Project Responder 4

2014 National Technology Plan for Emergency Response to Catastrophic Incidents

July 2014

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Project Responder 4:

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EXECUTIVE SUMMARY

Project Responder 4 (PR4) is the fourth in a series of studies begun in 2003 to focus on identifying capability needs, shortfalls and priorities for catastrophic incident response. The approach for the PR4 study allowed a longitudinal look at 11 years of enduring gaps and needs, and distinguishing them from emerging needs and technology. The results of this study are captured in this *Project Responder 4: 2014 National Technology Plan for Emergency Response to Catastrophic Incidents*.

PR4 identifies a set of enduring and emerging capability needs, frames them into technology objectives and assesses the state of science and technology to meet those needs. Findings are based on discussions with federal, state and local first responders as well as technical subject matter experts (SMEs). These interactions ensure that potential solutions reflect operational considerations and are based on an actionable and achievable technology path.

Capability Needs

This document identifies 14 capability needs that responders believe represent the highest priorities for improving their ability to respond to catastrophic incidents. Each of the capability needs may be improved, in whole or in part, through the application of technology solutions. The capability needs include enduring needs that were identified across the previous phases of Project Responder and emerging needs that will allow responders to leverage technological advances occurring in other fields. Responders prioritized these needs based on their impact on responder safety, population safety, consequence mitigation, decision-making and utility across multiple incidents.

Response Technology Objectives

This plan identifies 42 response technology objectives (RTOs) that address the 14 PR4 capability needs. The RTOs translate the capability statements into actionable, technology-centric objectives. Each identifies a high-level technology solution (or part of a solution) designed to improve the capabilities of the response community. Each capability need has at least one corresponding RTO, and some RTOs can address multiple needs. The RTO descriptions include projects that represent a proposed path forward for increasing capability. This plan also contains a series of technology road maps that illustrate the project timelines and resource requirements suggested by the SMEs for each RTO. In addition, the road maps highlight synergies and dependencies in the development process. This plan is intended to inform FRG as it makes investment decisions and proceeds with an acquisition strategy designed to address enduring and emerging emergency response needs. The capability needs and the related RTOs also provide DHS and other government agencies, academia and private industry with a vision toward which they can direct their efforts.

INTRODUCTION

Background

Responding to a large-scale catastrophic incident requires the coordination of personnel, equipment, communications, tactics, regulations and priorities, as well as the sharing of information and intelligence among many agencies and entities. This coordination and information sharing is difficult under normal circumstances but is exacerbated when the event is traumatic, the damage is widespread and the threats and dangers evolve. Inevitably, a catastrophic incident exceeds the resources of local jurisdictions, requires regional or national mutual aid and entails long-term response and recovery operations. There are gaps between what response agencies can currently do and what they feel is necessary for successful large-scale incident response. These gaps can be attributed to insufficient resources, procedures or training necessary to accomplish missions, or to changes that alter the response environment.

The Oklahoma City National Memorial Institute for the Prevention of Terrorism (MIPT) funded an effort in April 2001 to identify these gaps and improve the capabilities of local, state and federal emergency responders. That effort, called Project Responder, focused on identifying capability needs, shortfalls and priorities for catastrophic incident response. Because the response environment is constantly changing, Project Responder has periodically reevaluated capability needs by engaging emergency responders from a diverse set of disciplines and jurisdictions. Project Responder 4 (PR4) represents the latest iteration in this continuing effort.[1]

The purpose of Project Responder is to identify gaps between the current capability of emergency response agencies and what they consider necessary to respond to large-scale catastrophic incidents.[2] These gaps are prioritized and analyzed to produce actionable recommendations that have been used by DHS, other government agencies and private industry to guide development efforts that specifically address articulated operational needs. This effort is unique in its dedication to capturing the voices of responders from both traditional and nontraditional response agencies as they describe their needs and goals for policy, procedures and technology.[3]

It is beyond the ability of a single local or state agency to fund the development of new equipment, set universal standards for processes and procedures, facilitate the integration of existing resources and coordinate information-sharing protocols. State and local

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[1] See Appendix A for a history of Project Responder.

[2] Catastrophic incidents are defined in this document to include large-scale natural disasters and man-made events (terroristic and accidental) that exceed the capabilities and resources of a local jurisdiction or region.

[3] Project Responder uses the terms “emergency responders” or “emergency response agencies” to be inclusive of traditional and nontraditional agencies that are necessary for response to catastrophic incidents. This includes public safety entities (i.e., law enforcement, fire, emergency medical services, emergency management) and supporting entities (e.g., public health, public works, transit).

budgets are tight, and threats and hazards are numerous. It is the mission of the Department of Homeland Security (DHS) Science and Technology Directorate (S&T) to provide support when capability gaps cannot be satisfied at the state and local levels and when investments in science and technology can provide advances to responders throughout the country. S&T has an office specifically designated for this purpose. The Support to the Homeland Security Enterprise and First Responders Group (FRG) strengthens the response community's abilities to protect the homeland and respond to disasters.[4] The FRG does this through the development of existing and emerging technologies, knowledge products and standards. To this end, FRG needs to understand the capability gaps and priorities of the emergency response community as well as the potential solutions to fill those gaps. This ensures that their investments are made efficiently and effectively.

Previous iterations of Project Responder identified the capability needs of emergency responders through multiple changes in the response environment over more than a decade. PR4 builds on these efforts by examining the state of science and technology for opportunities to address the most persistent and highest-priority capability needs and develops a plan to address those needs. The FRG tasked the Homeland Security Studies and Analysis Institute (HSSAI) to resume its efforts on Project Responder and to develop this plan.[5] This document, *Project Responder 4: 2014 National Technology Plan for Emergency Response to Catastrophic Incidents*, identifies a set of enduring and emerging capability priorities, frames them into technology objectives and describes an incremental and actionable approach to technology development. This approach is illustrated through a series of technology road maps. Decision-makers, planners and acquisition personnel in the FRG are the intended audience for this document. However, the contents of this plan can also be used by other DHS and government agencies, academia and private industry to pursue targeted technology development opportunities.

This plan is based on an understanding of the capabilities needed to respond to catastrophic incidents. The technology programs identified as part of this plan correlate to the capability needs. HSSAI created this plan with the involvement and input of emergency responders, who have ultimate responsibility for response operations, and technical subject matter experts, who provided insight about the state of technology for these capabilities.

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[4] "Science and Technology Directorate Support to the Homeland Security Enterprise and First Responders," U.S. Department of Homeland Security, last modification: n.d., http://www.dhs.gov/st-frg.

[5] In April 2004, the first Project Responder effort produced the *Project Responder National Technology Plan for Emergency Response to Catastrophic Terrorism* following an extensive effort to understand the capability needs of the emergency response community and identify potential solutions for those needs. The 2004 plan focused on technology investment to improve capabilities and included the development of technology road maps comprised of initiatives to close gaps in responder capabilities. This document is a second iteration of that document.

Methodology Overview

This section provides a brief overview of the analytical processes used to obtain and assess data and to develop the plan's findings. Appendix B provides a more detailed description of each phase in the methodology.

The methodology consisted of data gathering and analysis based on HSSAI's research and structured discussions with the response community and Subject matter experts. This occurred through four phases: (1) identification and validation of enduring and emerging capability needs; (2) identification of technology objectives to meet those needs; (3) identification of potential science and technology solutions; and (4) development of a technology plan and corresponding road maps. The graphic below illustrates this process:

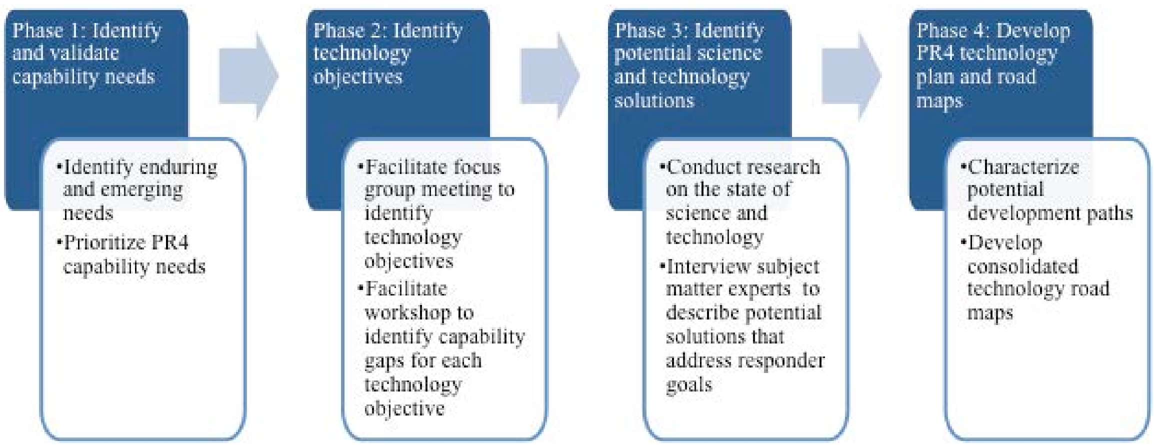

Figure 1. PR4 Methodology

The goal of phase 1 was to identify the capability needs that should be addressed in the plan and to validate those needs with a group of emergency responders. To do so, HSSAI facilitated a series of virtual focus group meetings with members of the First Responder Resource Group (FRRG) and InterAgency Board (IAB).[6, 7] During the meetings, participants reviewed the capability priorities identified during Project Responder 3
(PR3) and suggested new or evolving needs. HSSAI identified a set of 14 capability needs after analyzing the virtual meeting results. HSSAI then developed and distributed an online prioritization tool that responders could use to prioritize among the PR4

[6] Virtual focus group meetings were held using a collaborative Web-based system, allowing participants to review materials simultaneously and provide input and feedback verbally and through posted comments.

[7] The FRRG is distinct from the FRG. The FRRG is a multi-disciplinary group of responders established to provide input and feedback in support of the FRG's development efforts. The IAB is a federally chartered advisory group of state and local emergency responders. Its mission is to "strengthen the nation's ability to prepare for and respond safely and effectively to emergencies, disasters, and CBRNE incidents." For further information, see https://iab.gov.

capability needs. Participants rated the capability needs according to overall priority, criticality of need and other contributing factors.[8]

Simply identifying emergency response capability needs is not sufficient for technology development decisions. It is important to understand the actual capability gaps. These gaps represent the difference between current capability and what responders believe is required to effectively and efficiently complete their tasks and mission. This requires a clear articulation of the baseline capability—what responders have now—and the quantitative and qualitative goals that describe what they believe is needed. To gather initial data on baseline capabilities, HSSAI facilitated discussions with members of the IAB's Strategic Planning Subgroup. Participants reviewed the 14 PR4 capability needs and provided information and data about their current capabilities (technology, policy, procedures and training) available for response operations.

The goal of phase 2 was to translate capability needs into technology objectives. Technologists require an understanding of what is specifically needed before they can pursue new and innovative solutions. They also need to understand the problems that responders are facing and why current capabilities are insufficient. In phase 2, HSSAI conducted a focus group that included emergency responders and technical Subject matter experts to facilitate this understanding and identify RTOs. RTOs translate the operational capability needs into technical terms.[9] Federal, state and local emergency responders with experience in catastrophic incident response and recognized Subject matter experts in fields related to the capability needs participated in the focus group, held in Washington, D.C., in November 2013. Responders described each capability need and explained the operational issues that they face. Technologists translated the needs into RTOs that, as a whole, should address the capability needs.

Technologists are better able to identify a proposed path to address needs if they have a concrete understanding of responder goals for each RTO. HSSAI conducted a workshop in San Antonio, Texas, in March 2014 to capture these goals. Federal, state and local responders participated in a series of facilitated discussions describing both their current capabilities and what they believe is necessary to achieve mission success for each RTO.

The goal of phase 3 was to evaluate the state of science and technology to identify potential technology solutions that meet responder needs. HSSAI conducted a series of in-person and telephone interviews with Subject matter experts who work in fields related to the RTOs. These experts were from national laboratories, government agencies, academia, private industry and standards and professional organizations. HSSAI conducted interviews with several experts in each field to obtain multiple perspectives and inputs. The interviews produced information and data about the state of technology, proposed paths to meet responder goals, associated resource needs and potential barriers.

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[8] See Appendix C for a discussion of the PR4 Prioritization Process.

[9] See Figure 4 in the section on Key PR4 Concepts for a more complete definition of key terms used in the development of this plan.

In the fourth and final phase of this effort, HSSAI assessed and integrated the information from responders and Subject matter experts to identify actionable programs for increasing capability. HSSAI also developed technology road maps that illustrate an integrated pathway for capability advancement.

Enduring and Emerging Needs

The first *Project Responder National Technology Plan*, published in 2004, was a unique, multi-disciplinary examination of emergency response capabilities required to respond to catastrophic events. It reflected a comprehensive review of capability needs across the totality of the emergency response mission. Subsequent iterations of Project Responder updated and prioritized those capability needs to reflect changes in the response environment because of a focus on all-hazards response, the introduction of foundational response doctrine, evolving threats and a constrained fiscal environment.

The second and third iterations of Project Responder did not provide recommendations of potential technology solutions to meet the identified needs. There have not been significant changes to the response environment since the PR3 report was published in December 2011. Consequently, another comprehensive review of capability needs was unnecessary. A number of capability needs have endured across all phases of Project Responder. A review of results from the three previous Project Responder efforts indicates that participants consistently rated a number of capabilities as a high priority. Although the threat and response environments have changed over the intervening 12 years, many of the previously identified capability needs and gaps endure. Figure 2 illustrates the continuity in prioritization of some capability needs.

Capability Priorities Across Time[10]		
2004 Priorities	2008 Priorities	2011 Priorities
Body protection from all hazards	Command and management	Virtual simulation training
On-scene detection	Communications[11]	Responder location
Remote and standoff detection	Seamless data integration	All-environment communications
Point location and identification	Full-body personal protection	Remote tactical monitoring
Seamless connectivity and integration	Logistics support[12]	Body protection from all hazards
Mass victim decontamination	Mass prophylaxis distribution	Personal Protective Equipment (PPE)-integrated communications
Risk awareness and assessment	Training and exercise programs	Threat detection and monitoring
Mass medical prophylaxis	Mass victim decontamination	Resource availability
Mass casualty medical care management	Responder respiratory protection	Trend and pattern identification
Individual and collective protection	Point location and identification	Hazard identification
Surveillance and information integration	Prioritization and dissemination of threat information	On-scene resource status
Logistics information systems	Credentialing	Casualty location
Threat assessment/data collection/analysis		

Figure 2. Project Responder Capability Priorities, 2001 to 2011

As depicted in this graphic, responders consistently identify body protection, responder location, interoperable communication (voice and data), logistics management and threat

[10] A color coding system is used throughout this report to provide an organizational structure whereby color cues may help the reader understand which topic is being addressed (for example., information related to communications consistently uses red font or shading). Pages 15 to 17 illustrate the coloring assigned to each capability need.

[11] There were three capability needs related to communications in the 2008 *Project Responder Review of Emergency Response Capability Needs*.

[12] There were two capability needs related to logistics support in the 2008 *Project Responder Review of Emergency Response Capability Needs*.

assessment as priorities for capability advancement. HSSAI chose these enduring needs, and the others identified as high priority during the PR3 effort, as the starting point in identifying capability needs to address in PR4.

The other high-priority needs from PR3 include:

- Readily accessible, high-fidelity simulation tools to support training and exercises in incident management and response
- The ability to remotely monitor the tactical actions and progress of all responders involved in the incident in real time
- Communications systems that are hands-free, ergonomically optimized and can be integrated into PPE
- The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time
- The ability to rapidly identify hazardous agents and contaminants
- The ability to remotely scan an incident scene for signs of life and decomposition to identify and locate casualties and fatalities

It is also important to capture emerging needs—those that have arisen or increased in priority because of technological advancement, social or cultural change or other drivers. While the response environment has not changed significantly, changes and innovation in other areas have the potential to influence changes in response doctrine and operations. HSSAI identified two emerging needs from the responder inputs during the virtual focus group meetings:

- The ability to incorporate information from multiple and nontraditional sources (for example, crowdsourcing and social media) into incident command and operations
- The ability to identify, assess and validate emergency-response-related software applications

The first of these emerging needs was identified during PR3 but was not ranked among the highest-priority needs. The second emerging need was newly identified by responders in PR4.

Figure 3 illustrates the sources of the final set of 14 PR4 capability needs:

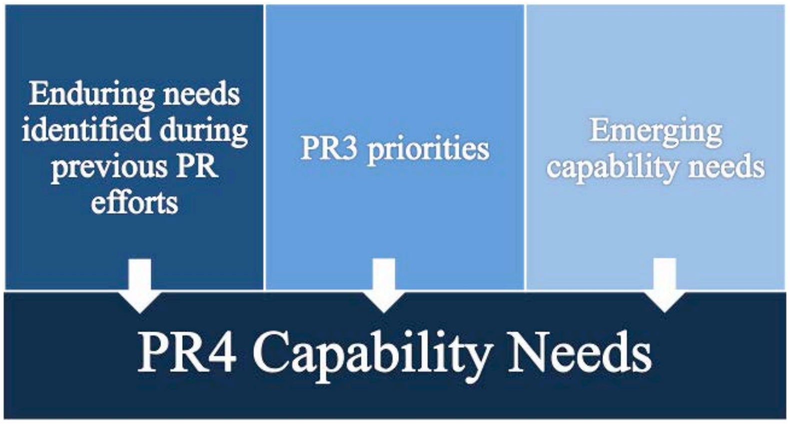

Figure 3. PR4 Capability Needs

Key PR4 Concepts

This plan is based on the concepts defined in figure 4. These concepts provide a structure to understand the capabilities needed for catastrophic incident response. The structure is hierarchical, with one level of the structure providing inputs to the next.

