainstormed SA technologies on the basis of how near-future they believed each technology to be (near, mid, or far) and how the proposed technologies relied on each other to evolve over time. Participants were also invited to list nontechnology issues that would have to be overcome to develop their idea (funding, training, policy, etc.). Respondent answers were compiled from all focus groups and validated against examples in AI and disaster management literature to winnow out those conceptualized technologies that were less relevant to our road map.[19] A red team–style focus group of five national security SMEs with experience in AI was formed to further anticipate difficulties and vulnerabilities that could appear in the envisioned future. These SMEs were presented with the results from the previous structured focus groups and asked to consider likely technical and strategic vulnerabilities of each type of technology identified.

The results of the literature review and focus groups were taken to inform an exploratory envisioned future, which is described at the end of this document in the section The Hurricane: Envisioning the Future.

Current Technology Used in Achieving SA

Our systematic review of the technology space for achieving SA in disasters included 302 academic studies and AARs. Relevant to this document, the most pertinent analysis was mapping technologies to their intended problem space and concurrently cataloging the problem spaces noted in the AARs. Overall, there was significant disconnect between researchers' priorities outlined in academic studies and the stated needs of end users in AARs, with statistically significant differences in frequency of mapping for communications, data analysis, and user interface technologies between published articles and AARs (Figure 1). In line with this result, none of the gaps identified in AARs were filled over time, suggesting that these identified needs continue to persist and that these issues are not being mitigated through the introduction of novel technologies or other factors. This result was further linked to the overwhelming majority of SA technologies being in immature stages of development

[19] Technologies that were not AI enabled or lacked a clear focus on achieving SA during disaster response were considered outside the scope of this work.



n = 282 articles, 20 AARs. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. The statistical significance of the data was determined using Pearson's chi-squared test of independence for contingency tables containing data from articles or Fisher's exact test for contingency tables with data from AARs and articles. *Source*: Kedia et al., "Technologies Enabling Situational Awareness."

Figure 1. Technology and Gap Categories Mapped by Record Type

at the time of publication. These observations suggest a continual problem in transitioning technology from concept to implementation. In summary, our analysis identified a demonstrated need among the response community to plug gaps related to disaster response but a perpetual inability of the current development pipeline to properly address these issues.

Interviews with officials involved in disaster response revealed the technologies commonly in use in emergency operations centers (EOCs). Somewhat surprisingly, the technologies most commonly described as being SA enabling are those that are in most office spaces around the country: telephones; short message service, or SMS; email; and spreadsheets. More infrequent, field-specific technologies were also described: seismographs to detect earthquake tremors, buoy-deployed sensors to warn of incoming tsunamis, and satellites to track weather patterns and perform overhead assessment after a natural disaster. An interesting phenomenon was the common co-opting of existing technologies for the purpose of SA in disaster response—these technologies, while demonstrating the importance of adapting everyday items for this purpose, are rarely AI/ML enabled.

A few interviewees spoke of certain more-specialized SA technologies being exceptionally effective. Examples of these technologies included RadResponder used by FEMA's Chemical, Biological, Radiological, Nuclear Office and the Touch Assistant Command and Control System (TACCS) used by the Department of Veterans Affairs (VA). RadResponder,[20] born of a joint-agency effort after the Fukushima nuclear disaster in Japan, provides SA on radiological levels in a given area via sensors and can track resources, which can be shared across organizations and inform the media.

[20] For more information, visit https://radresponder.net.

Table 1. Three Categories of Gaps Most Frequently Identified

Gap Category	Description
Communications and connectivity	The ability to transmit information by various means. The ability of a computer, program, device, or system to connect with one or more others.
Analysis and visualization	The process of inspecting, cleaning, transforming, and modeling data, especially using a computer, to discover something or to help with decision-making. The representation of information as a chart or other image.
Interoperability and sensors	The ability of two or more systems or components to exchange information and to use the information that has been exchanged. The power or ability of a device to do something, detect or measure a physical property, or record, indicate, or otherwise respond to information.

RadResponder can quickly record, aggregate, and distribute large amounts of data and thus is integrated into multiple stages of achieving SA. In the aftermath of Hurricane Maria, the VA began maintaining SA through its TACCS tool, which allows the VA's Integrated Operations Center in Washington, DC, to communicate with VA employees around the country in real time.[21] An example of a widely used technology that is not meeting the needs of end users is the more generalizable technology WebEOC, which is available to every state and territory in the United States thanks to FEMA purchasing licenses for its use. WebEOC is an online crisis-response management tool capable of incident plan development, critical event tracking, and resource tracking.[22] Several of the officials interviewed said that WebEOC is insufficient to efficiently ingest the enormous amount of data that EOCs receive, is unable to be easily customized, and does not help in obtaining or curating clear information from the on-the-ground responders who report information to WebEOC.

The interviews with responders largely mapped to the most commonly reported technological gaps identified in the systematic review of the literature: communications and connectivity, analysis and visualization, and interoperability and sensors (Table 1). According to the literature and AARs, gaps in communications and connectivity—the most commonly cited issue—were frequently related to issues in connecting large groups of people on conference calls or communicating across a large distance when the mobile phone network was not operational. Analysis and visualization gaps included inaccurate physical and epidemiological models or an inability to display large quantities of information in a readily understood manner. Interoperability and sensors gaps included a frequent issue of difficulty sharing data formatted in different ways and an insufficient ability to analyze all incoming sensor data in a timely fashion. While a few gap categories noted in the review were less directly related to technological development, such as training and infrastructure, the three primary gaps listed in Table 1 were the most frequently cited across the academic literature, AARs, and interviews with experts. The consistency of their appearance across these various informational sources supports the notion that these three categories are a rational basis and structure for organizing our technology road map.