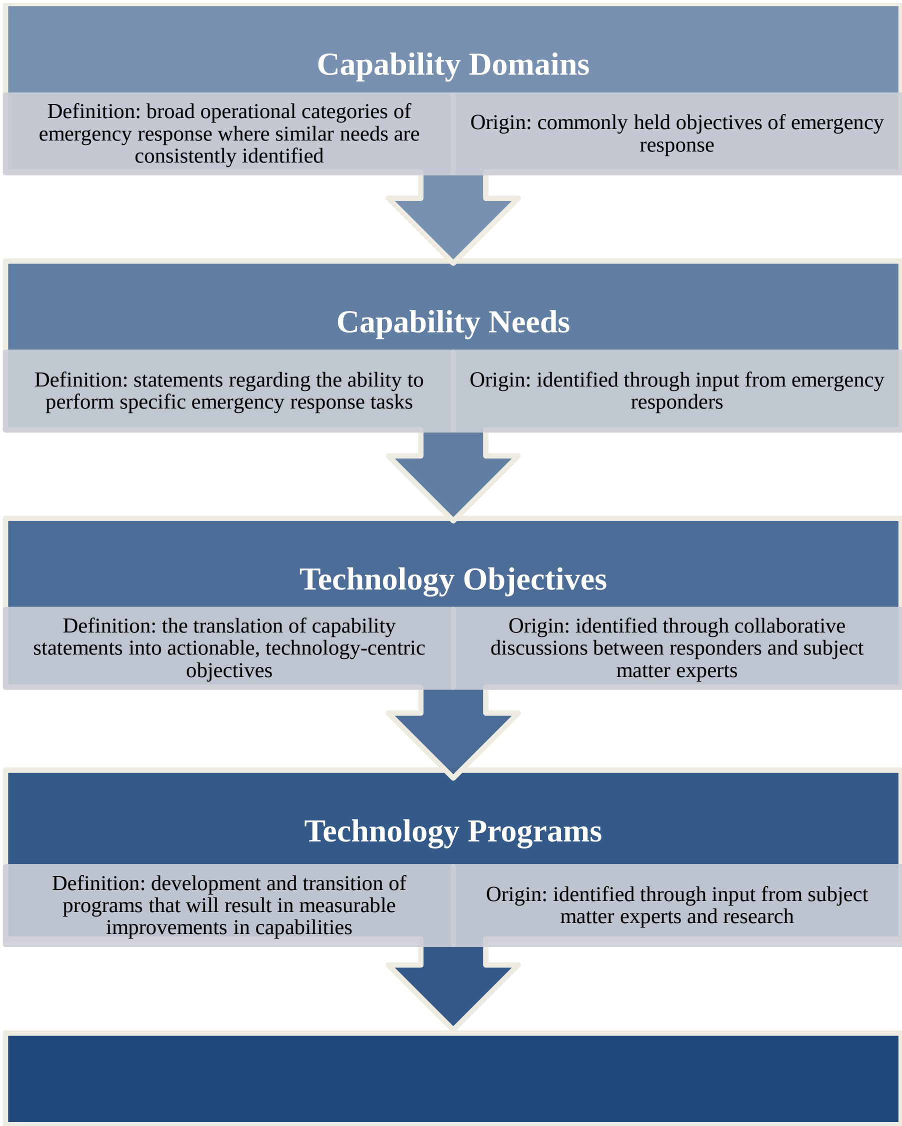

Figure 4. Key Concepts—Definitions and Origins

Capability domains represent broad operational categories of emergency response where similar needs are consistently identified. These domains provide an organizational construct to allow structured discussion around capabilities instead of disciplines or jurisdictions. The capability domains in this plan were originally described and defined in the PR3 report.[13]

The domains are as follows:

- *Situational awareness:* the capability to provide and distill specific knowledge concerning emerging threats, hazards and conditions in a

[13] The capability domains were derived from the FEMA Core Capabilities List, previous Project Responder reports, Presidential Policy Directive–8 and other relevant documents.

timely fashion to support incident management decisions across all phases of catastrophic incident response

- *Communications:* the capability to seamlessly and dynamically connect multiple persons/entities and convey meaningful and actionable information to all relevant parties
- *Command, control and coordination (C3):* the ability to identify incident priorities, allocate scarce resources and exchange relevant information to make effective decisions in a stressful environment
- *Responder health, safety and performance:* the ability to identify hazards to public safety personnel and develop appropriate mitigations to reduce morbidity and mortality associated with response activities
- *Logistics and resource management:* the capability to identify, acquire, track and distribute available equipment, supplies and personnel in support of catastrophic incident response
- *Casualty management:* the capability to provide rapid and effective search and rescue, medical response, prophylaxis and decontamination for large numbers of incident casualties and identify appropriate sheltering and transportation options
- *Training and exercise:* the ability to provide instruction on necessary skills for catastrophic incident response and coordinate and practice implementation of plans and potential response prior to an incident

Capability needs are statements that describe an essential ability required to perform a critical response function. They are identified through data-gathering efforts with the emergency response community. Participants in the virtual focus groups vetted the list of capability needs, examining each of the 40 needs identified during PR3 and suggesting emerging needs. Responders used an online prioritization tool to rate the capability needs according to several factors. Each of the capability needs fits into one of the capability domains.

RTOs translate the capability statements into actionable, technology-centric objectives. An RTO identifies a high-level technology solution (or part of a solution) for a capability need. HSSAI developed draft RTOs using data gathered during the focus group held in November 2013. Subject matter experts who participated in the data-gathering interviews vetted the RTOs and provided input on ongoing development efforts, technical challenges, potential technology programs and associated resource requirements. The 42 RTOs in the *Findings* section are described in terms of relevance, responder requirements, a summary of the state of technology, anticipated benefits and potential challenges or barriers to improving the capabilities.

Technology programs describe potential solutions for each RTO. The subject matter experts who participated in the interview process suggested programs to address the operational requirements articulated by the responders. The technology programs in this plan are listed in the *Path Forward* section of each RTO and illustrated in the technology road maps.

Participation

It has been a fundamental component of the Project Responder effort over all four iterations to involve responders—the men and women who will ultimately be responsible for responding to catastrophic incidents—in the identification and prioritization of capability needs and the development of proposed technology paths. Actions taken to address gaps in capability require the involvement of responders to identify potential impacts on operations. Development of technology solutions without responder input can result in wasted resources and tools or equipment that go unused because they do not meet operational requirements. While responders may not be able to identify technology solutions, they are able to describe in detail what they need to be able to execute their mission successfully. It is important to obtain this input from a set of participants diverse in terms of discipline, size and location of jurisdiction and level of government. Capabilities for emergency response vary significantly across the country and incorporating multiple perspectives helps ensure that the overall level of capability is understood.

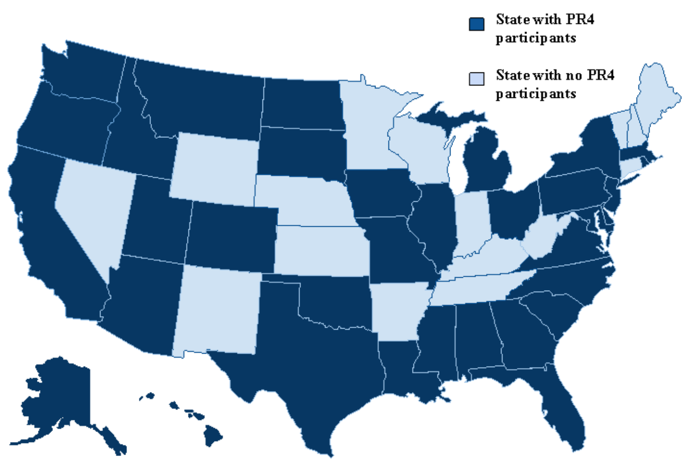

Figure 5. Geographical Distribution of PR4 Participants

HSSAI identified responders on the basis of their participation in the IAB and FRRG, previous participation in the Project Responder process, and experience with response to or management of large-scale incidents, as well as recommendations from some of the nation's most experienced and well-respected responders. Participants from traditional and nontraditional disciplines participated in the PR4 process, including the fire service, law enforcement, emergency medical services (EMS), emergency management, urban search and rescue, public health, public utilities and transit services. Federal, state and local responders from 34 states and the District of Columbia participated in the PR4 process.[14]

[14] This number does not include those responders who participated in the prioritization process. All members of the IAB and FRRG received an invitation to the online tool. Basic demographic information

HSSAI gathered input from Subject matter experts from national laboratories, government agencies, academia, private industry and standards and professional organizations who work in technology fields related to the RTOs. A group of 11 Subject matter experts participated in the focus group and more than 40 participated in the interview process. HSSAI identified Subject matter experts through review of technical documents, journals and conference proceedings; open-source research of available products; and recommendations by other experts. A list of all PR4 participants can be found in Appendix D.

Scope

This plan describes proposed development paths to improve high-priority capabilities for emergency response to catastrophic incidents. Catastrophic incidents include natural disasters and man-made events (terroristic and accidental) that exceed the capabilities and resources of a local jurisdiction or region. Project Responder is not focused on daily response activities (for example, fighting a house fire or conducting an investigation).[15]

In this plan, HSSAI identified science- and technology-based products and solutions (in other words, equipment, knowledge products, and standards) that can address responder needs. When applicable, this plan mentions potential non-technology solutions but does not address them in detail.

The Subject matter experts who participated in the focus groups and interviews estimated costs associated with the technology programs. HSSAI did not conduct an independent cost development effort or perform a formal cost and benefit analysis. In addition, HSSAI did not do a detailed assessment of technical risks associated with these programs.

The rationale and methodology for this plan were based on a capabilities-based planning approach. According to a RAND study for the Department of Defense, "[c]apabilities-based planning is planning, under uncertainty, to provide capabilities suitable for a wide range of modern-day challenges and circumstances while working within an economic framework that necessitates choice."[16] Capability-based technology planning begins by asking the operators—the users of technology—what they need to do that they cannot do today. This planning method focuses on the functions that need to be performed and provides technologists with a clear set of prioritized operational goals toward which they can direct their efforts. One limitation of engaging operators is that each has personal biases that may impact their input. To mitigate this concern, HSSAI used experienced

was collected from the 129 responders who participated, but their results were anonymous. Therefore, it is not possible to determine the number of responders who also participated in another PR4 event.

[15] Although Project Responder is not focused on the capabilities needed for daily response activities, it is important that new technologies that are developed for emergency response are also integrated into daily use equipment whenever possible.

[16] Paul K. Davis, *Analytic Architecture for Capabilities-Based Planning, Mission-System Analysis, and Transformation*, prepared by RAND National Defense Research Institute for the Office of the Secretary of Defense.

facilitators during the focus group and workshop discussion sessions and invited participants from multiple disciplines, agencies and jurisdictions to obtain varied perspectives.

HSSAI attempted to identify both the appropriate Subject matter experts and ongoing technology initiatives for the data-gathering effort. However, not all invited technologists were able to attend, and other experts or technology programs may not have been identified through HSSAI's research. Further, it is possible that some research and development in the areas addressed by the RTOs is classified and therefore cannot be included in this plan.

In the first Project Responder report (published in 2004), leading responder associations were given the opportunity to review and endorse the findings. This endorsement is valuable because of the implied concurrence with the study findings by a much larger group of responders. The period of performance associated with PR4 did not allow for the independent review and validation by these associations before the final plan was due to DHS. However, HSSAI did invite members of key associations to participate and obtained their input during the data gathering phases of this effort.

FINDINGS

This section details the findings from the PR4 effort. First, it identifies the PR4 capability needs by domain and summarizes the results of the prioritization process. Second, it describes some crosscutting considerations for technology development. Third, it describes each of the 42 RTOs that correspond with the PR4 capability needs.

Project Responder 4 Capability Needs

There are 14 capability needs for emergency response to catastrophic incidents that are addressed in this plan. As described in the *Enduring and Emerging Needs* section above, the capability needs were identified through analysis of capability needs consistently identified throughout all phases of Project Responder, other high-priority needs identified in PR3 and emerging needs suggested by emergency responders. The 14 needs are listed below. They are depicted in colored boxes by capability domain. This color coding system is used throughout this report to provide an organizational structure whereby color cues may help the reader understand which domain is being addressed.

Situational awareness is defined as the capability to obtain and distill specific knowledge concerning threats, hazards and conditions in a timely matter to support incident management decisions across all phases of a catastrophic incident response.

The ability to know the location of responders and their proximity to risks and hazards in real time

The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time

The ability to rapidly identify hazardous agents and contaminants

The ability to incorporate information from multiple and nontraditional sources (for example, crowdsourcing and social media) into incident command operations

Communications is defined as the capability to seamlessly and dynamically connect multiple persons or entities and convey meaningful and actionable information to all relevant parties.

The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)

Communications systems that are hands free, ergonomically optimized and can be integrated into PPE

Command, control and coordination is defined as the ability to identify incident priorities, allocate scarce resources and exchange relevant information to make effective decisions in a stressful environment.

The ability to remotely monitor the tactical actions and progress of all responders involved in the incident in real time

The ability to identify trends, patterns and important content from large volumes of information from multiple sources (including nontraditional sources) to support incident decision-making

The ability to identify, assess and validate emergency-response-related software applications

Responder health, safety and performance is defined as the ability to identify hazards to public safety personnel and develop appropriate mitigations to reduce morbidity and mortality associated with response activities.

Protective clothing and equipment for all responders that protects against multiple hazards

Logistics and resource management is defined as the ability to identify, acquire, track and distribute mission-specific equipment, supplies and personnel in support of catastrophic incident response.

The ability to identify what resources are available to support a response (including resources not traditionally involved in response), what their capabilities are and where they are, in real time

The ability to monitor in real time the status of resources and their functionality in current conditions

Casualty management is defined as the ability to provide rapid and effective search and rescue, medical response, prophylaxis and decontamination for large numbers of incident casualties and identify appropriate sheltering, transportation and destination options.

The ability to remotely scan an incident scene for signs of life and decomposition to identify and locate casualties and fatalities

Training and exercise is defined as the ability to provide instruction on necessary skills for catastrophic incident response and coordinate and practice implementation of plans and potential response prior to an incident.

Readily accessible, high-fidelity simulation tools to support training and exercises in incident management and response

Previous Project Responder efforts used a technique called Q methodology to prioritize the capability needs arising from the facilitated discussions. This methodology enables a group of participants to rank order a large number of opinion statements relative to each other. While Q methodology was well suited to rank order the larger number of capabilities identified in previous Project Responder iterations, it is less suitable for understanding the underlying factors necessary to prioritize a smaller subset of enduring and emerging capability needs. For PR4, HSSAI sought to identify and understand the specific factors that make each capability a priority. HSSAI asked emergency responders to identify the factors that cause one capability to be ranked higher than another. The factors were then used as the foundation to develop an online tool. The online tool provided a uniform assessment path for responders to follow when they evaluated each capability statement.

In the prioritization tool, responders were asked several questions, and the responses to each question were based on a seven-point scale. The full question set included the following questions:

- How would improvements in this capability improve *responder safety*?
- How would improvements in this capability improve the *safety of the affected population*?
- How would improvements in this capability improve the *ability to mitigate incident consequences*?
- How would improvements in this capability improve *decision-making for incident management*?
- Can improvements in this capability *be used in multiple types of incidents*?
- Overall, how important a priority is this capability?

Participants were also asked to rank what they perceived to be the three most critical capabilities and the least critical capability. The prioritization tool was distributed to all members of the FRRG and IAB. It was available over a two-week period. More than 125 responders participated, with a 90 percent response rate for each question. The results from the prioritization process indicate that six needs rank the highest in terms of overall priority. Figure 6 presents the overall priority ranking of the top six capability needs.[17]

[17] Appendix C provides more detail about the development and results of the PR4 prioritization process.

Capability Need	Mean Score
The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)	6.3
The ability to know the location of responders and their proximity to risks and hazards in real time	6.1
The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time	6.0
The ability to rapidly identify hazardous agents and contaminants	5.9
The ability to remotely monitor the tactical actions and progress of all responders involved in the incident in real time	5.7
Protective clothing and equipment for all responders that protects against multiple hazards	5.4

Figure 6. Capability Needs by Overall Priority Ranking

HSSAI also examined the criticality rankings of the capability statements. This assessment yields results that are similar to the rankings of overall priority. Three capability needs received significantly more votes than the other capability needs. Figure 7 presents the criticality ranking of the capability needs.

Capability Need	Number of Votes
The ability to know the location of responders and their proximity to risks and hazards in real time	85
The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)	70
The ability to detect, monitor, and analyze passive and active threats and hazards at incident scenes in real time	39

Figure 7. Capability Needs by Criticality Ranking

The same capability needs are consistently ranked highest given the two ranking methods, with the primary difference being that the highest ranked swap the first and second positions. Although the *ability to communicate with responders in any environmental conditions* is ranked higher in overall priority, responders assessed the *ability to know the location of responders and their proximity to risks and hazards in real time* as more critical to address first. Overall, the consistency of these rankings indicates their degree of importance to the responder community.

Considerations for Technology Development and Adoption

Participants in the PR4 process, both responders and other Subject matter experts, identified a number of issues that should be taken into consideration when reviewing the RTO descriptions. These issues address overarching or crosscutting factors that affect both the response community and those interested in pursuing the proposed programs described in this plan.