Predicting Future Technology Development

The primary gaps guided three structured focus group sessions with a total of approximately twenty-five self-identified AI/ML SMEs. The participants, all Johns Hopkins University Applied Physics Laboratory (APL) technical staff members, were presented with three challenge statements and a fictional disaster scenario. These challenge statements were crafted to reflect the primary gaps that

[21] VA, "Touch Assisted Command and Control System."

[22] FEMA, *Web Emergency Operations Center.*

were revealed by the review, and the focus group feedback assisted with conceptualizing the future applications of AI/ML to these disaster spaces. The challenge statements posed to the focus groups were as follows:

(1) **Communications and connectivity:** Sparse connectivity and the resulting lack of communication often hinders disaster response by limiting shared SA.

(2) **Interoperability and sensors:** The variety of actors responding to a disaster necessitates the use of technologies that are able to gather or exchange information between systems.

(3) **Analysis and visualization:** Disaster-response efforts require instantaneous data, which is not attainable given the current triaging (cleaning, processing, and interpreting) pipeline. As a result, data are often “expired” at the time of analysis and/or presentation to decision-makers.

Identifying Difficulties to Inform the Envisioned Future

AI-enabled technology has been minimally used in previous disaster situations, so the lessons learned were unlikely to identify difficulties that may be specific to AI/ML. The results of the red team focus groups are summarized in Appendix B. Both the red team and lessons learned were used to inform the envisioned future. The most frequently identified lessons learned from the DOTmLPF analysis of the AARs are listed in Appendix C.

Drawing a Map

The compiled road map, shown in Figure 2, is a visualization of the collected viewpoints of dozens of APL technical staff members as they imagined an optimistic, AI-enabled future. Table 2 discusses these identified technologies in more depth, is based on input from the APL staff members involved in the discussion, and emphasizes those technologies that received greater support. Several technologies were identified as supporting the implementation and development of other technologies. These synergistic connections are indicated on the map by arrows leading between technologies.

The road map as described provides several important implications for the next stage of technological development in the field of disaster response. The majority of technologies that will be available in the near future are born from established technologies that are adapted and applied to disaster-response applications. As the application stretches further into the future, technologies become more specialized, but at no point would the hardware be a device strictly limited to disaster settings. Across all time windows, the envisioned technologies could find use cases in multiple disaster scenarios, emphasizing that the field may benefit from prioritizing the development of technology with a diverse profile of applications. Chief among these applications was the use of sensor technologies (such as drones) to collect and relay information back to an EOC or inform on-the-ground responders or citizens in crisis. The red team analysis and review of lessons learned were used to offer practical concerns that could appear in the technology-enabled envisioned future. This future dovetails with the current state of SA technology for disaster response in the following section, The Hurricane: Envisioning the Future.

The Hurricane: Envisioning the Future

Leveraging AI in disaster-response efforts, when done effectively, can supplement and enhance the level of SA provided to responders and ease the burden placed on both the individual responders and the agencies responsible for responding to a disaster. Consider this potential scenario: a Category 5 hurricane striking the small island of Gazo, a fictional territory off the coast of the United States. To demonstrate the benefits of implementing AI technologies for disaster response, we present this

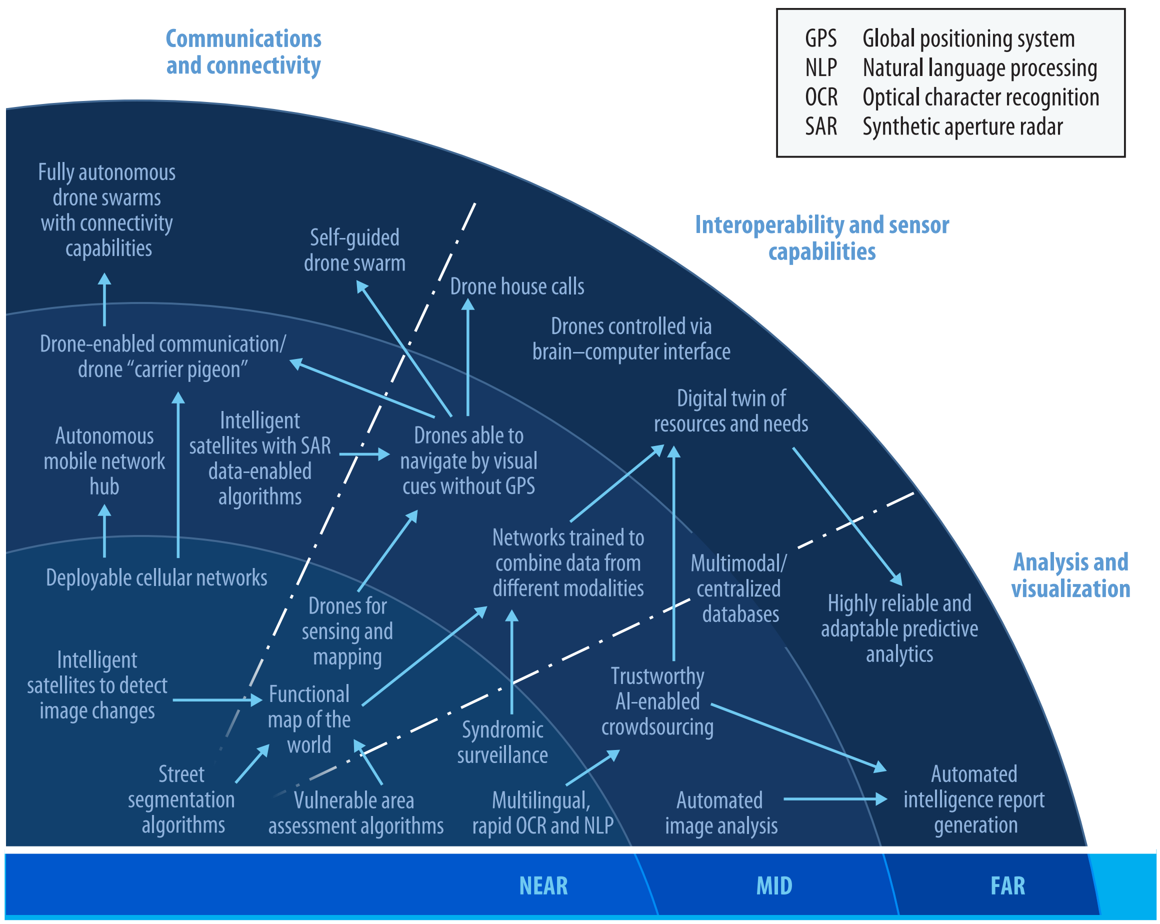


Figure 2. The AI-Enabled Technology Road Map for Near-, Mid-, and Far-Future SA Technologies