Big data. Addressing the capability needs identified in this plan may create significant big data challenges for the response community. Big data problems exist when large amounts of data are collected from multiple sources and the data sets become too large or complex to transmit, filter and process in a timely manner. Many of the devices or systems discussed in this plan will create data streams that must be transmitted in real time to incident command to be useful. Telemetry data showing the location of hundreds of responders on the incident scene, for example, will be less useful if the data transmission overloads existing communications infrastructure and is not received in real time. Responders and the population may be in jeopardy if sensors that detect the presence of hazardous agents cannot transmit pertinent information in real time. This issue is exacerbated during emergency response to catastrophic events because network connectivity and available bandwidth can be severely hampered. Big data problems persist once information is received by incident command. Numerous advances in technology will be useless if the transmitted information is so complex or extensive that it cannot be processed by incident command or the appropriate responder. The big data challenge transcends many of the technology programs and can impede the improvements promised by these new tools.

Crosscutting requirements. Each RTO described below includes a list of responder goals. These goals describe attributes that responders believe are necessary as part of the new tools, devices, systems and platforms developed to address the PR4 capability needs. There are a number of attributes that responders mentioned during nearly every RTO discussion. Instead of listing these goals repeatedly, they are addressed here as a set of base requirements:

- *Power source* – Availability of power sources can be a significant issue in catastrophic incident response, as the nature of the incident can damage or destroy the power infrastructure. Responders need tools that can utilize multiple power sources (for example, accessing the power infrastructure of on-scene buildings, generators and batteries). Portable power systems should be long-lasting and lightweight and should not use proprietary interfaces or components.
- *User interface* – The interaction between the responder and the device must be intuitive and easy to use. Responders do not want complex or cluttered displays. Components should be clearly labeled and the system should be based on a logical construct derived from responder requirements.
- *Cost* – Cost is a significant issue for the response community. The current fiscal environment dictates that budgets for public safety agencies are tight and

available funding for capital purchases is limited. Affordability should be a key factor during technology development, including initial costs and recurring maintenance and calibration.

- *Daily use* – Responders do not want a separate set of equipment that is only used during response to large-scale incidents. Responders may not have the time to re-familiarize themselves with equipment that has specialized functionality and is not used on a daily basis. Tools and systems developed to address the PR4 capability needs should be, to the extent possible, used during routine operations.
- *Training* – Training should be clear and concise. When possible, and appropriate, training should be available via Web-based instruction or provide a train-the-trainer option, where one staff member can learn to teach others about the specific topic.

Spiral development. The responder goals described for each RTO do not constitute a minimum set of requirements that must be met before new tools, devices, platforms or systems can be released. Responders stated that they would prefer incremental, continuous advancement over waiting several years for a piece of equipment that meets all of the stated goals at the same time. Not only do requirements change as the response environment evolves, but even minor advancements in capabilities can improve response operations. Likewise, some of the goals described below are quantitative in nature. They describe a specific weight or distance. Responders do not want these specifications to be construed as a minimum requirement. Being able to locate responders indoors to within 10 feet (instead of the one-foot goal described below) still represents a significant improvement over what is available today. Quantitative goals should also be subject to the spiral development methodology.

Reach goals. Some of the goals described below can be considered "reach goals," with quantitative criteria that exceed what technology can deliver today. During the workshop discussions, responders were asked to describe the attributes that they believe are necessary to complete their tasks and missions effectively, without consideration for cost or technical feasibility. The goals represent what responders believe that they need in terms of capability. As with the discussion on spiral development, these reach goals should be viewed as goals, not as minimum requirements before new products are released to the response community. As technology continuously advances, what was previously infeasible may become possible and the reach goals may someday be achievable.

Responder involvement. The criticality of involving the emergency response community during all phases of technology development should not be understated. Too often, products are developed without a clear concept of operations or understanding of operational realities. This results in tools and equipment that do not meet the demands of the user community and potentially wasted investment. Responders cited examples where buttons were too small to push while wearing gloves, devices were not ruggedized to withstand heat and humidity or responders were put in greater danger when trying to deploy a device. Responders can provide iterative input and feedback from requirements generation through testing and evaluation.

Resistance to change. The response community as a whole can be resistant to change. Many of the goals described in this document bring the capabilities of the response community in line with what is already available in other fields. However, responders often like to do things the way they have always been done. Responders reported that there is an internal struggle within the response community, and perhaps within each individual responder, between honoring tradition and culture and wanting improvements in capabilities. This struggle is not limited to only one discipline; there are multiple examples where advances in technology, even those that could improve responder safety, are rejected because they conflict with tradition. One important consideration for technology developers is that they will not be able to force change. Developers and manufacturers need to understand their customer and the motivations for why things are currently done as they are. Responders rely on whiteboards and grease pencils because that is what has worked in the past (and in some cases because that is what they could afford). The response community needs to embrace technology, but this may not be an easy sell. A younger generation of responders may embrace technology to a much greater extent, but new technologies introduced now may have to demonstrate not only that they can withstand the extreme conditions on the incident scene, but also that they can measurably improve capability.

Personnel qualifications. Greater use of and reliance on technology may mean that personnel qualifications may change or new staff positions may be necessary. Currently, many public safety agencies do not have a separate staffed position focused on information technology (IT). Often, IT work is assigned as an additional duty to a responder interested in the field, or IT issues are addressed through support contracts with outside firms. However, the need for an on-site, skilled, and dedicated IT staff becomes more acute as the number of networked devices on the incident scene increases.

Changes in doctrine. In addition to potentially changing the necessary skill set of public safety agencies, many of the technology advancements identified in this plan have the potential to notably change the tactics, techniques and procedures (TTP) used in emergency response today. For example, being able to remotely detect the location of casualties may change the current practice of sending out separate teams to search for trapped victims. Likewise, the ability to conduct virtual training and exercises may reduce the number of full-scale exercises that need to be held. A larger, multi-disciplinary body should periodically assess how TTP can evolve as a result of advances in technology.

Project Responder 4 Response Technology Objectives

Each of the 42 RTOs identified during the PR4 effort is described below. The RTOs are grouped by domain, and each domain is a separate section or chapter. The color coding system used above continues here (for example, all of the RTOs pertaining to situational awareness have blue shading and text boxes) to provide the reader with organizational cues.

Each domain chapter contains an introduction identifying the corresponding capability needs and describing each need as it applies to catastrophic incident response. Each RTO contains a number of components:

- *Relevance* – This paragraph describes how the RTO addresses a necessary component of catastrophic incident response.
- *Current capability* – This paragraph describes the equipment and resources that response agencies currently have available.
- *Responder goals* – These bullets list responder-articulated attributes that, taken as a whole, describe the increase in capability that responders believe is necessary.
- *State of technology* – This section provides a qualitative description of existing or proven capabilities in this or related areas, as well as ongoing development efforts.
- *Potential challenges* – These bullets identify conceivable technology and non-technology barriers that could inhibit development or operational implementation.
- *Anticipated benefits* – This graphic illustrates expected operational improvements associated with meeting responder goals.

Responders described current capability and identified goals over the course of multiple focus group meetings, a workshop and several other data-gathering sessions. Subject matter experts described the state of technology and suggested annual milestones and estimated potential costs during the interview process. HSSAI did not develop costs independently, and further refinement of costs should be among the initial steps taken during the acquisition process.

HSSAI gathered much of the information described below, including the current capability and state of technology sections in particular, from an amalgamation of sources. Specific citations are provided for all DHS and other efforts funded by federal agencies. For commercial programs and products, HSSAI chose to describe the state of technology in more general terms to avoid the perceived endorsement of specific products or manufacturers.

Situational awareness is defined as the capability to obtain and distill specific knowledge concerning threats, hazards and conditions in a timely matter to support incident management decisions across all phases of a catastrophic incident response.

There are four capability statements in this domain:

The ability to know the location of responders and their proximity to risks and hazards in real time

Since Project Responder began in 2001, emergency responders have consistently stated there is a need to precisely identify the location of responders in real time. Incident commanders and team leaders need a tool that displays the location of responders and their proximity to threats and hazards. During a catastrophic incident, responders may operate over an extensive geographic area without adequate knowledge of the hazards and threats. The ability to geolocate responders (identify their location on the incident scene tied to latitude, longitude and altitude coordinates or area-specific designations such as a street address), in all environments (in other words, indoors, outdoors and maritime), combined with simultaneous awareness of incident hazards, could greatly improve the safety of emergency responders. As an example, precise geolocation of responders may have prevented the catastrophe that occurred in Arizona on June 30, 2013, when 19 Granite Mountain Hotshot crewmembers were killed after being overtaken by an approaching wildfire threat. Incident command did not have adequate situational awareness or the ability to communicate with the crew to alert them of the impending hazards.

Subject matter experts identified five RTOs that correspond with this capability:

- Indoor (Above and Below Ground) Responder Geolocation
- Outdoor Responder Geolocation
- Maritime (Above and Below Water) Geolocation
- Infrastructure Standards for Technology Integration
- Rapid Building Characterization, Generation and Display

The ability to rapidly identify hazardous agents and contaminants

Upon arriving at an incident scene, responders may have little or no awareness of the hazardous agents or contaminants that may be present. This lack of awareness places responders at increased risk of exposure to a range of threats, including unknown toxins, biological agents or contaminants, during response operations. Catastrophic incident response only amplifies this issue, as the scale and scope of a catastrophic incident increase the likelihood of numerous hazardous agents on the scene. Even minimum exposure to many of these agents can cause significant health concerns. Responders need the ability to detect hazardous agents remotely and understand pertinent information regarding protective actions or treatments.

Subject matter experts identified three RTOs that correspond with this capability:

- Improved Standoff Detection and Identification of Multiple Hazards
- Multi-Sensor Integration and Analysis
- Risk Assessment and Decision Support to Command

The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time

Threats and hazards during a catastrophic incident can change rapidly. Dangers detected at incident onset may increase, decrease or evolve over time, while new and unexpected hazards can emerge. Both passive and active threats and hazards can exist simultaneously on incident scenes, particularly during catastrophic incidents, increasing the potential risk to civilians and responders. Responders need the capability to continuously detect, characterize, monitor and analyze threats and hazards. On-scene, rapid detection and timely alert of changes to the threat environment is critical for responders to take timely protective actions. Broad understanding of threats and hazards, and real-time changes to them, would inform response operation decisions.

Subject matter experts identified three RTOs for this capability:

- Remote Monitoring of Threats and Hazards
- Combined Effects Assessment
- Automated Red-Force Tracking[18]

The ability to incorporate information from multiple and nontraditional sources (for example, crowdsourcing and social media) into incident command operations

Emergency managers rely on multiple information inputs to make decisions. These inputs include field observations, sensor data, model outputs, images and video, media reports, databases and other sources. With advances in technology, responders are exploring ways to integrate nontraditional sources of valuable data (for example, sensors attached to infrastructure, road cameras, social media data) into decision-making processes. Responders noted the increasing importance of information from nontraditional sources and the need to integrate these information streams into a common operating picture. Although responders see value in systems that could aggregate and analyze nontraditional information sources, they also emphasized the need to verify information. To be actionable, responders need to be confident that data has been validated and obtained from a verified source. At present, nontraditional data are not fully incorporated into incident command common operating pictures for decision-making.

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[18] Red forces denote a specific threat or hazard and could be a person or persons (for example, active shooters or suspects), or an item such as a weapon or an explosive device.

Subject matter experts identified two RTOs that correspond with this capability:

- All-Source Collection and Integration of Data
- All-Source Information Validation

Indoor (Above and Below Ground) Responder Geolocation

Relevance: Responders frequently operate inside buildings, underground (for example, basements, subway systems) and under debris and rubble. Responders may not have adequate knowledge of their own location or those of other responders indoors, especially if the environment is impaired by smoke or lack of light. Moreover, incident commanders who are managing the response may not know the location of personnel deployed on-scene. These circumstances become exacerbated during a catastrophic incident when individuals are responding from multiple jurisdictions, further degrading situational awareness. Incident command needs the ability to locate, evacuate or rescue at-risk or trapped responders, identify personnel at key locations and notify responders if they are in proximity to threats and hazards. This requires precise location of responders on-scene. Geolocation is the geographical position of an object, usually defined by latitude, longitude and altitude. Knowing the coordinates of responders and their proximity to hazards is critical for responder safety.

Current Capability: Currently, most agencies do not have the capability for real-time automated geolocation of responders on the incident scene. Responders often transmit their location coordinates verbally, using hand-held radios. Real-time geolocation requires the responder to wear a device that broadcasts global positioning system (GPS) coordinates. GPS works by constantly transmitting a signal to satellites in orbit to calculate a position. These signals contain metadata on the exact time the signal was transmitted and where the satellite was when the signal was sent. The device then calculates the time it takes for four or more of these signals to reach the device from a satellite to trilaterate the location.[19] These signals are not powerful enough to penetrate building walls or even a thin piece of metal, which makes indoor and below ground geolocation very difficult, even with the most sophisticated technology available. Even if a responder knows his or her own GPS coordinates, they must then be transmitted in real time to incident command. Incident commanders generally rely on the last known position (as communicated by the responder or approximated based on tasking) to identify the location of personnel in GPS-denied environments, such as inside buildings. In an emergency situation, it is possible to “ping” the smartphones carried by many responders to identify their last known position. However, because GPS signals are obstructed indoors, this position may be temporally and geographically out of date. The

[19] In addition to Standalone GPS, described above, Assisted GPS (A-GPS) also represents a capability to support geolocation. A device can report multiple data points (for example, the location of Wi-Fi points, satellite data, other provider infrastructure) back to the network. The carrier can use this information to identify the approximate location of the device. Similarly, the carrier can provide wireless phase locations to public safety agencies to support the location of devices. These capabilities are currently available, but are not used frequently by response agencies in time-sensitive situations.

newest generation of land mobile radio systems can automatically transmit a GPS signal at a rate determined by the system administrator if connected to a digital trunking system.

Responder Goals:

- Accurate geolocation of responders to within one to three feet for x, y and z coordinates
- Real-time and recurring transmission of responder location to incident command
- Graphic display of the location of all responders on the incident scene
- Integrates with graphic display of on-scene hazards and threats
- Integrates with 3-D display of buildings and structures to identify the room or specific area in which the responder is located
- Integrates with other information about the responder's condition (in other words physiological data, personal alert safety system [PASS] alarm activation)
- Integrates with common electronic situational awareness tools
- Location transmitters should be ruggedized, simple and transparent and users should not be able to turn them off
- Integration of transmitters into PPE or other existing equipment with minimal or no net weight gain for the responder[20]
- Size, weight and power (SWP) suitable for responder operating conditions
- Assumes no prior knowledge of the environment (for example, no maps available or prior information about the building)
- Incorporates a confidence level to indicate the accuracy of location
- Affordable to outfit entire workforce
- Caches data when connectivity is offline and automatically forwards when connection is restored

State of Technology: Significant advances have been made with regard to responder location and hazards sensors, but there are still significant limitations with existing technologies. It is not currently possible to pinpoint a responder's location within one foot (the ideal metric identified by responders). Indoor geolocation, particularly when the subject is underground, is a harder technology issue to address than outdoor geopositioning, largely due to the lack of GPS accessibility indoors.

[20] PPE is defined here to include all garment layers and associated protective equipment (for example, a self-contained breathing apparatus) designed to provide body and respiratory protection for emergency responders.

Technologies said to be state of the art work in controlled testing environments but experience issues when operating in realistic emergency-response-like conditions. For example, accuracy decreases when individuals wearing geolocation devices perform actions that are common during an incident such as crawling, climbing or even jumping. Ongoing research continues to advance the state of the art, but most systems available today are considered to have a relatively low readiness level.

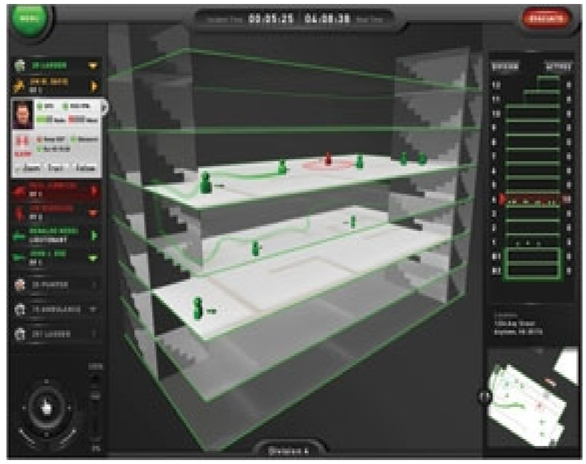

Figure 8. GLANSER – Indoor Location System

The Geospatial Location Accountability and Navigation System for Emergency Responders (GLANSER), largely supported by DHS, is being developed to provide geolocation for emergency responders.[21] GLANSER includes a geospatial locator unit that fuses information from inertial, barometric pressure, Doppler velocimeter and radio frequency (RF) ranging to compute the responder's 3-D location. That information is sent to the incident commander base station, which could be mounted on a responder apparatus, such as a fire truck, over an ad-hoc mesh radio network. The commander can then view a two-dimensional or three-dimensional display of a responder's location and status.

Other organizations, including the Department of Defense (DOD), also rely on GPS technology in difficult operating environments such as inside buildings, in urban canyons, under dense foliage, underwater and underground. The Defense Advanced Research Projects Agency (DARPA) is currently funding the Adaptable Navigation Systems (ANS) program.[22] As with GLANSER, the goal is to establish GPS-like information irrespective of the operating environment.

Industry has developed location systems that could be ready for distribution with minimal additional time and funds. These are primarily proximity systems, which provide the general vicinity of a responder's location based on networked sensor data from the responder and from other nearby responders. Other commercial providers are transitioning capabilities developed for the U.S. military, using inertial measurement units (IMUs) affixed to the user's footgear for localization in GPS-denied environments.