high-level hurricane scenario (at right) as well as the current, future optimistic, and future pessimistic responses to this disaster for each of the primary gaps identified above (analysis and visualization, communications and connectivity, and interoperability and sensors). We refer to these responses as the following:

Status quo: The expected response to the disaster with current technologies

Envisioned future: Potential future response aided by AI technologies; based on current efforts in these fields, burgeoning research areas, and focus groups

Envisioned difficulties: Potential future response disrupted by mal-use and misuse of AI-enabled technologies as well as unaddressed DOTmLPF challenges

Scenario

On the morning of July 5, the National Oceanic and Atmospheric Administration begins tracking a relatively benign tropical depression forming in the southeastern portion of the Caribbean. The projected path predicts the storm will dissipate before reaching any landmasses, so few pay it any heed. However, on the evening of July 7, the storm picks up strength, becoming a Category 2 hurricane named Emma, and unexpectedly diverts its path straight for the US territory of Gazo. Overnight, Hurricane Emma strengthens into a Category 4 and slams into the island of Gazo the following morning, causing widespread flooding and damage to the island, whose residents had little time to prepare for the storm's arrival. FEMA, the US Coast Guard, and the American Red Cross rapidly deploy assets to the island and are met by the local emergency management team.

Table 2. Primary Technologies of Interest for Development

Technology of Interest	Progress and Consideration
Street segmentation algorithms (near future)	This technology is under development but usually not applied to disaster scenarios. It can help catalog the presence of streets and identify blockages and hazards; it could potentially be aided by drone mapping and could contribute to a heat map of vulnerable areas.
Multimodal database capabilities and centralized database (mid to far future)	Software technology is under development for data integration to increase the speed of data analysis. Centralizing data will require policy action to ensure privacy, data security, and access for the appropriate users.
Intelligent satellites with synthetic aperture radar data-enabled algorithms (near to mid future)	Synthetic aperture radar technology is making progress with ML but requires further verification in different scenarios, including disasters with extreme weather. Allowing for visualization despite cloud cover would be highly beneficial and easily applicable to disaster use. Intelligent satellites that could identify image changes could also be used to prioritize areas of damage when on-the-ground sensors are not available.
Autonomous mobile network hubs (near to mid future)	Some industry mobile network solutions are already available for disaster response, but autonomous solutions are under long-term development. Successful implementation will require communication beacons that are mechanically resilient as well as having AI/ML capabilities to determine the optimal placement. This technology would contribute to filling the most frequently mentioned gap in communication.
Drones able to navigate by visual cues without the global positioning system (GPS) (near to far future)	Drone technology has made massive progress and may be able to operate without GPS in the not-too-distant future. Technology developed for military applications could be translated to disaster response. Image analysis is also being developed independent of disaster response. Further autonomous capabilities that are useful for disaster-response applications will develop if there is sufficient investment in both mechanical resiliency and AI/ML.
Syndromic surveillance and modeling (near future)	Technology has been advancing in disease surveillance efforts but will require significant public and policy buy-in to ensure data are available from as many locations as possible. Epidemiological modeling using AI/ML is being produced by some researchers and continues to require thorough validation and verification to ensure that it becomes superior to other modeling methods.
Trustworthy AI-enabled crowdsourcing (near to mid future)	Technology is being considered, and some preliminary crowdsourcing technology already exists, but significant hurdles will need to be overcome to ensure that crowdsourced data are trustworthy, reliable, and safe.
Multilingual rapid optical character recognition and natural language processing (near future)	Technology already exists via cell phone applications to perform a significant amount of translation of spoken and written word, but it may not be considered trustworthy enough by many to be used under such serious circumstances. This technology is constantly under development by industry and academics and is easily translated to disaster scenarios.
Highly reliable and adaptable predictive analytics (mid to far future)	AI-enabled predictive analytics currently exist for some industry users. In disaster response, they are helpful in identifying what materiel first responders require or products a population may need after a disaster, including food or health items. This technology may also be associated with mapping vulnerable populations and developing intelligence reports using AI. However, given the highly varied nature of disaster response and the noted difficulties with this technology, significant further work is needed to ensure appropriate use.

Analysis and Visualization

In our hurricane scenario, outdated maps and baseline population information evolve into AI-enabled analysis and visualization tools that permit more rapid and accurate assessments of the physical infrastructure and populations in need of assistance. Displaying these data enables the immediate development of response activities, including the provision of material, personnel, and logistics support.