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[21] "GLANSER: A Scalable Emergency Responder Locator System," Worcester Polytechnic Institute Workshop, 2011, http://www.wpi.edu/Images/CMS/ECE/GLANSER_-_WPI_PPL_2011_-_AmitKulkarni-Aug1(1).pdf.

[22] "Adaptable Navigation Systems", DARPA: Strategic Technology Office, last updated: n.d., http://www.darpa.mil/Our_Work/STO/Programs/Adaptable_Navigation_Systems_(ANS).aspx.

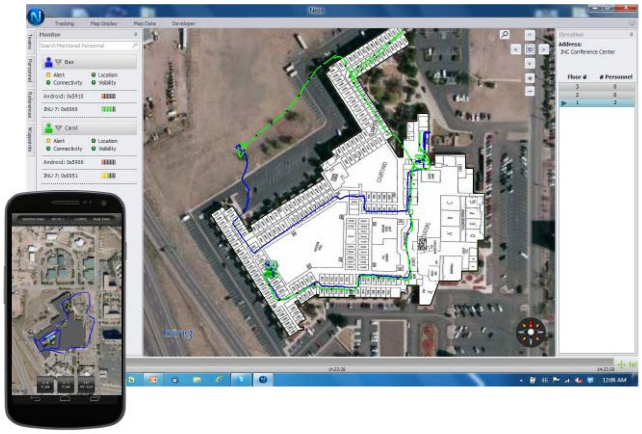

Figure 9. Graphic Display of Responder Location and movement

Research is also ongoing to identify other innovative methods for indoor geolocation, such as Wi-Fi fingerprinting. This approach measures the signal strength of nearby Wi-Fi networks in range along with cartographic knowledge of the network and calculates a relative position. The accuracy of such systems depends on various factors such as walls and the number of people in the room also using Wi-Fi. Currently, the precision of this type of technology can be as good as three meters when there is sufficient Wi-Fi infrastructure and the facility has been pre-mapped. It also has some of the same affordability issues as other approaches and assumes there are available Wi-Fi networks nearby. In the absence of available networks, the technology is ineffective.

Software is currently available to create point-to-point encryption for data, chat, photo transfer, location data and voice communications. The software uses existing smartphone hardware for cellular, GPS and atmospheric sensors (for example, air-pressure changes) to determine geolocation. The use of external sensors (either tethered or wireless) can be integrated to improve location accuracy or report personnel well-being. The software has an alert capability that can notify other personnel, as well as display the alert within a common operating picture (COP). The alert can provide location data, and the transmission of personnel vital information is in development. The alert is manually activated but could be automatically triggered by predetermined criteria (for example, heart rate too high, oxygen saturation levels too low). The software operates over Wi-Fi networks (including mesh) and cellular data, from 2G Edge up to long-term evolution (LTE).

Although multiple products are in development and have shown advancement toward responder geolocation requirements, there are still significant tradeoffs with each type of technology being used. Some of the limitations that are being addressed include:

- *Radio frequency* – Fundamental technological problems include reflection and the significant signal interruption caused by barriers and construction materials such as metal. Addressing this issue is essential if a solution uses RF.
- *Inertial navigation* – Small inertial sensors (for example, accelerometers or gyroscopes) that are affordable to responders currently do not have low enough drift to allow precise geolocation based on inertial sensors alone. The goal is to make small, affordable sensors that have the same performance outcomes of

existing sensors that cost thousands of dollars. To this end, DARPA has established the Micro-Technology for Positioning, Navigation and Timing (Micro-PNT) program.[23] The goal of this program is to develop technology for self-contained, chip-scale inertial navigation and precision guidance for munitions, as well as for mounted or dismounted warfighters. This program addresses size, weight, power and cost concerns and may ultimately allow for the development of a single unit that comprises all necessary devices (for example, clocks, accelerometers and gyroscopes).

- *Low-frequency signals* – These signals can be used to bypass the issue of other high-frequency technology. However, construction materials such as wiring and pipes in a building may produce false readings and throw off the device. In addition, power line noise, caused by sparking or arcing utility pole hardware, is usually most disruptive to lower frequencies.

- *Video* – Video data can be used to sense where an individual is located in a building. However, it has varying levels of effectiveness, particularly in darkness or smoke-filled environments. Research is ongoing to use infrared technology to improve accuracy in these conditions.

A recent influx of indoor responder location technologies has raised concerns among the standards development community. Many of these technologies carry very precise accuracy claims, but when placed in conditions designed to mimic response environments, they do not perform to the levels asserted. As a result, the International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC) 18305 standard was drafted to address requirements for indoor responder location and tracking systems. For this standard, "indoor" responder location is defined as any environment where there is no "line of sight to the sky." Under this definition, responders working within or under rubble piles would qualify as "indoor," even though some response entities would classify such activity as "outdoor" since there is no standing structure.

ISO/IEC 18305 is still in the development phase, currently under ballot for validation from the response community. Final publication of this standard is expected sometime in 2015; however, the standard is already in use in some European nations. Once finalized, ISO/IEC 18305 will be the first standard to address responder location systems and will join only a handful of other standards related to location and tracking (including a National Institute of Justice standard on offender tracking).

[23] "Micro-technology for Positioning, Navigation, and Timing." DARPA: Microsystems Technology Office, last updated, n.d., http://www.darpa.mil/Our_Work/MTO/Programs/Micro-Technology_for_Positioning,_Navigation_and_Timing_(Micro-PNT).aspx.

Potential Challenges:

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

- There is a correlation between the size, cost and accuracy of sensor technologies. Responders need small, affordable and accurate sensors.
- Subject matter experts stated that current technologies impose trade-offs in reaching the goal of geolocation to within one to three feet. Experts estimated that devices built to meet this parameter could be very expensive (tens of thousands of dollars per device).
- Systems that rely on inertial navigation require initialization, often achieved using GPS. However, GPS accuracy is, at best, within 10 to 15 feet (and worse near buildings). This further impedes the goal of geolocation to within one to three feet.
- Compensating for a lack of GPS access indoors and underground with accurate location technology may require a higher bandwidth than proximity location. This requires the use of more sophisticated devices than some of the radio and communications technology currently used on incident scenes.
- Insufficient bandwidth and cross-traffic interference may hinder the transmission of responder location data in real time.
- Each location system assumes different levels of infrastructure already present in the building. Some systems require Wi-Fi capabilities be present in a structure, while others assume no Wi-Fi capabilities.
- Systems must be tested against a variety of construction materials and building types to truly mimic reality. Finding a suitable environment that meets these needs may be difficult.

Outdoor Responder Geolocation

Relevance: Responders often operate outdoors across extensive geographic areas and in austere conditions. When deployed to these areas, responders are often unaware of the location of other nearby responders unless it is verbally communicated. In addition, incident commanders who are tasked with managing the response also may not know the location of the response teams in the field. Knowing the location of these responders and their proximity to threats is extremely important for outdoor incidents that span long distances, such as wildland firefighting. There have been instances where the lack of location information and communications has resulted in severe injury and death. In addition to safety benefits, incident commanders may also be able to allocate resources more effectively and monitor the progress of those in the field.

Current Capability: The military's blue force tracker systems provide an outdoor geolocation capability but are not designed or deployed for emergency responder use.

Currently, responders use hand-held radios (for example, 700/800 MHz, VHF, UHF) to verbally communicate coordinates to dispatch and other responders on-scene. Real-time responder geolocation can be done using GPS units, but they are costly and not widely deployed at the individual responder level. If used, these GPS locators are typically fixed to an apparatus such as a fire truck or police cruiser, which does not provide adequate location information for each responder on the incident scene.

Responder Goals:

- Accurate geolocation of responders to within one to three feet for x, y and z coordinates in hazardous outdoor environments and in remote areas
- Real-time and recurring transmission of responder location to incident command
- Graphic display of all responders on the incident scene
- Integrates with graphic display of on-scene hazards and threats
- Incorporates terrain and building information
- Integrates with common electronic situational awareness tools
- Location transmitters should be ruggedized, simple, transparent and users should not be able to turn them off
- Integration of transmitters into PPE or other existing equipment with minimal or no net weight gain for the responder
- SWP suitable for responder operating conditions
- Incorporates a confidence level to indicate the accuracy of location
- Affordable to outfit entire workforce
- Caches data when connectivity is offline, and automatically forwards when connection is restored

State of Technology: Numerous locator devices exist for markets such as outdoor recreation. For example, hikers often use personal locator beacons (PLBs) that can send out a geolocated distress signal. PLBs communicate via military satellites on a recognized distress frequency. PLBs that rely on GPS can guide searchers to within 100 meters of the user's position.[24] Other devices, called satellite transmitters, can transmit GPS location and data messages to an e-mail, cellphone short message service (SMS) or emergency response center with a pre-scripted message to convey that assistance is needed or that the user is okay. These devices only operate with a clear view of the sky and without interference from other RF signals. Therefore, being in close proximity to other GPS devices can decrease accuracy. The concern is that many of the commercial systems are not ruggedized to the response environment, do not transmit a

[24] "PLBs and Satellite Messengers," REI, last updated: n.d., http://www.rei.com/learn/expert-advice/personal-locator-beacons.html.

location continuously or in real time and cannot be networked together to provide an integrated picture of responders on scene.

DARPA has a project to help address the issue of RF interference called Advanced RF Mapping (RadioMap). This effort provides real-time awareness of radio spectrum use across frequency, geography and time. The goal is to provide a map that gives an accurate picture of spectrum use in complex environments.[25] RadioMap allows individuals to identify when the spectrum is jammed or clear, thus adding to the confidence level of how accurate a location is.

As mentioned above ("Indoor Responder Geolocation"), DARPA is also working on a geolocation program called ANS, which establishes GPS information irrespective of the operating environment.[26] Specifically, DARPA is working to develop improved IMUs, alternate sources to GPS for external position fixes and new algorithms and architectures for rapidly reconfiguring a navigation system with new and nontraditional sensors.[27]

Potential Challenges:

- Responders are concerned about the cost of outfitting an entire response unit with GPS devices and sensors that are not precise enough to improve responder safety during rescue missions.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Maritime (Above and Below Water) Geolocation

Relevance: Responders often operate in maritime environments with limited knowledge of the location of responders either on or below the surface. Having the capability to remotely monitor the location of responders, including divers beneath the surface, will improve safety and responder tactics during swift-water rescues or incidents involving maritime conveyances. Responders need the ability to know the geolocation of responders in three dimensions in maritime conditions in fresh and salt water.

Current Capability: Few technologies exist to geolocate emergency responders in the maritime environment. For geolocation on the water, GPS devices are fixed to an apparatus (for example, a rescue vessel) and not the individual responders. Therefore, incident commanders do not have a precise location of all responders at the incident scene. Most agencies do not have the capability to conduct underwater geolocation of

[25] "Advanced RF Mapping," DARPA: Strategic Technology Office, last updated: n.d., http://www.darpa.mil/Our_Work/STO/Programs/Advanced_RF_Mapping_(Radio_Map).aspx.

[26] "Adaptable Navigation Systems," DARPA: Strategic Technology Office, last updated: n.d., http://www.darpa.mil/Our_Work/STO/Programs/Adaptable_Navigation_Systems_(ANS).aspx.

[27] Ibid.

responders. Sophisticated dive teams may utilize fiber-optic umbilical cord cables tethered to a diver for location, underwater communication and safety purposes.

Responder Goals:

- Accurate geolocation of responders within three feet for x, y and z coordinates in hazardous outdoor environments and in remote areas
- Real-time and recurring transmission of responder location to incident command
- Graphic display of all responders
- Integrates with graphic display of on-scene hazards and threats
- Incorporates information pertaining to the body of water
- Integrates with common electronic situational awareness tools
- Location transmitters should be ruggedized, simple, transparent, and users should not be able to turn them off
- Integration of transmitters into PPE or other existing equipment with minimal or no net weight gain for the responder
- SWP suitable for responder operating conditions
- Incorporates a confidence level to indicate the accuracy of location
- Affordable to outfit entire workforce
- Caches data when connectivity is offline and automatically forwards when connection is restored

State of Technology: Technology for maritime geolocation is primarily focused on emergency position indicating radio beacons (EPIRBs) and personal automatic identification systems (AISs). EPIRBs work in the same manner as the PLBs described in the RTO above. The beacon broadcasts a distress signal and location coordinates via satellite. The satellite can determine the user's position to within three miles.[28] An AIS is used for tracking marine vessels. The system uses an indigenous navigation system to identify the location and speed of the vessels. Both EPIRBs and AISs are attached to the vessel, not to individuals on the vessel. Personal AIS beacons that will notify the vessel if the user is in distress have been developed for divers and boaters. The beacons use a combination of AIS and GPS signals to transmit location information but must be turned on manually. Personal AIS beacons can work at depths up to 60 meters.

[28] "What is an EPIRB?,," last updated: n.d., http://www.epirb.com/how_does_an_EPIRB_work.php.

Potential Challenges:

- Locating responders or victims underwater does not necessarily mean that the remains can be retrieved, especially if the depth or hazards in the water impede rescue efforts.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Infrastructure Standards for Technology Integration

Relevance: There are multiple opportunities for responders to leverage the information technology, surveillance and power infrastructure in buildings on an incident scene. Responders desire improved situational awareness with regard to building layouts, elevator shaft locations, structural properties and any other characteristics that may impact their response (for example, enhance or degrade communications). The collection and consolidation of this data would benefit the development of responder indoor location and communication technologies. Being able to leverage the infrastructure (for example, cameras, antennas, electrical systems) inside a building during an incident could help improve signal strength and bandwidth issues for improved indoor geolocation.

In addition to technology integration benefits, construction standards such as backup generators, pressurized stairwells, hardened elevator shafts and centralized hose plug-ins for gross decontamination efforts could improve resilience to natural and man-made events.

Current Capability: There is currently no standard for infrastructure mapping of new or existing buildings in cities across the country. Specifically, there is not a standard requiring building construction to include technology (such as radio frequency identification [RFID] tags) that would facilitate the use of responder locating devices inside structures. The International Building Code (IBC), developed by the International Code Council, addresses the inclusion of fire prevention measures during building and construction. The National Fire Protection Association (NFPA) developed an alternate code, NFPA 5000 Building Construction and Safety Code.[29] These general codes are adopted and amended by state and local jurisdictions. Revisions to these codes could include guidance on the integration of technology elements into newly constructed buildings.

[29] "NFPA 5000 Building Construction and Safety Code," National Fire Protection Association, last updated: n.d., http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=5000.

Responder Goals:

- Building code requiring:
    - Two-way communications systems for newly constructed buildings
    - Bi-directional antennas and repeaters for high rises and tunnels
    - One-way paging or intercom system to communicate with each room in the building
    - Responder access to camera systems
    - Secondary generators for sustained power loss
    - Integration of networked sensors to detect the structural integrity of the building
- Requirements to submit digital copies of all building blueprints for integration into situational awareness systems

State of Technology: The next steps for achieving responder location, rather than proximity, are dependent on the integration of multiple existing pieces of technology rather than new development. This includes installing light infrastructure (such as time-of-flight beacons and anchor sensors) in buildings before incidents occur, using LTE networks instead of radio networks, and integrating preexisting maps and building specifications into the location system. Each of these technological devices or data would greatly enhance the ability to locate a responder indoors within a narrow radius. Integrating these items would also cut down on the size and expense of any final location device, particularly the inclusion of light infrastructure in buildings before an incident. Without the light infrastructure system, sensors have to be bigger, stronger and, by extension, more expensive.

Potential Challenges:

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

- The addition of technology into building design will result in higher costs during construction. The building industry fought strongly against the home sprinkler requirement, and it is anticipated that it will oppose other proposed standards that increase costs.
- There is a question of who will maintain digital copies of all building plans. The agencies responsible for maintaining residential and commercial building plans may not have systems that integrate with response agencies.

Rapid Building Characterization, Generation and Display

Relevance: Responders often arrive at an incident scene with limited knowledge of building layouts and information. Only those with extensive experience of a geographic area may be familiar with building characteristics. Responders would benefit from knowing the location of doors, exits, stairwells, power and technology infrastructure and known hazards in the building (for example, gas lines). Better understanding of building layouts would provide a significant advantage when trying to rescue a trapped or unresponsive responder as well as during other tactical operations. Responder positioning could be notably enhanced if combined with a 3-D rendering of buildings on the incident scene. Being able to quickly understand the building layout in a readily available format and the location of responders within the building can greatly improve tactical operations and decision-making.

Current Capability: Responders use open-source imagery to gain insight about target buildings. Images are typically limited to external visualizations of a building and do not provide indoor mapping capability. Digitized building blueprints are not readily available in most jurisdictions. Available blueprints have not been collected or integrated into a usable format that is accessible to responders.

Responder Requirements:

- Rapid 3-D rendering of interior and exterior features
- Readily accessible blueprints of buildings
- Includes attribute data of buildings (including the number of rooms or estimated residents living in apartment building)
- User-friendly display of information (for example, heads-up display)

State of Technology: Several technologies exist that can rapidly characterize, generate and display a 3-D visualization of a building. These technologies are not automated and require human interaction.

Multiple software platforms allow a user to rapidly create a two- or three-dimensional model of individual buildings and populate the model with known data about the building. For example, upon arrival at an incident scene, a user could identify the impacted building on a map and build a model of that building based on in-person observations such as shape, number of stories and building material type. These tools use available street-level and overhead satellite imagery as inputs for the creation of the models. Integrating up-to-date maps and preexisting building data can help improve the technology's output and provide greater detail for the response community.

These 3-D renderings can be integrated into other software programs that illustrate incident effects. The Defense Threat Reduction Agency (DTRA) funded the development of NucFast, a software platform that uses National Geospatial-Intelligence Agency (NGA) building footprint data to model the 3-D structural components of buildings. The system incorporates data sets from the Federal Emergency Management Agency's (FEMA) Hazus program to model the effects of a nuclear detonation. The system can display a range of effects (for example, rubble pile distribution, thermal loads, structural failures, probability of fire initiation) at the individual building level. The outputs of this system could be used to significantly improve the safety of responders and the population.

Potential Challenges:

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

- Many existing building plans are not digitized and it may require a significant effort to convert existing files.
- Digital building plans will need to be updated as buildings and structures are renovated. Responders need access to the most recent copy of the plans. However, there is a question (as mentioned above) regarding which agency is responsible for obtaining and maintaining these updated plans in each municipality.
- Responders noted that there may be privacy challenges related to estimating the number of residents living in apartment buildings or multi-family dwellings.

Improved Standoff Detection and Identification of Multiple Hazards

Relevance: Responders face a large number of diverse hazards during a catastrophic incident, including caustic gases and volatile organic compounds (VOCs), radioactive contamination, biological agents, deficient oxygen levels and explosives and secondary devices. These hazards can be detected, characterized and measured using sensor technology. Specifically, sensors that measure the quantity, volume and concentration of these hazards provide the basis for making time-sensitive decisions that impact the health of responders and the public. This RTO focuses on the initial detection of hazardous agents and characterization of critical information. Ongoing surveillance and monitoring of threats is covered in a separate RTO called “Remote Monitoring of Threats and Hazards.”

Current Capability: Responders currently use a variety of sensors and detectors to detect hazardous agents, including personal radiation detectors (PRDs), multi-gas chemical detectors, infrared sensors, medical infection control sensors and motion detectors. However, accessibility to and availability of these devices varies depending on jurisdiction. For example, all New York City responders (law enforcement, fire and EMS) carry PRDs, but only district-level law enforcement supervisors in other jurisdictions carry these devices. Cost is one of the most prohibitive factors impacting availability. Additionally, the spectral range for available devices is limited. For example, the majority of PRDs detect gamma signatures but do not have the ability to identify individual isotopes or neutrons. Conversely, chemical sensors can identify a specific agent but cannot provide concentration levels from a safe distance. Responders reported that they have no sensor or detector for real-time biological agent detection or identification. Most of the current detectors and sensors can be mounted to various platforms, including manned and unmanned ground vehicles and aircraft. Other technologies utilized for this capability include building security systems, acoustic sensors and multi-spectral cameras.

Resources such as the Radiation Emergency Medical Management (REMM) tool and the *Emergency Response Guidebook* (ERG) provide a consolidated repository of approved information and aid in the characterization of hazards. These resources provide guidance about radiological and chemical incidents, including information about individual isotopes or toxins, standoff distances, relevant protective actions and basic medical treatments or countermeasures.

Responder Goals:

- Detects hazardous agents in real time, including chemical, biological, radiological and explosive particles and signatures, within a set perimeter around response personnel
- Identifies the specific agent or isotope
- Detects or measures other pertinent data (for example, oxygen displacement) that impacts hazardous conditions
- Measures the current concentration and records exposure over time
- Provides pertinent information, including modes of exposure, protective action information (for example, appropriate PPE, standoff distances, immediate treatments, decontamination requirements)
- Generates automated alerts in multiple formats (in other words, audible, visible, tactile) when preset or site-specific thresholds have been reached
- Integrates personal detectors into PPE, communications devices or other daily equipment
- Affordable to outfit entire workforce
- Relays information in real time to incident command, caches data when connectivity is offline, and automatically forwards when connection is restored
- Integrates with common electronic situational awareness tools
- Deployable on multiple platforms (for example, manned and unmanned ground and aerial vehicles, fixed and mobile)
- Compliant with relevant standards
- Equipment should be intrinsically safe and ruggedized

State of Technology: There are multiple technologies in development that could improve capabilities for identifying and characterizing hazards on the incident scene.

A commercial manufacturer developed a chemical detection armband that uses a customizable set of chemical detector cassettes. The system uses a color-changing detection system that alerts the user to the presence of a toxic gas. The U.S. Coast Guard uses the system extensively. The company developed preconfigured kits for hazardous materials (hazmat), clandestine methamphetamine labs and other specific incidents to expand use to the response community.

Other applications are being developed specifically for the response community. S&T recently developed Chem-Tag, a small, lightweight, low-cost unit that alerts users when it detects carbon monoxide, methane or hydrogen cyanide.[30] S&T anticipates that Chem-Tag could be integrated into responder garments or equipment. A related program, in development by S&T's Homeland Security Advanced Research Projects Agency (HSARPA), is the Cell-All sensor, designed to continuously "sniff" the air around the user for volatile chemical compounds.[31] S&T envisions that it will be integrated into publicly available smartphones, providing alerts to individual citizens when it detects that they are in the presence of hazardous chemicals and alerting authorities after identifying specific threats such as chemical warfare agents. Similar technologies use a smartphone's camera to detect radioactivity. The current version of the system allows users to monitor personal radiation exposure, but it is anticipated that users will soon be able to compare their measurements with others in their area. Radiation measurements can also be transmitted to response personnel.

The DHS Domestic Nuclear Detection Office (DNDO) is developing technologies for spectroscopic personal radiation detectors that can better detect, identify and locate radiological or nuclear sources. The devices use advanced scintillating materials, which help to better identify specific sources than can be done with current materials.[32] DNDO is also supporting the development of domestic capability to produce stilbene, an organic scintillator for the passive detection of neutrons.[33]

DARPA leads many of the advances in this area and is primarily focused on addressing deficiencies in current systems. For example, DARPA has funded a program called the Compact Mid-Ultraviolet Technology (CMUVT) program.[34] The goal of this program is to develop ultraviolet (UV) components that will improve the size, weight, power and capability of chemical- and biological-agent detectors. Another DARPA program, the Advanced Wide FOV Architectures for Image Reconstruction and Exploitation (AWARE), is using innovative camera designs and distributed aperture sensors to create a gigapixel camera small enough to be deployed on a small unmanned aerial platform.[35]

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[30] "Smartphones now capable of detecting gas," Homeland Security News Wire, October 3, 2011, http://www.homelandsecuritynewswire.com/node/33274.

[31] "Cell-All: Super Smartphones Sniff Out Suspicious Substances," DHS, last updated: December 26, 2012, http://www.dhs.gov/cell-all-super-smartphones-sniff-out-suspicious-substances.

[32] "Advanced Radiation Monitoring Device," DHS, last updated December 31, 2013, http://www.dhs.gov/advanced-radiation-monitoring-device.

[33] "Stilbene, an Organic Scintillator for Fast Neutron Detection," DHS, last updated June 16, 2014, http://www.dhs.gov/stilbene-organic-scintillator-fast-neutron-detection.

[34] "Compact Mid-Ultraviolet Technology," DARPA: Microsystems Technology Office, last updated: n.d., http://www.darpa.mil/Our_Work/MTO/Programs/Compact_Mid-Ultraviolet_Technology_(CMUVT).aspx.

[35] "Advanced Wide FOV Architectures for Image Reconstruction and Exploitation (AWARE)," DARPA: Microsystems Technology Office, last updated: n.d, http://www.darpa.mil/Our_Work/MTO/Programs/Advanced_Wide_FOV_Architectures_for_Image_Reconstruction_and_Exploitation_(AWARE).aspx. The acronym FOV in the title refers to field of view.

Real-time detection of biological agents remains a challenging problem. DHS S&T funded the Detect-to-Protect (D2P) program to assess multiple sensors that have been designed to identify and confirm the release of biological agents within minutes. The D2P program held a series of tests in 2012 to detect biological agents in the Boston subway system.[36]

Potential Challenges:

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

- Responders did not specify a precise desired standoff distance. Subject matter experts stated that this is a critical point as the size, weight and cost of the sensor rise, and performance degrades, as the distance is extended.
- Responders are continuously concerned about false positives and negative rates, which in turn could lead to distrust and disuse of technology.
- Similarly, there are concerns about false positives and inaccuracies from cellphone applications that detect radiological signatures. The public may not have sufficient understanding of the measurements, other potential sources of radiation (for example, nearby persons receiving nuclear medicine treatments) or the effects of background radiation to properly assess and understand alerts from these applications.
- The accuracy of sensor systems is increased when the measurements are analyzed against normal background levels for agents and contaminants. However, few communities collect such data.

Multi-sensor Integration and Analysis

Relevance: Responders need to be able to assess their current level of risk from multiple threats. For individual responders, this generally involves carrying multiple types of sensors on their person as part of their PPE, in their hands, or deployed on an apparatus (for example, radiation pagers, five-gas meters). Incident command also relies on measurements from multiple types of fixed and mobile sensors deployed on numerous platforms. However, the measurements and readings from these sensors are rarely integrated, and analysis of the results is done individually. This RTO focuses on the integration and miniaturization of sensors so they can be deployed on a smaller number of platforms and the analysis of those sensors can be combined to provide a comprehensive picture of hazards on the incident scene.

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[36] "DHS using Boston subway system to test new sensors for biological agents Homeland Security News Wire," *Homeland Security Newswire*, August 27, 2012, http://www.homelandsecuritynewswire.com/dr20120827-dhs-using-boston-subway-system-to-test-new-sensors-for-biological-agents.

Current Capability: There is limited integration of sensors and analysis conducted in the response community. The primary exception is the multi-gas meter, which is a single system that can identify oxygen levels, lower explosive limits (LELs) and concentrations of the most common VOCs (for example, ammonia, chlorine, hydrogen cyanide, phosphine, and sulfur dioxide). Advanced models include radiation detection and the ability to interchange toxic sensors. These are available in hand-held devices or larger, mobile devices that allow standoff detection and monitoring of hazardous agents.

Responder Goals:

- Appropriate SWP for integration of multiple sensors and imaging systems into several platforms, including:
  - Personal device (size and weight of a deck of cards)
  - Man-portable systems (backpack size, less than 25 pounds)
  - Unmanned aerial systems (under six pounds)
  - Unmanned ground vehicles (weight unspecified)
- Includes a common hub or interface, allowing interchangeable sensor configuration
- Ability to adjust or tune sensors for different environments (for example, smoke, steam)
- Ability to network sensors and integrate outputs and data measurements for combined assessment of existing hazards
- Integrates with common electronic situational awareness tools
- Relays information in real time to incident command, caches data when connectivity is offline and automatically forwards when connection is restored

State of Technology: Subject matter experts advised that nanotechnology might offer substantial enhancements in the development of new and smaller sensors. Scientists from the Center for Nanotechnology at the National Aeronautics and Space Administration (NASA) Ames Research Center developed a chemical-sensing, platform-based nanotechnology.[37] Each sensor in the array consists of a nanostructure, chosen from many different categories of sensing material that can measure the concentration of chemical molecules. Researchers believe that lightweight and compact sensors can be made at low cost.

DARPA is also investing in miniaturized sensors. One example is the Low Cost Thermal Imager-Manufacturing (LCTI-M) program.[38] Researchers are trying to develop very low-cost, high-performance thermal imagers that can be can be inserted into hand-held units,

[37] "Carbon Nanotube Sensors for Gas Detection," NASA, last updated: March 29, 2008, http://www.nasa.gov/centers/ames/research/technology-onepagers/gas_detection.html.

[38] "Low Cost Thermal Imager-Manufacturing," DARPA: Microsystems Technology Office, last updated: n.d.,http://www.darpa.mil/Our_Work/MTO/Programs/Low_Cost_Thermal_Imager_(LCTI-M).aspx.

modified cellphone products, rifle sights, helmets, eyeglasses, micro-Unmanned Aerial Vehicles (UAVs) and other small form-factor devices for real-time target recognition, acquisition and network sharing of data. The goal is for the devices to be made available for every vehicle, surveillance device and dismounted warfighter, significantly improving situational awareness.

HSSAI research found few ongoing efforts to develop a standardized plug or hub for the integration of sensors onto a common platform. The chemical armband described in the RTO above represents one success in this area. The system includes 14 different sensors that can be interchanged on the armband to create a configuration that best meets the needs of the user. The sensors are packaged in cassettes that plug into the armband base. The form factor for each cassette is the same, allowing it to take any place on the base. While integrated onto the same armband, the sensors are not fused together to give an integrated indication of hazards. Other manufacturers have developed bridging devices with multiple connectors attached via wires to a central hub. Such devices allow sensors from different manufacturers to be used on the same platform. One issue is that there are limited connectors of any one type, restricting the number of sensors from the same manufacturer that can be attached.

Potential Challenges:

- Participants stated that manufacturers might be unwilling to use a standard hub or plug configuration for their sensors, citing commercial advantages in having proprietary interfaces.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

Risk Assessment and Decision Support to Command

Relevance: The sensors and imaging systems involved in the identification, characterization and monitoring of threats and hazards may produce large amounts of technical data and require analysis of complex information. These data include sensor readings, model projections, reporting of conditions from the incident scene and other pertinent information. In many cases, command staff members cannot incorporate the large amounts of data coming in or do not have the technical training to understand the data and information. This makes it difficult for incident command to assess the level of risk and make appropriate life-safety or operational decisions. Responders stated the need for a decision support system that will improve their understanding of the threats and hazards on the incident scene and support accurate decision-making. This RTO is important because increased understanding of pertinent data and information will allow command staff at all levels to make decisions that improve responder and population safety.

Current Capability: There is no single source of information that incident command can use to make key decisions about hazards and threats. Information is available in multiple sources and formats, but it is not integrated with a tool that guides incident command staff through response.

Responder Goals:

- Guides incident command staff through key decisions points, integrating actual and projected data and information (including sensor readings, model outputs, technical calculations, first-hand accounts from the scene, etc.)
- Provides recommended decisions or courses of action for each decision point and confidence levels for those recommendations
- Indicates where key inputs are missing that could improve confidence levels
- Provides cues and checklists for additional support
- Integrates all risk alerts onto one common display
- Integrates with common electronic situational awareness tools
- Incorporates the criteria levels (for example, established exposure limits) established during pre-planning efforts
- Includes pre-populated and user-defined decision points

State of Technology: Several decision support systems are commercially available to the emergency response community. These systems integrate incident-specific measurements with modeling capability to provide specific operational recommendations and guidance. One example is the Chemical Companion Decision Support System, funded in part by the Technical Support Working Group (TSWG) and the U.S. Marine Corps Systems Command.[39,40] The software is accessible via mobile devices and desktop and laptop computers. The chemical companion offers decision support capability, such as a respiratory protection tool that guides users through a series of questions about environmental conditions and hazardous materials and delivers a recommendation on what type of respiratory protection is required. A detection tool helps the user determine which detectors should be used and aggregates the results of multiple devices. The chemical companion is free to law enforcement and fire departments.

Decision-makers face challenges in rapidly evolving environments when there may be a lack of communication or situational awareness. In an attempt to overcome these

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[39] The Technical Support Working Group conducts the national interagency R&D program for combating terrorism through rapid research, development, and prototyping. "Our Missions," Combating Terrorism Technical Support Office, last updated: n.d , http://www.tswg.gov/?q=missions.

[40] "Chemical Companion Evolves from Information Resource to Sophisticated Decision-Support System," Georgia Institute of Technology, last updated February 19, 2014, http://www.news.gatech.edu/2014/02/19/chemical-companion-evolves-information-resource-sophisticated-decision-support-system.

challenges, DARPA established the Distributed Battle Management (DBM) program.[41] The goal of this program is to develop automated decision aids to assist airborne battle managers and pilots with managing air-to-air and air-to-ground combat. While this particular application is DOD-specific, the research and conceptual application of automated decision aids could also have applications for the civilian response community.

Potential Challenges:

- Responders may be hesitant to rely on computer-generated recommendations.
- Participants stated that liability concerns might hinder development of this system. Developers will not want to expose themselves to criminal or civil liability if the guidance is inaccurate or inconclusive.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

Remote Monitoring of Threats and Hazards

Relevance: It is important for emergency responders to have the ability to continuously evaluate existing, emerging and potential hazards in areas affected by a catastrophic incident. Areas that may need monitoring include a broad radius around an incident scene, areas where response and recovery actions are underway or specific ingress/egress routes. Remote monitoring provides the necessary input for incident command to assess the present dangers and emerging threats over time without exposing responders to additional risk. This RTO focuses on the development of multiple platforms to support monitoring of threats and hazards on the incident scene and potentially affected areas. This RTO is important because real-time, continuous surveillance improves the safety of emergency responders and the affected population still in those defined areas. This RTO focuses on the ongoing surveillance and monitoring of threats through the development of multiple platforms. Initial detection and characterization of hazardous agents is covered in a separate RTO (see "Improved Standoff Detection and Identification of Multiple Hazards").

Current Capability: Responders currently rely on several fixed and mobile platforms for remote monitoring of the incident scene. In many cases, man-portable systems are placed throughout the incident scene and affected area, but this involves risks to the personnel placing the system. Sensor systems are also often attached to manned aircraft to provide aerial images and measurements. Responders also rely on traffic and surveillance cameras to remotely monitor key areas. In addition, some Special Weapons and Tactics (SWAT) teams use unmanned ground vehicles (UGVs) for remote assessment of threats (primarily explosive devices), but these are cost-prohibitive for many agencies.

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[41] "Distributed Battle Management," DARPA: Strategic Technology Office, last updated: n.d., http://www.darpa.mil/Our_Work/STO/Programs/Distributed_Battle_Management_(DBM).aspx.

The Federal Aviation Administration (FAA) currently prohibits the use of most unmanned aerial systems (UAS) for response operations, but they are used to a limited extent.[42] In addition, many states have enacted laws prohibiting or significantly limiting the use of UAS by law enforcement.