Status Quo

Gazo was ill-prepared for a hurricane of this magnitude. The roofs of thousands of homes have been ripped away by Emma's 152-mph winds, leaving many without shelter during Gazo's rainiest season. Many people are unaccounted for, which is creating chaos for first responders trying to decide which area of the island to cover first. Baseline data—which the EOC needs to contextualize the information it is receiving from the field—are lacking. Responding agencies have been unable to find recently updated information on the location of vulnerable populations or any copies of previously generated hazard maps that may help them prioritize neighborhoods that were at a higher risk of severe damage.[23]

Envisioned Future

An analyst at the EOC pulls up a dashboard featuring a map of Gazo. Noting that the existing imagery is dated, the system automatically determines the *optimal satellite constellation with synthetic aperture radar (SAR) capabilities* to collect data on the affected area and submits a request to the constellation to collect these data. Leadership reviews the request to reassess the area via *drone imagery* and *SAR-onboard aircraft* and agrees to deploy the aircraft to the area upon adequate weather conditions. The SAR data coming in from the satellite constellation allow initial analysis of the conditions of the roads and bridges around the island and provide feedback on areas that require further investigation by the drones. The planned drone and SAR-onboard aircraft trajectory is updated to accommodate these needs. *Street segmentation algorithms* run on the satellite SAR data, which alert the analyst that several major roads are obstructed. They also indicate the locations of several hospitals and nursing homes in the area that may be impacted by blocked roadways and downed power lines.

The dashboard displays the segmentation algorithm's count of the number of damaged buildings in the surveyed area as well as the anticipated number of residents affected based on the data auto-retrieved from the resource database. The system suggests several courses of action for providing assistance to the individuals in the damaged buildings, including, for each course of action, the associated resources needed and a risk assessment.

Envisioned Difficulties

- Bad actors have found the listings of vulnerable populations online. The decision to make this location information public was intended to allow neighbors to help meet immediate needs, so the data manager started posting incoming location information on an unencrypted website. Local scam artists are now targeting those on the list for theft.
- The resource database had not been updated since it was first mandated three years ago because it was found to be cumbersome and the population has significantly shifted since then. The algorithms are running based on old data, and at least one of the nursing homes that is flagged as concerning has been shut down for over a year, resulting in wasted time.
- The drone imagery algorithm misidentifies a caustic chemical spill from a local factory as water because no data on a chemical spill of this nature were previously reported and the classification algorithm cannot tell the difference. Responders are directed to an area of potential hazard with high confidence and are lucky that someone smells the chemical before walking through it.

Status Quo

Emergency responders are struggling to understand the needs of Gazo because hazard maps are unavailable and Hurricane Emma caused

[23] Nick et al., "On Linkages."

landslides throughout the island, blocking roads to remote villages. With many homes destroyed and access to basic necessities limited and cut off in certain areas, delivering supplies to the impacted residents of Gazo becomes a high priority. Medicine, clean water, and generator needs can be estimated, but the damage to shipping docks makes importing goods more difficult and emphasizes the importance of precision so as not to crowd the supply chain with nonessential goods. Emergency responders know that vulnerable populations will be the first to die if they do not have access to medicine, clean water, or power.

Envisioned Future

The analysis of the SAR data informs the EOC that two of Gazo's emergency warehouses are located in areas convenient to the high-impact sites and do not appear to have sustained significant damage. The drones, which are already tasked with traveling near these areas to collect further imagery, are instructed to fly by the warehouse locations while downloading additional information regarding the route. Connection is briefly lost on multiple occasions en route because of limited service in the area, but the drones are able to continue flying uninterrupted by using *computer vision technologies*—which allow them to match their current surroundings with landmarks on the map—to navigate obstacles and adjust course. Along the way, the drones are able to collect imagery on the surrounding area and *quickly process the images* to determine the most impacted areas. Upon approaching the warehouse, the drones transmit a request to the Warehouse Operational Unit (WOU), a machine designed to run the warehouse, for the inventory and status of the supplies within. Connection permitting, the drones submit the most relevant information back to the EOC. Potential courses of action are assessed using the *onboard processing capabilities of the drones*, comparing the recent damage assessment generated from image processing within the area with a previously *established centralized database of information* on the residents gathered from the census data, electronic health records, and self-reported data, such as house occupancy, demographics, and medical needs. The drones relay orders to the WOU on the need and intended dispersion of supplies, along with recommended routes based on the road blockages identified in the SAR and drone imagery analysis. The WOU is notified that the most at-risk patient, Elisabeth Humer, at 381 South Charles Street, uses an oxygen tank because of her recorded chronic obstructive pulmonary disease. Her delivery of a generator equipped with gas and oil is prioritized, and a neighbor is contacted to help her set it up.

Envisioned Difficulties

- Underground market traders are able to intercept the drone transmission regarding supplies and ransack the warehouses. They sell the goods on the market before responders can deploy any of them.
- Over the past several years there has been public outrage related to the theft of protected medical data, so individuals have been allowed to opt out of this tracking system. The outcry was especially bad among Gazo residents because of a history of the federal government mismanaging their data, and data on about half the citizens are unavailable responders. Though Elisabeth Humer may have had her life saved by a caring neighbor, she is embarrassed to have her medical needs advertised publicly and vows to sue the responding agency to ensure that only medical personnel have access to her data.
- The WOU depends on user input to track goods in and out of the location, a task that has been mismanaged by the contracting agency staffing the warehouse. As a result, the inventory information relayed to the EOC is woefully inadequate and overestimates the resources available

to the responding team, particularly those related to fuel and palatable water.

Communications and Connectivity

To overcome disrupted communications and connectivity in the current hurricane scenario, we envision the establishment of temporary wireless networks and AI-enabled data processing at the speed of data acquisition for more accurate, timely SA for responders and EOCs.

Status Quo

The EOCs are having a litany of problems associated with obtaining information from and passing directives on to their staff in the field. Cellular networks are down in Gazo as the hurricane wreaks havoc on the local infrastructure. With towers turned into debris, it is vital that first responders find alternative means of communicating wirelessly. Since standard modes of communication are inoperable, the EOC staff are only able to gain SA when they return to the base at the end of their shift. In turn, situation reports, which inform decision-makers, can only be updated every twenty-four hours after the information is retrieved and processed. When information comes in from different agencies responding to the disaster, the data are nearly impossible to compile into one report because the different staffs used different software tools. The data collections often have overlapping information that could provide an idea of the larger picture of the situation if properly combined. Combining these disparate data sources requires intense human analysis as it is easy to inadvertently make mistakes when there are so many similarly named streets and people, overlapping data are being double-counted, and data are being entered into the wrong spreadsheet.