Responder Goals:

- Platforms to remotely capture threat- and hazard-related data in multiple topographies (for example, inside buildings, at various depths and elevations, over rubble and across different terrains)
- Operates within multiple environments (for example, smoke, humidity)
- Equipped with configurable sensor packages (see the “Multi-Sensor Integration and Analysis” RTO)
- Platforms in various sizes and configurations (for example, UGVs, UAVs, mobile and man-portable systems)
- Uses a common hub or interface for sensors and imagers
- Continuously integrates captured data with geographic information system (GIS) location of platform
- Able to operate multiple platforms in networked and/or swarm configuration
- Equipment is ruggedized, intrinsically safe and nondegradable due to hazard
- Sufficient power supply to support duration of monitoring (variable by platform)

State of Technology: Unmanned aerial and ground systems are well suited to carry sensors that detect threats and hazards. Use of these systems for emergency response is currently limited by government restrictions, liability concerns and cost.

UAS technology is mature, and the platforms are used regularly by DOD in its operations outside of the United States to conduct many of the same tasks that emergency responders would perform. The systems can provide sustainable monitoring of threat and hazard conditions over the incident scene and affected areas and regularly carry traditional remote sensing payloads, such as hazard sensors or multispectral cameras.

Advances in UAS may provide significant improvements in capability once regulatory issues are resolved. UAS that can be used for domestic missions range in size from the large Predator (27 feet long, 2,250 pounds loaded and unit cost of approximately $4 million) to hand-launched platforms that weigh less than 10 pounds. DHS S&T is currently funding the Robotic Aircraft for Public Safety (RAPS) project to test and evaluate Small Unmanned Aircraft Systems (SUAS) equipped with sensors, including various imaging systems.

[42] The term *unmanned aerial vehicle* has largely been replaced with the term *unmanned aerial system* to reflect the fact that the vehicles are complex systems controlled by human operators.

Small unmanned ground vehicles (also referred to as robots) are able to enter buildings and other structures that may be inaccessible for aerial systems. Advanced robots are able to climb stairs, open doors and move over uneven terrain, including rubble. The BigDog robot, funded by DARPA, can transport heavy loads of remote sensing payloads over terrain that cannot be traversed by wheeled or tracked UGVs.[43] There are ongoing DARPA efforts to improve the bullet resistance of BigDog, which could allow it to operate during an active shooter incident. Other developers are focused on using microrobotics to create small platforms (some only a centimeter across) that can be deployed to reach small areas or confined spaces.

Robots are regulated by Occupational Safety and Health Administration (OSHA) requirements, which ensure that their electronics will not ignite fuel or cause an explosion (referred to as intrinsically safe). Subject matter experts stated that complying with these requirements adds significantly to the cost of the platform, making the price unreachable for many response agencies.

Developers are also working to reduce the costs of UAVs and UGVs through the application of 3-D printing for on-site manufacturing of platform components. Agencies will be able to rapidly print the non-electrical parts of these platforms to build low-cost parts. Printable components include wheels, cases, wings and braces. Developers envision a “kit in a box” option that would enable users to purchase a set of electronic components and print the other required pieces for the UAV or UGV. Parts can be printed on-scene with commercially available 3-D printers (which are becoming less expensive and more accessible for response agencies).[44]

Potential Challenges:

- Federal and state regulations and restrictions hinder the application of UASs for emergency response missions within the National Airspace System.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

Combined Effects Assessment

Relevance: Large-scale incidents typically present multiple threats and hazards to emergency responders. The initial hazard often causes secondary or cascading effects, each presenting a unique challenge for responders and presenting unforeseen risks to both responders and the public. The tsunami that hit Japan in 2011 illustrates the potential for multiple and combined effects. This natural disaster caused radiological and chemical

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[43] “BigDog – The Most Advanced Rough-Terrain Robot on Earth,” Boston Dynamics, last updated: n.d., http://www.bostondynamics.com/robot_bigdog.html.

[44] On-site 3-D printing has additional applications for emergency response outside of UAV or UGV platforms. Responders will be able to print spare or replacement parts for multiple pieces of equipment on scene.

incidents, numerous fires and the collapse of a dam.[45] Incident command needs to understand the potential for secondary effects, the conceivable impacts of all incident effects and how those effects combine to mitigate or exacerbate the situation. This information will allow incident command to assess the priorities of threats and make appropriate PPE and protective decisions for responders and the public. Responders want to address the most critical impacts without ignoring the potential for secondary issues or consequences.

Current Capability: There is little integrated capability to understand and assess combined incident effects. In many cases, jurisdictions identify potential hazards and potential effects through pre-event assessments, but do not include incident-specific information based on actual conditions. There are several tools available for characterizing hazards during an incident, including the Hazard Prediction and Assessment Capability (HPAC), Computer-Aided Management of Emergency Operations (CAMEO), and HotSpot. These tools can be used for both pre-event planning and post-incident overlay of data to indicate hazards. In addition, many tools use GIS overlays that allow "painting" of hazards on a map of the incident scene.

Responder Goals:

- A multi-layer graphic display that illustrates individual and combined hazards on a GIS-enabled street-level map, including critical infrastructure and key resources (CIKR) and known hazards
- Calculates combined effects supported by sensor measurements and model outputs
- Integrates outputs with digital situational awareness tools
- Includes decision support materials to prompt consideration and analysis of potential secondary effects
- Includes predictive modeling functionality to illustrate the impacts of potential secondary or combined effects

State of Technology: Advances in technology for this RTO are primarily focused on the graphic display of threats and hazards for improved situational awareness. The Idaho National Laboratory, for example, is developing a robotics platform that will both map the interior of a structure and display the presence of chemical or radiological hazards on the map. The system uses lasers to create a two- or three-dimensional map of the building infrastructure, and the presence of each hazard is illustrated through a series of colored

[45] On March 11, 2011, an undersea earthquake triggered a tsunami that caused extensive damage, resulting in nearly 25,000 casualties and damage to more than one million structures. The tsunami also caused a nuclear accident at the Fukushima Daiichi nuclear plant after seawater flooded the rooms where emergency generators were stored, diminishing power available for the coolant system. Lack of electrical or backup power sources led to a meltdown in three of the seven reactors. Chemical explosions occurred in two of the reactors at Fukushima due to high concentrations of hydrogen gas. The tsunami also caused a separate, large explosion at a petrochemical plant.

layers. This system would potentially allow responders to avoid hazardous areas when conducting operations inside of structures. The robotics platform could also carry a camera, allowing responders to see images of threats or hazards before they enter.

A number of other systems have been developed to display multiple threats on GPS maps, helping to create a common operational picture of the threats and hazards present on the incident scene. These systems allow the user to import digital images of the incident scene, many of which are readily available on the Internet. The user builds shapeforms onto the image and customizes a graphic display of buildings and structures on the incident scene. The user can then overlay threat and hazard data and other information onto the 3-D map, including plume models and images. Advanced systems incorporate additional modeling capability, such as rubble pile distribution, thermal loads on infrastructure, structural failures and air-blast effects.

Potential Challenges:

- Despite advances in graphic display of threats and hazards, there are deficiencies in the ability to assess the impact of threats and hazards on each other and the resulting impacts on response operations and responder health.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

- Building and customizing shapeforms to create a 3-D display of the incident scene is not complex, but does take time (depending on the size of the incident scene). The utility of existing systems would be significantly improved if communities develop 3-D image files of structures before an event.

Automated Red-force Tracking

Relevance: In the military realm, hostile or opposing forces are referred to as “red forces” and friendly forces are referred to as “blue forces.” The emergency response community uses a similar concept. Red forces denote a specific threat or hazard and could be a person or persons (for example, active shooters, suspects) or an item such as a weapon or an explosive device. In a hostile situation, responders and decision-makers need to know the location and movement of these threats and their proximity to other response personnel, critical resources and infrastructure. Real-time tracking of red forces can allow incident command to improve the safety of response personnel and enable more efficient neutralization of the threat.

Current Capability: On an incident scene where there are red forces such as active shooters, it is critical for responders to have situational awareness and know the location of the threats. Responders do not currently have an integrated red-force tracking technology platform. Instead, they utilize a host of tools, including closed-circuit television (CCTV) and other video cameras, social media, visual surveillance and facial recognition software to identify and track threats. Red-force tracking technology is used to identify and monitor the movements of enemy forces on the battlefield, but these technologies have not been adapted for domestic use.

Responder Goals:

- Integrates with responder location/tracking system
- Identifies red-force elements
- Generates covert alerts to responder regarding proximity to red force
- Integrates red-force tracking into situational awareness tools for tactical decision support
- Identifies when a red force approaches high-risk areas/targets
- Ability to covertly place surveillance tags on a red force
- Displays data in heads-up field of view

State of Technology: The U.S. military funds a number of development efforts to identify and track threats. Primarily designed for blue-force tracking, several systems allow warfighters to visualize friendly and hostile forces on a graphic display.

The U.S. Army's Force XXI Battle Command Brigade-and-Below/Blue Force Tracking (FBCB2/BFT) provides advanced situational awareness to warfighters.[46] Warfighters see blue icons on a computer screen inside their vehicle, indicating the location of their teammates. They can also plot improvised explosive devices and enemy locations with red icons on the same computerized topographical map, which are visible by all team members.

A similar capability is available in helmet-mounted heads-up display (HUD) units that allow users to identify and tag persons thought to be a threat. The tagged persons are shown with an icon that is continuously visible in the field of view, even if the threat is not. The system is able to calculate and display the distance of the warfighter from the identified threats.

DARPA is funding the Urban Leader Tactical Response, Awareness and Visualization (ULTRA-Vis) program, which is focused on creating a prototype for an augmented reality system.[47] Augmented reality is accomplished by superimposing a computer-generated image onto the user's view of the real world. This should allow warfighters to overlay full-color graphical iconography onto the local scene as observed by the soldier. The augmented reality system is a lightweight, low-power holographic see-through display

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[46] "Army fields next-generation blue force tracking system," U.S. Army, last updated July 15, 2011, http://www.army.mil/article/61624/.

[47] "Urban Leader Tactical Response, Awareness and Visualization," DARPA: Information Innovation Office, last upated: n.d., http://www.darpa.mil/Our_Work/I2O/Programs/Urban_Leader_Tactical_Response,_Awareness,___Visualization_(ULTRA-VIS).aspx.

with a vision-enabled position and orientation tracking system that the warfighter wears. In doing so, warfighters are able to significantly increase their understanding of the areas and visualization of threats.

DARPA is also focusing on advances in imaging systems to support red-force tracking. For example, the Autonomous Real-Time Ground Ubiquitous Surveillance-Infrared (ARGUS-IR) is a 1.8 billion-pixel sensor system for persistent tracking of threats.[48] ARGUS-IR can be deployed on UAS or UGV platforms.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

Potential Challenges:

- Responders reported concerns with mis-identification of threats when using a red-force tracking system. In addition to the potential for labeling friendly forces as hostile, there could be significant liabilities associated with taking actions against innocent civilians.
- Law enforcement officers currently face legal and privacy issues with using technologies such as facial recognition for red-force identification and surveillance of red-force actors.

All-source Collection and Integration of Data

Relevance: The ability to incorporate information from multiple and nontraditional sources into incident command and operations is a well-defined need from the emergency responder communities. There has also been an increase in disaster-affected populations that utilize social media platforms to communicate and self-organize to identify needs, threats, and solutions during an incident. Emergency responders at the federal, state and local levels have voiced interest in using nontraditional sources of information to improve decision-making through increased situational awareness and public information needs. This information could take the form of crowdsourced information or social media data, for example. The response community would like to use this information in conjunction with traditional information sources (for example, sensor readings, 311 data, weather maps, traffic camera feeds) to improve decision-making during emergencies.

Current Capability: Responders are currently facing data overload. Most information coming from the incident scene is collected, analyzed and disseminated by individuals, with little help from technology. Making sense of large volumes of information can be difficult and time consuming. Some agencies use social media in limited ways, including monitoring individual tweets, posts and other content. However, they do not use high-performance analytics to rapidly make sense of large quantities of information, so they do

[48] "Autonomous Real-Time Ground Ubiquitous Surveillance – Infrared," DARPA: Information Innovation Office, last updated: n.d., http://www.darpa.mil/Our_Work/I2O/Programs/Autonomous_Real-time_Ground_Ubiquitous_Surveillance_-_Infrared_(ARGUS-IR).aspx.

not gain adequate situational awareness from these sources. Overall, the capability to collect and analyze big data is limited, and the emergency response community has not developed or endorsed a standard operating procedure for collecting, analyzing and integrating social media data into operations.

Responder Goals:

- Ingests data in multiple formats (for example, keyhole markup language [KML], keyhole markup language zipped [KMZ], Javascript object notation [JSON])
- Automates the collection and display of data streams
- Identifies those individuals that the public relies on for information and/or whose messages have more influence over the actions of others
- Determines sentiment of social media messages
- Automates the classification of information and dissemination of threat information
- Ensures the security of collected information
- Integrates and overlays social media data on top of existing data sources
- Provides a customizable search function with simple queries
- Automates queries and alerts responders for anomalies or results that need to be investigated
- Conducts analysis (for example, trend and pattern, link, sentiment, keyword alerting) in real time
- Displays confidence levels to inform decision-makers of information accuracy
- Filters exigent social media content from metadata (for example, embedded exchangeable image file format [exif] data)
- Produces customized reports and visualizations in different formats for dissemination

State of Technology: There are numerous tools available to assist emergency responders with visualizing data, including platforms that allow a user to view data in different layers. State emergency management offices are also working in this area to build virtual systems that collect and display information to make it accessible for responders (for example, Virtual Alabama). Tools that mash up data can be useful, yet data collection and analysis are time consuming and largely dependent on the responder. Without the aid of technology that can automate some of the analytics to reduce cognitive load, responders may quickly get overwhelmed with the large volume of incoming data during a catastrophic incident.

A lot of progress has been made in the past few years on technologies to automatically collect, analyze and disseminate data, including that from nontraditional sources such as social media content. These tools, however, are not immediately available or ready for use by the emergency responder community. Furthermore, data from nontraditional sources (for example, audio, photo, video, sensors) has not been effectively combined, and its fusion remains a technical challenge. Emerging technologies have been used in pilot studies and ad hoc experiments, each resulting in mixed results. Many of these technologies do not easily integrate with other systems and are not "responder friendly" or able to be used in realistic operating conditions without significant assistance from developers.

To date, most existing social media and other data fusion technologies have not been developed with an emergency response application in mind. As a result, the outputs yield limited actionable information that is in formats that are not easy for the response community to quickly analyze and use to make decisions.

Similar to emergency responders, DOD systems have difficulty managing the vast amount of information intake. Therefore, DARPA started a program called XDATA to enhance the ability of software tools to process and analyze large and incomplete data sets.[49] The goal of this research is to enhance the ability to use timely and actionable information to make well-informed decisions.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

Potential Challenges:

- Building collaboration with the public and private sectors to share information and input can be challenging.
- Sharing information is often hindered more because of human barriers (for example, existence of or lack of reciprocal trust, commitment to keep information in shared databases current) than technology barriers. These issues will not be resolved through the development of new technology.
- Technology in development needs to keep up to date with evolving social media and other nontraditional source information.
- There are privacy concerns with using personally identifiable information that need to be addressed.
- There are technical challenges with the collection and integration of unstructured data not available in a standard application programming interface (API) with other data streams.

[49] "XDATA," DARPA: Information Innovation Office, last updated: n.d., http://www.darpa.mil/Our_Work/I2O/Programs/XDATA.aspx.

All-source Information Validation

Relevance: There are many different situations where responders have difficulty validating information that comes in through 911 or social media, including unverified calls or reports, until a responder adjudicates the information on-scene. The ability to validate information, tips from the public or other incident-specific information is important when responding to an incident. The ability to validate information becomes harder when responders attempt to incorporate nontraditional information sources, such as social media, with traditional sources.

Current Capability: Currently, there are very limited examples where crowdsourcing or technology aids the verification process of incoming information. To date, validation of incident scene data is largely a human-based capability from responders on-scene. In industry, however, there are examples of data (for example, traffic reports) being validated through crowdsourcing. This type of third-party validation might have application in the emergency response enterprise.

Responder Goals:

- Automated validation of nontraditional information and data
- Includes confidence level indicator for how valid data might be
- Validates the user, time, and location of the information
- Validates content including text, photos, and videos
- Analyzes patterns, behavior, and history of user
- Integrates historical and environmental trends and alerts when aberrations occur

State of Technology: Technology to automatically collect, integrate and analyze data is still emerging, and so is the ability to validate that information. Currently, the state of the art for data validation relies mostly on contributions from large groups of people, called crowdsourcing.

Crowdsourcing is increasingly used by responders to gain situational awareness and validate information. For example, one mobile application uses crowdsourcing as a way to identify and confirm road status, hazards, police activity and other pieces of data to help drivers gain better situational awareness. This type of crowdsourcing is done in real time: drivers can easily plot points of interest, and other drivers nearby are asked to confirm the information. Once the data points have been confirmed multiple times, they are plotted on a map. If the data points are disputed multiple times, they are removed from the map. This creates a dynamic map of crowdsourced information that maintains itself with other users keeping it up to date.

DARPA has also incorporated crowdsourcing into a process that more effectively evaluates commercial off-the-shelf (COTS) software. This process, called the Crowd Sourced Formal Verification (CSFV) program, uses large numbers of non-experts to perform formal verification faster and more cost-effectively than the traditional approach of a few specialized engineers.[50] To accomplish this, DARPA has developed a simulation game that creates a fun and interactive environment to help complete formal verification proofs.