Envisioned Future

Using estimated population densities, a collection of drones deploy from the EOC, *autonomously reposition*, and provide a *temporary wireless network* to the greatest number of affected citizens. The impacted citizen locations are updated via reports both from the agencies responding to the hurricane and from voluntary check-ins via social media platforms; the drones are able to reason over this information and automatically reposition as new data are fed into the localization algorithms.

The uncrewed aerial vehicles (UAVs) receive prioritization directions from the EOC to assist first responders as they venture into an area of Gazo that has not responded to wireless service pings, implying that this area does not have sufficient connectivity. This area of Gazo contains a hospital as identified in earlier drone monitoring of the region along with a medley of downed trees and potentially flooded roadways that would make the first responders' route difficult.

The *UAV mini-swarm* is alerted that the connection between devices, both in the air and on the ground, will probably be inconsistent. To reduce risk, the drones are able to toggle onboard sensors to track the movement of the other drones and the first responder vehicles. A series of *beacons* are laid along the route as breadcrumbs for the drones should they need to return to the EOC. Upon arrival at their first data-collection point, the first responders are able to set out docking stations for the drones that they identify via these onboard sensors and return to periodically to convey information to the first responders. These individuals can compile the information from the drone scouts to send back to the EOC by directing a chosen drone to follow the breadcrumb beacons back to the headquarters.

As data are received by the EOC, the information is sent to an *AI-enabled postprocessing algorithm* known as Data Entry Manager and Triaging Repository (DEMTR). The algorithm leverages a knowledge graph to understand the input fields and draw connections between the fields in these data and the existing collection of information from earlier reports. DEMTR is able to piece together information from different data sources created from the collection efforts of the different responding agencies and generate an output that is consistent with the EOC's preferred format. While uploading the data, DEMTR notices that the temperature field contains input that is consistently much higher than existing temperature data collected in degrees Celsius. DEMTR notifies an EOC analyst of this anomaly and provides the option to convert the data in the collected field from degrees Fahrenheit to degrees Celsius. With the data aggregated upon arrival, the EOC is able to keep an updated status of the situation that uses all information collected to form a more complete picture.

Envisioned Difficulties

- Though it was thought that someone higher up the chain had done their due diligence when choosing to deploy the drones, shortly after the UAVs are set up, the EOC receives an irate call from someone representing the Federal Aviation Administration. No one provides specifics, but it becomes clear that there is extremely sensitive airspace involved and half the island is strictly off-limits to these types of drones. Responders are left scrambling to find alternative means of communication.
- The drones have difficulty maintaining elevation as winds increase and must be taken down periodically throughout the day to ensure their safety, limiting the wireless network. At least this rotation allows them to recharge so they do not run out of batteries as quickly, which had also been a concern.
- Gazo does not have many drone hobbyists, and citizens are understandably confused and wary of seeing such large drones deployed during a disaster response. Some overzealous individuals start spreading rumors that the drones are spying on them and try shooting the drones out of the sky with pellet guns. When that does not work, they engage a local computer hacker to try to bring down a nearby drone.
- The drone-enabled cellular network seems to be working for the first two days, but officials start noticing a steady decline in the number of calls being managed by the temporary network. A survey later shows that cell phone batteries and battery packs had been quickly depleted, and because power generators had been prioritized for refrigerators and medical equipment, even with the network in place, no one could make a call. As a result, the drone-enabled network was not overly useful to the citizens of Gazo.
- The software's algorithm had full confidence that it was correctly combining CSV files on the basis of similar row and column headers, as well as a verification of numbers. Unfortunately, it quickly becomes apparent that the algorithm was not able to adjust for the redistricting that occurred a few years ago, leaving several data sets inaccurately depicting the jurisdiction of some hospitals and emergency facilities. Later, it is discovered that it had also inappropriately combined metrics of food in "days of food left per household" and "days of food left per person" because the original data sets were inconsistently labeled. Because of the negative feedback the responders received in response to their poorly informed original recommendations, decision-makers are wary of trusting the program again and revert to verifying every single line of data by hand.

Interoperability and Sensors

Technology use by a variety of disaster responders in our hurricane scenario introduces barriers in sharing and using the gathered data. To facilitate interoperability and use of multisensor data for precise response, system-agnostic technologies that identify, gather, and exchange information empower improved data sharing are envisioned below.

Status Quo

Different response agencies are attempting to coordinate efforts. However, some agencies are collecting data using mobile applications that work on only Android operating systems, while another is using an in-house MacOS application to track their resources and operations. All agencies have some overlap in the type of data they are collecting, but each has its own specific organizational requirements as well, so combining efforts on needs assessments in the field is dismissed. Language barriers with locals have prevented some agencies from discerning the needs of the community. At coordination meetings, some response agencies are using paper maps and handouts to share their current work, while others are sending out CSV and PDF files on data collected. Altogether, this is creating a massive analysis problem as the EOC scrambles to collect and collate data from the field but lacks the bandwidth to validate the data and to deconflict information from disparate sources, which are causing inconsistencies in situation reports.

Envisioned Future

Responders are equipped with *system-agnostic software* to work on the device of their choosing, based on the task at hand. The software uses common architecture to collect and store data from the responders as well as the ability to *interpret imported data* from other software used by other agencies via a knowledge graph that equates the common concepts between the collected data in each. While traversing the impacted areas, the responders are able to reference digital images of the paper maps that were downloaded into the software tool earlier. These maps included handwritten directions from a few local guides that indicated areas that had seen flooding in past heavy-rain circumstances. The tool recognizes that the processed image is a map and implements *optical character recognition* (OCR) to allow the responders to search the map image for text, both printed on the map as labels and written on the map as additional notes. This OCR-enabled map processing allows the tool to incorporate the local knowledge of flood-prone areas into the suggested routes for the responders and also factor the risk associated with these areas into the analysis of the surrounding regions.