Other technologies exist that validate whether a post or photo has been edited or published elsewhere using a photo's exif data. This data is embedded within the image file itself and contains location information. Similar to how online image gallery programs recognize this data and can display the date and location of a photo, other tools can use this to detect false or uncertain information that is published following an event.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

Potential Challenges:

- Given the nature of crowdsourcing, it is difficult to validate certain data in real time.
- There may be issues related to gaining access to information necessary for verification.

[50] "Crowd Sourced Formal Verification," DARPA: Information Innovation Office, last updated: n.d., http://www.darpa.mil/Our_Work/I2O/Programs/Crowd_Sourced_Formal_Verification_(CSFV).aspx.

Situational Awareness Path Forward:

Subject matter experts identified the following technology programs as necessary to meet some or all of the responder goals listed in the situational awareness RTOs above.

- Continue enhancement of sensors and other technologies to improve signal strength around and through barriers
- Transition existing state-of-the-art technologies for outdoor responder geolocation
- Transition existing technologies and improve signal transmission in maritime environments
- Obtain necessary consensus to develop infrastructure and construction standards for newly constructed buildings
- Integrate responder geolocation technologies with systems for automated 3-D rendering of interior infrastructure from digital blueprints
- Continue development of detection and identification devices
- Continue development of sensor technologies, including miniaturization (to integrate with small UAS and UGVs) and modularization
- Develop standard public safety UAS platform (total weight under 55 pounds; payload weight under 6 pounds; hand-launched; low power supply; simple data transmission; standardized payload interface; under 400-foot altitude) and a low-cost standard public safety robot (standard payload interface)
- Encourage adoption of legislation that authorizes public safety use of UAS platforms
- Enhance and integrate modeling outputs to display multiple threats on a common operating platform
- Transition existing state-of-the-art technologies used for military application to emergency response use
- Identify information needs and requirements, resources and data streams for data integration
- Identify data streams that need to be validated using training set of human and historical data; develop algorithms to assess data sources for validation signatures

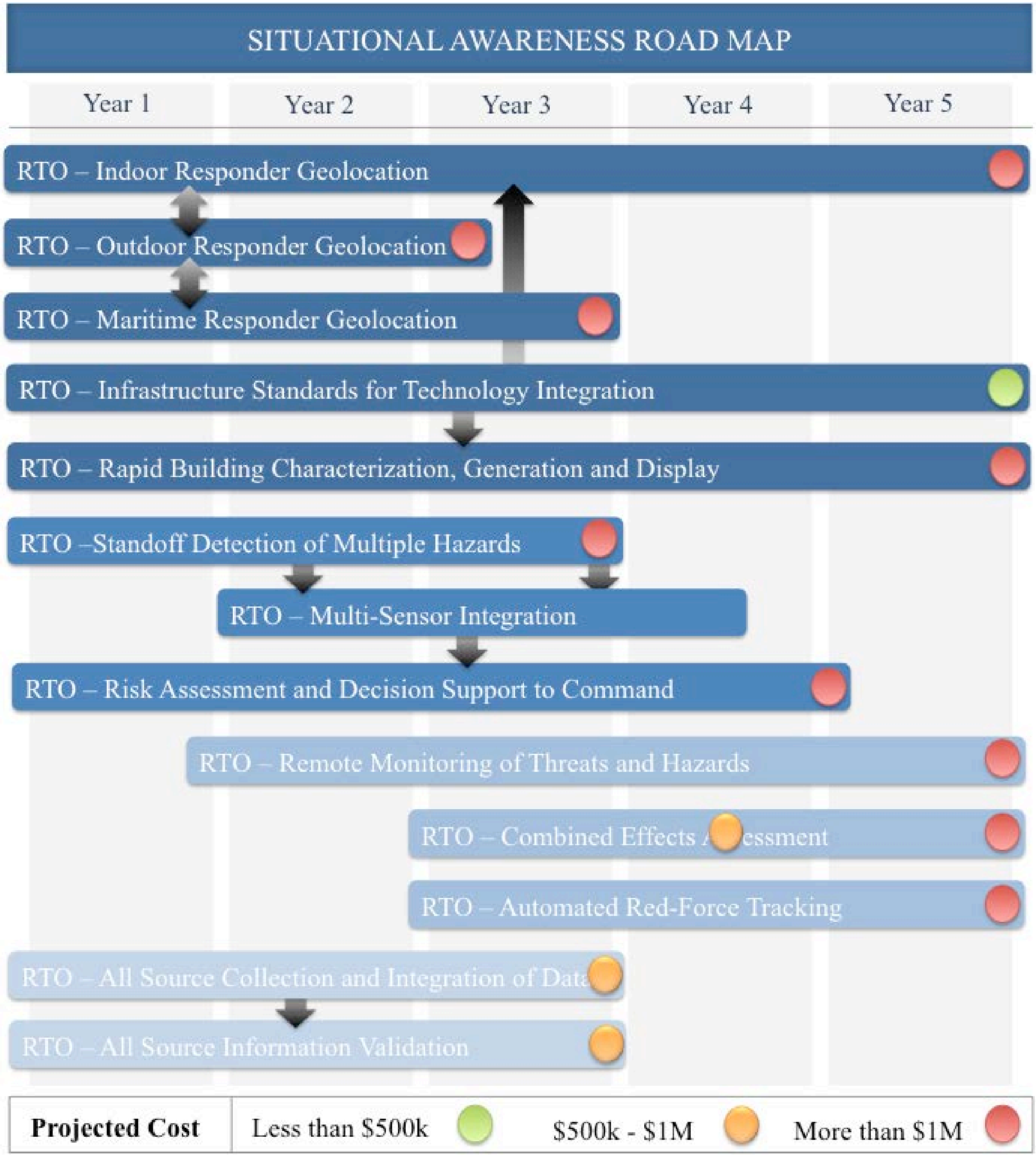

Figure 10. Situational Awareness Technology Road Map

Communications is defined as the capability to seamlessly and dynamically connect multiple persons or entities and convey meaningful and actionable information to all relevant parties.

There are two capability statements in the communications domain:

The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)

The ability to communicate with responders in any environmental condition is crucial because communications enable safe and effective catastrophic incident response. Coordinating the efforts of emergency managers, civic leaders, responders and the public depends on timely, reliable and effective modes of communication. During a catastrophic incident, communications will involve an increased number of responders, jurisdictions and systems across a vast geographic area. Deficiencies in communications capacity, interoperability or infrastructure can strain or overwhelm steady-state capabilities; all of these deficiencies are exacerbated during large-scale incidents. Responders' ability to communicate with each other has a significant impact on operational efficiency and safety. Message transmission or clarity can be substantially reduced when operating in certain environments, particularly inside buildings, tunnels, underground spaces or over long distances. Significant research has been done to help improve communication systems that operate effectively in all environments; however, most response agencies still lack this capability.

Subject matter experts identified three RTOs that correspond with this capability:

- Voice and Data Communications Through All Physical and Electronic Environments
- Disaster Resistant Communications Systems
- Graceful Degradation of Communications Signals

Communications systems that are hands-free and ergonomically optimized and can be integrated into PPE

Most response agencies rely on land mobile radio systems that require a push button to transmit messages and use an attached speaker to broadcast received communications. While these systems may function effectively most of the time, it may be difficult to use them during tactical activities. Some radio systems offer a hands-free option, but responders continue to report that communications systems hinder their ability to perform tasks. In addition, radio systems add weight to the burden already carried by many responders. Integrating communications systems with PPE garments and equipment has the potential to improve the efficiency and effectiveness of response operations, improve communications clarity, and reduce the number of devices responders need to carry.

Subject matter experts identified one RTO that corresponds with this capability:

- Multi-sensory Communications Systems Integrated with PPE

Voice and Data Communications Through All Physical and Electronic Environments

Relevance: Some environments are conducive to sending and receiving communications, but others pose significant challenges. For example, communications can be difficult inside buildings, tunnels or underground spaces. Communications may also be degraded if equipment and infrastructure have been damaged by the incident. Regardless of the operating environment, emergency responders must be able to seamlessly send or receive orders and information, provide tactical updates, request help and receive warnings about hazardous or changing conditions. Therefore, the need to ensure verbal and digital communication through all physical and electronic environments is essential.

An additional component of this RTO is the transmission of sensor and other field-based data to incident command. An effective response requires the availability of pertinent information for decision-making. This information must be accurate, actionable and received as quickly as possible in an evolving response environment. Advances in technology will produce additional data streams, all containing information that may be necessary for incident command or on-scene responders.

Current Capability: The ability to transmit verbal and digital communications through all physical and electronic environments varies widely among response agencies and jurisdictions. Most jurisdictions own the hardware and equipment to communicate via push-to-talk radios and maintain limited network connectivity within their system. Agencies with larger budgets are able to deploy integrated repeater networks to transmit and amplify signals in areas where there otherwise would be a dead zone or degraded communications. These repeaters amplify signals so that it can be retransmitted over hills or past barriers. New York City has invested in a private long-term evolution (LTE) network to provide coverage for nearly the entire city. However, the ability to deploy a series of repeaters and utilize a private network is not the typical standard in all U.S. jurisdictions. In fact, most jurisdictions simply do not possess the capability to consistently communicate in all environmental conditions.

Despite advances in this field, new technologies are not often developed or tailored for the unique needs of the field of emergency response. Many state-of-the-art technologies are available to the general public (for example, smartphones that provide network connectivity and immediate access to data). However, these technologies were not developed to address the unique conditions of emergency response, so they cannot be effectively utilized in unpredictable and varying response conditions.

Responder Goals:

- Communicate through all environments, including inside buildings, underground and through physical barriers

- Rapidly-deployable (within 15 minutes)
- Portable components
- Powered using multiple sources including those on the incident scene
- Utilizes the existing infrastructure within buildings to enhance or amplify signals or clarity of communications
- Uses different bands across multiple systems without having several pieces of equipment
- Encrypted and secure
- Separate frequencies for emergencies and mayday-type alerts (for example, PASS)
- Effective communication in remote areas
- Provides enhanced quality and clarity of voice communication in all verbal transmissions

State of Technology: Many advances in the communications field have applicability to the operational needs of the response community. Technology is continuously being improved to include stronger signals capable of transmitting through challenging operational environments, such as through barriers and underground. The state of the art for verbal and digital communications includes various types of technology, including cellular and satellite communications, repeaters, mesh networks and cellular on wheels (COWs). All of these technologies have benefits and limitations with regard to responders being able to communicate in catastrophic conditions.

Radio frequencies (for example, cellular and satellite communications) – Communications devices such as a responder hand-held radio, walkie-talkie, cellphone, or satellite phone use RFs to connect with either terrestrial towers or a satellite in orbit to support voice, SMS and low-bandwidth Internet access. These devices operate using ultra-high-frequency (UHF) radio waves that propagate by line of sight. These radio waves can be easily degraded or blocked by hills, buildings, multipath radio wave interference or other barriers on an incident scene. Although satellite devices require line of sight, they are typically used in remote areas where cellular towers are not available, but there is access to open sky without obstruction. When barriers exist, a signal can be enhanced with the use of signal repeaters. However, there is a trade-off between transmission power and the available data rate. To maintain a given signal strength, power needs to be increased as distance between the device and the transmitter increases.

Mobile cell sites – Mobile cell sites such as COWs, cell on light trucks (COLTs) and cell in a box (CIAB) can be used in areas where cellular network coverage needs to be expanded or established. These technologies are similar to fixed cellular towers but are temporary installations. They are available in different sizes that can handle a range of signal loads and are deployable on varying platforms, such as a box or a truck. The range of a cell tower depends on a number of factors, including the height and direction of antennae, frequency of signal, power strength, ambient weather and absorption of environment (for example, building, vegetation).

Signal repeaters (also known as breadcrumbs) – Wireless communication devices that utilize radio waves can be boosted using signal amplifiers or perpetuated using various types of antennas. Repeaters are used to continue a signal in areas where it would otherwise be blocked or degraded (for example, inside a building or around a barrier). The repeaters work by collecting a signal and then retransmitting it in a much smaller scale to a cellular tower. Repeater use is increasing rapidly, and so are advances in the technology of size, weight and signal strength. For example, DHS is investing in a project to develop a very small (one-inch square, half-inch thick) repeater that is both waterproof and heat-resistant up to 500 degrees. This type of signal repeater was designed specifically to develop a network in signal-denied environments for the emergency response community.

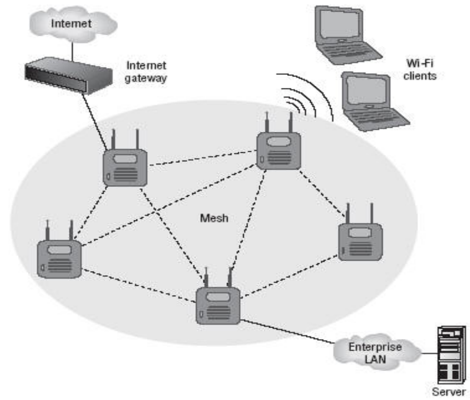

Figure 11. Mesh Network Diagram

Mesh networks – Similar to repeaters that propagate signal, devices such as laptops, cellphones and other wireless devices can link as radio nodes. This is called a mesh network. This means that only one node needs to be wired or connected to a network connection and other wireless devices can link to it (instead of a cellular tower) and act as routers to send data using the built-in Wi-Fi transmitters. Each device, or "mesh node," uses routing protocols to determine whether to keep the data it receives or pass it along to the next device until a destination is reached. Therefore, each device only needs to transmit the data as far as the next node in the network instead of to a cell tower or satellite. If one node drops out of the network, the data can quickly find another. There are two main advantages for responders to use mesh networks. First, they can leverage radio physics to pass information through signal-denied environments and across long distances. Second, they can use sophisticated triangulation and time-of-flight algorithms to determine the location of nodes and users in the network, such as responders on an incident scene. The limitations of mesh networks include the sophistication of the network setup, maintenance and the availability of nodes in a given area.

Figure 12. Cell on Wheels

In addition to these technologies, an effort is underway to revolutionize multiple aspects of emergency responder communications. The First Responder Authority Network (FirstNet) is an independent authority within the National Telecommunications and Information Administration that is tasked to "provide emergency responders with the first nationwide, high-speed, broadband network dedicated to public safety."[51]

FirstNet is focused on enhancing and optimizing operational capability through the development of a new Band Class 14 network. To develop this network, Congress allocated 20 MHz of radio spectrum to FirstNet, and responders will have priority or preemptive access to the system during response operations. Each state will develop an individual radio access network that connects to the FirstNet core network.

FirstNet will employ LTE technology that incorporates a radio access network (RAN). RAN is the component of LTE that includes cell towers as well as mobile hotspots in vehicles that can connect to the core network over satellite or other types of wireless infrastructure.[52] This technology should improve communication coverage for emergency responders, including coverage in challenging operating environments.

Improving the ability to transmit information in challenging environmental conditions is a shared goal among many disciplines. The U.S. military is funding multiple efforts that may benefit the response community. A small number of the most pertinent efforts are described here. DARPA currently has a funded program called the A-to-I Look-Through program to help advance this complex issue.[53] The goal of this program is to improve the operational bandwidth, linearity, and efficiency of electronic systems when the desired outcome is to receive and transmit information using electromagnetic (radio) waves, especially under extreme size, weight, power and environmental conditions. This program will rely upon developing new electronic processing subsystems methods and architectures based on new understandings of mathematical principles and embedded signal processing.

DARPA often initiates challenges to motivate teams of researchers to make progress in certain areas. It has initiated the Spectrum Challenge to help develop innovative approaches to adaptive, software-based radio communications in multi-user environments. The Spectrum Challenge was issued to address the fact that "first responder radios need to be able to communicate reliably in such congested and contested environments and to share radio spectrum without direct coordination or spectrum preplanning."[54] The ultimate goal is to develop protocols for radio software that will indicate the best communication channels when there are multiple interfering signals.

[51] "About FirstNet," First Responder Network Authority, last updated: n.d., http://www.firstnet.gov.

[52] Ibid.

[53] "Analog to Information Look Through," DARPA: Microsystems Technology Office, last updated: n.d, http://www.darpa.mil/Our_Work/MTO/Programs/Analog-to-Information_(A-TO-I)_Look_Through.aspx.

[54] "Spectrum Challenge," DARPA: Information Innovation Office, last updated: n.d., http://www.darpa.mil/Our_Work/I2O/Programs/Spectrum_Challenge.aspx.

Potential Challenges:

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

- FirstNet is still in the early development stage, and the time frame until implementation has not been determined. Different states are exploring different approaches to create the required radio access networks.
- Each state faces political, governance and local control issues for management of their radio access network.
- Manufacturers will have to develop devices that have access to the new frequency band.
- FirstNet will initially focus on data transmission and interoperability. Response agencies will continue to use land mobile radio systems for voice communications. Voice over LTE (VoLTE) will likely replace land mobile radio systems at some point, but this capability will require longer-term development.
- Responders anticipate significant challenges with building the backhaul infrastructure large enough to support public safety requirements an efficient allocation of the spectrum.

Disaster Resistant Communications Systems

Relevance: Effective response requires the capability to provide reliable, coordinated communications—including secure and nonsecure data, video and voice—among and across levels of the government and response community. However, catastrophic incidents have the ability to significantly damage or completely destroy the communications infrastructure and systems used by emergency responders. For example, incidents such as a nuclear detonation produce an electromagnetic pulse (EMP). An EMP can cause serious disruption and widespread damage to electronic devices and networks, including communications systems and technology equipment.

A nuclear detonation or use of an EMP device is a low-likelihood incident, but even incidents that involve more routine threats or common operating environments can have devastating effects on communications systems. Extreme heat or cold, high winds or water can also critically damage equipment and networks.