As the responders are interviewing residents, they toggle on the recording feature of the tool, which is enabled with *natural language processing* (NLP). The NLP-enabled tool processes speech in the many languages spoken by the residents of Gazo and is able to quickly translate the residents' reports while simultaneously collecting notes on the areas of interest defined by the EOC. This communication helps responders identify those residents in need of help and learn important information from the community.

Envisioned Difficulties

- Responders have become fully reliant on the language-processing software to understand reports from the residents of Gazo and are comfortable operating without an additional human translator. Unfortunately, it takes too long for them to realize there is little difference between the words for "sleeping" and "dying" in the local dialect, and they have mistakenly disregarded several urgent reports.
- Responders begin to rely entirely on their tablet devices for maps and locations, and a malicious software bug results in an entire squad's devices going blank. No one has prepared for such a situation by printing or drawing additional maps, and the responders are forced back to the EOC via a circuitous route.

Status Quo

EOCs are sending first responders into dilapidated buildings first to rescue any victims trapped inside, risking potential injury to their first responders.

However, there is little alternative available to responders hoping to find the missing civilians.

Envisioned Future

Miguel Zamorano, a Gazo native, is drawn to his front door as a small remote piloted ground vehicle makes its way to the entrance. Turning to face Miguel, the vehicle introduces itself as an *emergency resource and inventory checking (ERIC) unit*. It asks Miguel how many people are currently residing in his residence and the amount of survival rations he has remaining. After thanking Miguel for his time, ERIC then navigates to the next residence on the block as it wirelessly dispatches an order for more supplies to be delivered directly to Miguel's door.

At the same time, a *swarm of highly agile UAVs* fly through a nearly collapsed building, mapping and processing the building's layout as they search for missing persons and high-risk vulnerabilities in the infrastructure.

Envisioned Difficulties

- Some people have discovered that the "self-reporting data" would be used to determine need and have started lying to get priority treatment. After all, how would the drone know they are lying? Already, the team has discovered one self-reported "medical emergency" was a citizen who wanted their TV to have a power generator, and someone with a stockpile of rations tried requesting more to sell on the underground market. A young group of pranksters thinks it would be funny make multiple reports of an emergency situation at the same location, and it is not until the fifth responder investigates the scene that the EOC decides to stop sending a drone to those households.
- About half of households still refuse to open their doors to the drones because they are scared and have no way of knowing the drones are meant to help them. Rumors spread of one drone breaking someone's window, injuring a person living inside. While this was unintentional and due to an unexpected wind gust, responders admit that accidents can happen with drones. Angry citizens try to damage or steal the drones, hoping to sell them for parts.
- Despite that drones were brought from the mainland, there simply are not enough to check every household in Gazo every day. Some people feel that they are being left behind and worry they will not receive the rations and emergency services they need. These fears are compounded further when it is discovered that there are not enough food rations to support the entire country and that everyone will only get a fraction of what they need.
- Malicious actors seize a UAV and reprogram it to detect police and first responder activity, providing an early-warning system while they burglarize local businesses and homes. They capitalize on the UAV's ability to identify secure infrastructure for transit and subsequent targets for raids.

Technology to Enable the Future

The continued development in any of these major technology areas may result in significantly improved SA capabilities for the response community. However, it will be important to consider the plausible envisioned difficulties associated with these technologies as well. The next section, Enabling a Bright Future, offers several points of consideration to ensure that these technologies are developed in a thoughtful and operationally relevant manner.

Enabling a Bright Future

Filling the primary gaps in SA distilled from this analysis may occur with the proper application of new AI-enabled technology. However, as seen in the envisioned futures, new technology often comes with a steep learning curve for the responders rendering assistance, the defense infrastructure learning to cope with an additional potential vulnerability, and the public trying to adapt to changing methods of interaction. Additionally, technologies that could be of significant help to disaster-response efforts may never be implemented if at least one organization is not motivated to take ownership of the tools and champion their use. Some technologies may cause significant public and legislative controversy as they are implemented, especially if there are concerns over privacy and data security. With few exceptions, a singular piece of AI-enabled technology cannot be handed to a responder during a crisis and achieve high utility if that responder has no prior training in the tool or access to expert assistance with it. In some cases, the presence of additional technology can even be a hindrance if decision-makers are unable to make sense of conflicting or overabundant information, or if they are unsure how to develop a course of action based on a new type of information with which they have no experience.[24]

Transitioning from the current state of technology used in disaster response to an AI-enabled future, as seen in the hurricane scenario, is not a one-step process. Instead, there are many milestones to be met and research and a great deal of development to be done before the envisioned future can be realized. Enabling assumptions that must be addressed for each technology may be simple technical needs, such as an electrical power source for the computer, or there may be complex regulatory decisions like whether surveillance drones can be legally flown in a civilian area.

The most common recommendations for introducing AI-enabled technologies from our red team exercise were consistent across the board: improved cybersecurity, sufficient end-user training, and clear legal policy for any new technology.

[24] Winter, "Too Much Information?"

The lessons learned from AARs also frequently mentioned the need for end-user training with new technologies as well as a dearth of trained personnel to meet surging demand during an emergency. Another common refrain was a lack of power or batteries to support needed technology, an issue that could have direct implications for several of the proposed AI-enabled technologies of our envisioned future. It is concerning how frequently current technology, both for SA and direct disaster response, is unable to be used in the field because of underlying insufficiencies: not enough trained workers to use mapping software,[25] electricity outages due to insufficient generators,[26] and inadequate leadership decisions intended to avoid panic,[27] to list just a few examples. Any AI-enabled technology must be introduced with an evaluation of the challenges faced by its predecessors so as to avoid similar obstacles.

The data gathered from the focus groups gave a glimpse of the problems and areas that are of current concern in the realm of AI/ML-assisted disaster response. Over time, these concerns will change and new requirements will arise, necessitating reevaluation of optimal technologies to achieve improved SA. Thus, a framework must be applied to enable us to stay current with SA technology for disaster response, bridge the gap between technology development and implementation, track the performance of implemented technologies, and identify new gaps.

Discover opportunity: The world of AI is moving very quickly, and re-examination of the proposed solutions using continual, automated assessments of new developments across academia and industry as well as implementation in governments

[25] Rosinski et al., *After-Action Report.*

[26] Texas Department of State Health Services, *Hurricane Harvey Response.*

[27] US NRC, Office of Nuclear Security and Incident Response, Division of Preparedness and Response, *Japan Incident Response.*

and nongovernmental organizations can keep us abreast of changes in the field. An example of such a solution is APL's Publicly Available Information Pipeline endeavor that could be leveraged and expanded to maintain a robust understanding of state-of-the-art technology for SA. Importantly, an appreciation of how needs are changing in disaster settings must also be cultivated to most effectively discover technology opportunities.

Effectively partner: As demonstrated by the more traditional systematic literature review described above, the transition of technologies from the research and development phase to operational use is not keeping pace with rapid AI technology expansion. While the American AI Initiative promotes research and development, training, and collaboration, establishing trusted partnerships is essential to support technology transfer to the field. Within the AI/ML domain, it is imperative that efforts are made a priori to establish large sets of "disaster training data" on which new technologies can base decision-making. Establishing a comprehensive data platform to ingest, integrate, and make available disaster data will hasten technology emergence and transition.

Continually evaluate: As new technologies are operationalized in disaster settings, an evaluation of not only the technology's use but its fulfillment of an organization's mission will be required. In other words, how well does the technology improve the execution of the mission? Answering this question requires mission analysis to establish essential elements for execution and effectiveness metrics as well as iterative, if not continual, data collection and analysis efforts to baseline newly adopted AI/ML technologies against the standard in the field. Additionally, leveraging the aforementioned data platform as a larger systems architecture could help integrate the adoption of SA technologies for disaster response with performance indicators that elucidate courses of action for an organization.

Define a new path: New technology implementation often reveals unanticipated gaps. Identifying the opportunities within these gaps, whether technological or DOTmLPF prerequisites to enable the use of AI/ML technologies for SA in disaster response, will foster vision and innovation. Intentional execution to deliver impact will fill these gaps.

Conclusion

This study aimed to add to the discussion of ongoing technology development in the world of disaster response. Given the current federal push and public interest in AI/ML technologies, we believe it is informative to consider these technologies in the context of an envisioned future, one plagued by the disaster-response difficulties we have seen historically and continue to see today. However, this work alone cannot definitively indicate the most valuable investments to improve disaster response. It is important to note that while one can apply this framework and even contribute to the development of the needed technologies, architecture, and analysis, the foresight needs to originate with those who aspire to collect, use, and incorporate this information into operational settings for improved SA. The use of AI/ML for SA in disaster response must have a champion, and this champion will likely need to arise from a federal government entity that can strive for a new and different future in disaster response.

Significant technical gaps remain in the ability of responders to maintain SA during disasters. A review of the recent technological literature, interviews with experts, and analysis of AARs all emphasize similar technology gaps during disaster response that could be filled, in part, through technological remediation. The primary identified gaps are in the areas of communications and connectivity, analysis and visualization, and interoperability and sensors. Many of the technologies that are used most often in disaster response are ones we use every day: email, conference calls, and spreadsheets.

Some agencies have more complex software and advanced sensors to track things like weather patterns, but these tools are rarely AI enabled. In this study, we provided a plethora of ideas for ways in which to augment current SA capabilities and create new ones with the application of AI/ML. The interdependence of these technology ideas was displayed such that the progression of near-term innovation that may seed far-future ideas is clear. These stepping-stone technologies represent potential high-impact opportunities for development.

In reviewing lessons learned and through a focus group with national security SMEs, a better understanding of the underlying, nontechnology enablers that will be needed to support new technology emerged. These enablers include clear policy and regulation, cybersecurity, training and qualified personnel, and sufficient infrastructure to include power and network access. AI-enabled technologies may be able to offer advances in the field of SA for disaster response. If applied in a conscientious, well-informed manner, considering both appropriate use cases and constraining factors, an AI/ML-augmented system could drastically reduce the destruction, morbidity, and mortality associated with these critical events.

Appendix A Definitions

Federal Emergency Management Agency Community Lifelines

In February 2019, the US Federal Emergency Management Agency (FEMA) established community lifelines as a framework for prioritizing sectors that need to be stabilized in the acute aftermath of a catastrophic incident. Per FEMA's own definition, "A lifeline enables the continuous operation of critical business and government functions and is essential to human health and safety or economic security."[28] FEMA identifies "safety and security," "food, water, shelter," "health and medical," "energy," "communications," "transportation," and "hazardous material" as the seven core community lifelines. Publication of the lifelines is meant to assist communities in developing resiliency in these sectors in advance of a disaster—doing so will simplify the response and can help limit excessive morbidity and mortality from the aftereffects of a disaster.

National Response Framework

The National Response Framework (NRF)[29] defines the means by which the US government responds to disasters and emergencies. Now in its third edition, the guide is published by Department of Homeland Security and is defined by five key principles:[30]

(1) Engaged partnership

(2) Tiered response

(3) Scalable, flexible, and adaptable operational capabilities

(4) Unity of effort through unified command

(5) Readiness to act

The NRF establishes the roles and responsibilities of individuals and organizations during a response, from households to the federal government; enumerates the fifteen core capabilities that are essential to deliver effective disaster response; and identifies coordinating structures and the scenarios in which those structures should be leveraged.

National Incident Management System

The National Incident Management System (NIMS)[31] is a guiding document of principles and methods published by the Department of Homeland Security with the aim of improving coordination between government, nongovernmental organizations, and the private sector during all stages of the disaster life cycle. The document sets standards for resource management, command and control, and communications

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28 FEMA, "Community Lifelines."

29 DHS, *National Response Framework.*

30 DHS, *National Response Framework.*

31 DHS, *National Incident Management System.*

and information management. The predefined standards and procedures enable disparate organizations to smoothly plug into a collective effort, whether that be a locally managed routine sporting event or a whole-of-government response to a Category 5 hurricane on the East Coast. NIMS also describes the Incident Command System (ICS) that defines a common hierarchy for command and management during an incident response.

ICS

The ICS is a standardized approach for domestic incident management. The ICS is based on fourteen management characteristics defined in NIMS, including common terminology, unified command, chain of command, and manageable span of control. The ICS allows for the integration of individuals or entire agencies into an incident response without the need for time-consuming orientation activities and clearly defines the command and control hierarchy to prevent conflicting management priorities.

Stafford Act

The Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act) is a federal law passed in 1988 that sets the relationship between the federal government and state and local governments with regard to disaster assistance. Among other items, the Stafford Act sets the terms by which the president is able to make emergency and major disaster declarations. These declarations can be made in preparation for or in the direct aftermath of a disaster after a request by the governor of the affected state is approved by the president of United States and allow for mobilization of federal resources (including personnel and funding) to be used for response efforts. Most federal agencies cannot respond to a disaster until a presidential declaration has been made.

The Stafford Act defines a major disaster as "any natural catastrophe (including any hurricane, tornado, storm, high water, winddriven water, tidal wave, tsunami, earthquake, volcanic eruption, landslide, mudslide, snowstorm, or drought), or, regardless of cause, any fire, flood, or explosion, in any part of the United States, which in the determination of the President causes damage of sufficient severity and magnitude to warrant major disaster assistance under this Act to supplement the efforts and available resources of States, local governments, and disaster relief organizations in alleviating the damage, loss, hardship, or suffering caused thereby."[32]

[32] Stafford Act, Pub. L. 93-288.

Appendix B Results from Red Team Analysis

Primary Technology	Common Needs	Implementation Impediments	Possible Vulnerabilities
Drones	Cybersecurity, legal guidance for new technology, training for end users and trained developers, new courses of action with new technology	• Cost • Airspace regulations • Question of ownership (local or federal?) • Privacy concerns	• Reliant on weather conditions and limited battery life • Could cause fear, concern among the public • Could be corrupted by hackers or bad data
Predictive analytics		• Development of algorithms • Privacy concerns • Insufficient training data	• Black swan events are impossible to properly train for or predict • Poor training data could lead to poor outcomes
Imagery collection and analysis		• Development of algorithms • Privacy concerns • Ownership and sharing of imagery data	• Some data may be classified and require additional protections or limitations • Mistrust if the computer makes a mistake
Natural language processing and optical character recognition		• Development of algorithms • Concerns over black box models • Training for users	• Mistrust if the computer makes a mistake • May not work in a communications-denied environment

Appendix C Lessons Learned Summary Results

The lessons learned referred to most often across all reports are summarized in the table below.

Table C-1. Lessons Learned across the DOTmLPF Framework from AARs

Area	Description
Doctrine and policy	Standard operating protocols (SOPs) for both new and existing technology are needed. Special consideration should be given to issues of personal security, personal identifiable information, cybersecurity, and social media use. Insufficient SOPs exist to guide what to do with new types of data, how to interpret or trust those data, what to rely on, and how to determine priorities. Ideally, these decisions would be in place before the onset of a disaster and made by leadership as appropriate.
Organization and interoperability	Organizations are often unable to easily work together. This is often attributable to differences in priorities, the types of language or jargon used, and access to data (classified, military, etc.); in some cases, organizations may not have previously considered interfacing with other stakeholders (public, private, government, military, etc.). Responsibilities are unclear between groups.
Training	Training in software and hardware use must be improved, and, in general, first responders' comfort with technology needs improvement. Specific training for technology developers is needed to ensure high-quality products that are useful for the first responder.
Materiel	Power requirements and communications infrastructure are vital to achieving SA but are frequently lacking. Predictive models in planning and decision-making are desired for natural disasters and epidemics (fires, hurricanes, floods, plagues). WebEOC is clunky and not sufficiently agile to show the specific types of information desired by various groups, and there is a recognition that "throwing technology at the problem won't fix it."
Leadership and education	Leaders must have sufficient training in disaster SOPs before a disaster strikes, and the chain of command in any given environment must be clear, especially when the staffs of multiple jurisdictions or agencies are working together.
Personnel and qualifications	Frequently there are insufficient personnel during times of surging need, or personnel are not qualified in the necessary types of technology needed to achieve SA.
Facilities	The physical needs of all personnel must be met so that they can perform their functions as needed. This includes facilities that allow personnel to sleep, eat, work, meet, and relieve each other.

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Appendix D Interview Content

To gain a better appreciation for the current approaches and challenges for gaining situational awareness (SA) in the field, individuals and organizations directly involved in disaster response were contacted for interviews regarding their organizational approach to gaining and maintaining SA within their scope of work. Interviews were conducted with a variety of stakeholders representing the local, state/regional, and federal levels. In total, fifteen individuals or groups from a variety of organizations involved in disaster response participated in interviews. Each interview was semistructured and consisted of five core questions:

(1) What is your organization's role in disaster response?

(2) Who are the major players with whom you interact in a response?

(3) What is your current approach to maintaining SA?

(4) What technology are you using in the emergency operations center and in the field?

(5) What are the biggest gaps or shortfalls in maintaining SA during a response?

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