Current Capability: Public safety radio systems are ruggedized to provide protection against commonly encountered hazards. Radios used by the fire service generally have a higher degree of thermal protection, while radios used in marine environments are waterproof or water resistant. However, standard radio systems used regularly by emergency responders do not protect against EMP or extreme conditions. Further, communications systems include more than just the radios. The towers, repeaters and other equipment must also be disaster resistant. In many cases, this part of the communications infrastructure is most vulnerable. Following Hurricane Sandy, for example, 25 percent of cell towers were inoperable within 12 hours of the event. One solution is for radios to be stored in boxes hardened to shield the effects of an EMP. However, it is not operationally feasible to place all daily-use radios in boxes when not being actively used. Purchasing a separate set of radios that can be stored in preparation for an event is not financially possible for most jurisdictions. Many jurisdictions maintain a cadre of amateur radio (also called ham radio) operators. Amateur radio has dedicated bands, reserved by the Federal Communications Commission (FCC), that have frequently been used to support response operations.

Technologies including communication facilities, towers, radios, repeaters and other equipment are hardened against adverse effects from catastrophic incidents at varying levels. For example, some facilities have taken measures to include using flame-resistant materials, carefully selected locations that are elevated yet stable and resistance to high-powered winds. Other disaster resistant technologies include repeaters that are built with heat resistance for use in firefighting scenarios. Most cell towers also include backup batteries and sometimes generators to withstand power outages.

Responder Goals:

- Public safety grade communications infrastructure (including radios, towers, repeaters and other necessary equipment) against conditions such as electromagnetic pulse, heat, blast, water and extreme temperatures[55]
- Rapidly deployable (within 15 minutes)
- Intrinsically safe and ruggedized components
- Easily portable components

State of technology: DOD maintains a number of military standards regarding EMP preparedness. Many critical defense systems comply with nuclear survivability and hardening requirements, which protect against EMP threats. DTRA continues to conduct EMP assessments on the critical power infrastructure, specifically the power grid and telecommunications networks. However, there has been limited transition of military capability in this area to emergency response applications. Research has also been done to develop electrical cables that are insulated and shielded from electromagnetic interference to protect electronic devices. For devices that are not hardened, storage options offer protection to critical items. However, because it is not possible to predict the size, strength and proximity of an EMP, it is unclear what level of protection exists.

DARPA has programs dedicated to enhancing reliable, secure and resilient communications. One such program is the Safer Warfighter Communications (SAFER)

[55] "Public safety grade" refers to the hardening of network components to ensure that the communications systems of emergency response agencies will remain operational during and immediately following a major natural or manmade disaster on a local, regional, and nationwide basis. "Defining Public Safety Grade Systems and Facilities", National Public Safety Telecommunications Council. May, 2014.

program.[56] The goal of this program is to develop technology that enables safe and resilient communication over the Internet. The technology will also enhance applications such as instant messaging, email, social networking, streaming video, voice over Internet protocol (VoIP), video conferencing and other media that promote effective communication.

Additional research is ongoing to develop survivable communications networks that can provide connectivity in the absence of power and network connectivity. One system relies on creating open-source tools that will allow citizens to use their existing infrastructure as part of a rapidly deployed network to meet basic communications needs. The system includes small modules powered by small solar panels or previously powered large electronic devices (such as a hybrid motor vehicle) that can be acquired by citizens or civic groups to provide ad hoc communications capability when needed.

Potential Challenges:

- Responders are concerned about the costs of an EMP-hardened radio system, anticipating high costs for a low-probability event. Purchasing these radios may not be feasible in the financially constrained environment that currently exists for many jurisdictions.
- Public safety communications may rely on commercial cellular or wireless networks and equipment, which are also not hardened against EMP effects. Development of a civilian standard will be sufficient only if commercial carriers also harden their systems.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Graceful Degradation of Communications Signals

Relevance: While responders rely on communications for incident response, they are aware that there are times when the communication signal will become so weak, or completely lost, that transmission is no longer possible. However, it is not possible to predict when the communication signal will be lost, and responders are often in the position of not realizing they are no longer transmitting until they do not receive a response. This “no-notice” loss of signal can cause a lack of transmission in critical incident information and can place the responder’s life in danger.

There is a need for responders to have more notice on the status and degradation speed of their communication signal and a more graceful degradation of the signals. This would allow responders to adapt quickly to the pending lack of communications and transmit critical pieces of information before losing connectivity.

[56] “Safer Warfighter Communications,” DARPA: Information Innovation Office, last updated: n.d., http://www.darpa.mil/Our_Work/I2O/Programs/SAFER_Warfighter_Communications_(SAFER).aspx.

Current Capability: Responders described the current degradation as "a point where communication just falls off," meaning that there is currently no capability, with limited exception of a screen display similar to the reception bars on a typical cellphone, to alert the responder to a diminishing signal. A screen display is not ideal, as emergency responders cannot constantly look at a visual indicator while simultaneously transmitting information.

The strength signal itself does not allow for reduced communications, it simply goes from fully functioning to not transmitting anything. Responders are not afforded an opportunity to transmit shorter or more concise verbal message as the signal degrades. There is no gradient or step-wise loss of functionality.

Responder Goals:

- Alerts for the degradation level with corresponding effectiveness level (an indication of how well messages are being transmitted)
- Audio indicator when the signal is lost completely
- Directional interface that guides responders toward stronger signal strength
- Ability to poll on-scene radios for signal status to determine if the user is losing reception
- Enhanced capability that functions with current technologies

State of Technology: Some radios and cellphones have preset text messages that can be used in lieu of voice transmission when signals become very weak. These devices typically switch to a text system and can send out a small amount of texts that are preprogrammed with short commands, alerts or maydays. In addition, some radios can automatically switch bands and search for the strongest repeater or tower every 15 seconds, depending on the strength of the signal, helping to maintain signal strength.

DARPA established the Adaptive RF Technology (ART) program to advance the hardware used in hand-held communication radios.[57] DARPA is developing a fully adaptive and reconfigurable framework that is agnostic to specified waveforms and standards. DARPA believes that this will enable the individual warfighter, using a small-scale unmanned platform to analyze and characterize the signal environments. This will allow the warfighter to determine the signal strength and changing conditions.

[57] "Adaptive RF Technologies," DARPA: Microsystems Technology Office, last updated: n.d., http://www.darpa.mil/Our_Work/MTO/Programs/Adaptive_RF_Technologies_(ART).aspx.

Potential Challenges:

- Responders are concerned that adding features or improvements may increase the size and weight of existing systems. The goal is to increase the performance of PPE, including communication devices, without adding size or weight.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Multi-sensory Communications Systems Integrated with PPE

Relevance: The standard communications platform employed by the vast majority of response agencies is a hand-held push-to-talk radio used for verbal communications. These types of radios clip onto the exterior uniform or protective garments of responders. Recent developments in multimodal interfaces and displays are expanding the possibility of more sophisticated communications mechanisms that rely on multiple senses, such as sight, hearing and touch. As part of this RTO, responders would like to receive and access information visually. They would like to see a display of key operational and physiological data and information. This could include life-safety data, such as the amount of oxygen remaining in a self-contained breathing apparatus (SCBA) tank or blueprints or schematics for the building in which they are working. They would also like to be able to identify the location of other responders, resources and hazards/threats, both within and beyond their field of view. Responders could also receive just-in-time training or instruction via visual display.

Current Capability: As mentioned, most response agencies rely on land mobile radio systems that require a push button to transmit messages and use an attached speaker to broadcast received communications. Responders reported that it is often difficult to use these radios during tactical activities. For example, a firefighter operating in full protective gear, including breathing apparatus and heavy gloves, may find it difficult to transmit a message while dragging a hose line or carrying tools or to receive a communication due to sound dampening from the SCBA mask and loud ambient noise. Radio devices currently exist that can be operated using hands-free features, often through the use of bone-conduction microphones that transmit sound through the bones of the skull into the inner ear. However, performance is often still degraded by the noise of the incident scene. Some headgear worn by firefighters or SWAT teams integrates communications equipment, but other factors degrade the clarity of these communications.

Responder Goals:

- Equipment integrates into PPE or other existing equipment with minimal or no net weight gain for the responder

- Hands-free activation
- Multiple configurations based on the needs of each discipline
- Minimal SWP
- Noise-filtering mechanism that accounts for significant ambient noise
- Multi-sensory display of information, including key operational and physiological data and information
- Ruggedized, waterproof, thermal resistant, intrinsically safe, simple, and not able to be turned off by the user
- Integrates into PPE for all disciplines

State of Technology: The technology to support a heads-up display (HUD) for responders to send and receive information is widely available. HUDs are also used by the general public for a variety of purposes, such as displaying speed and distance on a car on the windshield while the car is in motion. They are also used extensively in aircraft to display needed pieces of information.

Figure 13. Information Available in HUD

While HUDs are not routinely used in emergency response, the technology could be tailored to the unique needs of each response discipline. DHS S&T, for example, has funded the development of a thermal HUD for use by firefighters. This HUD helps to address the need for firefighters to be able to monitor their internal and external temperatures, which is difficult when they don level-A hazmat suits. When dangerous thermal levels are reached, this particular HUD provides the firefighter with an alert. [58]

There are several other opportunities for advancement in this area, including the transition of HUD systems developed by DOD for the warfighter, as well as commercial development of products such as Google Glass. Users can see information such as maps, temperature and logistical information in their line of sight while wearing the glasses. Applications have already been developed specifically for the fire and law enforcement disciplines using the Google Glass platform. Researchers are exploring the integration of this technology into the face shield of responders' helmets and headgear.

The U.S. military continually invests in programs that help to advance the way in which warfighters are able to visualize their operating environments. As part of this effort, DARPA established the Urban Leader Tactical Response, Awareness and Visualization

[58] "S&T Project Roundup What We Worked on in September 2013," FirstResponder.gov, last updated: n.d., http://www.firstresponder.gov/SitePages/ResponderNews/Article.aspx?s=Articles&itemID=192.

(ULTRA-Vis) program.[59] Under this program, a prototype for an augmented reality system was developed. Essentially, soldiers are able to use this prototype to overlay full-color graphical iconography onto the local scene observed by the soldier. This is accomplished by integrating a lightweight, low-power holographic see-through display with a vision-enabled position and orientation tracking system on the solider. In doing so, warfighters are able to increase their understanding of the areas and visualization of threats.

Advances are also expected in the use of bone-conduction technology. Commercial providers expect to release headsets that incorporate a bone-conduction microphone, allowing two-way communication. This would allow responders to send and receive communications without a device blocking the ear and preventing the reception of other ambient sounds.

Potential Challenges:

- Responders are concerned about the vulnerability and security of communications when using wireless connectivity.
- Google Glass is not ruggedized for the requirements of the incident scene.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Communications Path Forward:

Subject matter experts identified the following technology programs as necessary to meet some or all of the responder goals listed in the communications RTOs above.

- Develop public safety grade VoLTE systems for public safety use
- Develop a civilian EMP survivability standard to which public safety communications systems can be built
- Collect requirements for and integrate a signal indicator into existing radio equipment
- Transition adaptive RF technology being developed for military applications to emergency response applications

[59] "Urban Leader Tactical Response, Awareness and Visualization," DARPA: Information Innovation Office, last updated: n.d., http://www.darpa.mil/Our_Work/I2O/Programs/Urban_Leader_Tactical_Response,_Awareness,___Visualization_(ULTRA-VIS).aspx.

Figure 14. Communications Technology Road Map

Command, control and coordination is defined as the ability to identify incident priorities, allocate scarce resources and exchange relevant information to make effective decisions in a stressful environment.

There are three capability statements in this domain:

The ability to remotely monitor the tactical actions and progress of all responders involved in the incident in real time

Incident commanders are responsible for setting objectives and assigning tasks to efficiently respond to emergencies. The number of tasks and personnel scale with the size of an incident; therefore, catastrophic events may be difficult to manage without the aid of technology. Incident commanders need the ability to know the progress of tasks and to have up-to-date situational awareness to manage within a complex workflow environment. Incident commanders can effectively re-task personnel or allocate additional resources if they can monitor responder actions and tasks. Ideally, incident commanders would be able to achieve this level of command and control with little burden on the responders in the field. Therefore, tactical actions of responders and other information should be remotely collected without impeding or degrading the performance of existing communications. Responder actions also need to be monitored in real time and integrated into a holistic workflow management system that tracks the level of completeness for each assigned task.

Subject matter experts identified two RTOs that correspond with this capability:

- Real-time Monitoring of Responder Actions
- Intelligent Integrated Workflow System

The ability to identify trends, patterns and important content from large volumes of information from multiple sources (including nontraditional sources) to support incident decision-making

The digital age has increased the availability of and access to data that could help inform emergency response operations. During catastrophic incidents, responders can be overwhelmed by the amount of incoming data from both traditional and nontraditional sources. Successful utilization of this data depends on the ability to collect, aggregate, validate, analyze and disseminate incident-specific data and information. Responders require a system capable of ingesting large amounts of data, identifying emerging trends and patterns and filtering for key information. Such a system would not replace human analysis, but would act as a decision support tool to assist both analysts and decision-makers.

Subject matter experts identified three RTOs that correspond with this capability:

- All-source Information Analysis System
- Real-time Predictive Analysis and Modeling
- Incident-scene Information Recognition and Pattern Analysis

The ability to identify, assess and validate emergency-response-related software applications

As technology advances, so do the support tools available to emergency responders. Although some of these support tools are hardware, many are in the form of computer software, including applications that help the responder prepare for, respond to and recover from catastrophic incidents. Software designed to support emergency responders provides timely, critical and accurate information regarding a range of threats and response actions. Responders need to be able to trust that these applications provide valid information, function when necessary, operate on all relevant platforms and protect sensitive information.

Subject matter experts identified three RTOs that correspond with this capability:

- Core Requirements Standard for Response-related Software Applications
- Software Development Kit for Integration of Response-related Software Applications
- Platform for User Evaluation of Response-related Applications

Real-time Monitoring of Responder Actions

Relevance: Incident command is responsible not only for developing strategic and tactical plans, but also for ensuring that those plans are implemented and the associated tasks are carried out. Incident commanders may be overwhelmed by the complexity of catastrophic incidents and may not be able to effectively monitor the actions and progress of the response. Incident command would like to be able to track the progress of teams and individual responders in completing the missions to which they have been assigned. This would allow decision-makers to identify when a mission needs more resources and when responders can be directed to other tasks.

Current Capability: At this time, there is no commonly used tool for monitoring responder actions on scene. Existing capabilities rely largely on voice communication between responders and the incident commander, particularly through the transmission of information requests and progress reports. While this practice allows the incident commander to receive on-demand updates, the reliance on voice communication can detract from overall mission success and responder safety.

This is due to two main factors:

- Potential unreliability of communications systems in certain situations (such as when operating in wide geographic areas or inside buildings)
- Continuous changes in the incident scene (potentially limiting the accuracy of transmitted messages)

The capability to remotely monitor actions and progress could resolve these concerns by providing real-time information and increased reliability that improve decision-making.

Commonly used computer-aided dispatch (CAD) systems are able to visually monitor the progress and location of emergency response vehicles. These systems use a transponder affixed to the apparatus to provide real-time updates of the location of vehicles. CAD systems also work with mobile data computers (MDCs) that are installed in many response vehicles. Responders are able to update their status via the MDC, which provides updates in the CAD system.

Responder Goals:

- Automated system to collect tactical inputs from individual responders in real time
- Includes preset command features to translate verbalized tactical actions into status updates (for example, need more resources, task complete) to limit the burden of effort on the responder to use push-to-talk radios during an incident
- Integrates the status of all responders into a common operating picture on a dashboard for command visibility
- Displays tasks in an automated sliding scale that adjusts based on task completion
- Includes customizable settings, including task lists and timers for each task
- Includes an override feature for an administrative user to update the status when a responder cannot make updates
- Relays information in real time to incident command, caches data when connectivity is offline and automatically forwards data when the connection is restored
- Does not interfere with other radio communications
- Provides appropriate SWP to provide functionality but does not place an extra burden on the responder
- Interoperable and easily integrated with other monitoring or communications equipment
- Scalable to quickly add responders during an incident

State of Technology: Development efforts are underway to extend the visual display of vehicles that exists with modern CAD systems to personnel. Existing systems are able to notify personnel that they have been called into service via an application on their mobile device. Responders confirm receipt, and the system tracks their progress toward the incident scene via cellular and wireless networks. Responders are able to send and receive communications, which can be used to relay and update tasking orders. Current products are unable to track the completion or activities at the task level. However, development efforts underway include products that can incorporate pre-plan information, which could potentially be used to track tactical progress, and can be integrated with other electronic situational awareness systems.

Other commercially available software systems help manage and track resources, including personnel, throughout incident response. As described above, tracking the progress of personnel working on assigned tasks requires check-ins from the field. These check-ins can be automatically categorized and updated on an incident manager's status boards, which include event logs, unit logs, operating procedure status tables and situation reports. These systems allow commanders to establish incident objectives (for example, organizational or division assignments, medical plans, communications strategies, safety messages).

Note: The state of technology for real-time tracking of responder location and display on a common operating platform can be found in the "Indoor Responder Geolocation" and "Outdoor Responder Geolocation" RTO discussions.

Potential Challenges:

- Current systems rely on connectivity at the incident scene, but this is far from guaranteed. Developers are currently working on offline options that will allow information to be cached and then forwarded when connectivity is restored, but that functionality is not yet available.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Intelligent Integrated Workflow System

Relevance: When on scene, responders are focused on tasks related to saving lives and mitigating threats. The role of an incident commander is, in part, to monitor task progress and the workflow until the objectives are met. The term *intelligent integrated workflow* refers to a system that automates portions of the monitoring and management to expedite the process. With insight into the workflow, incident commanders can anticipate resource demands or reassign assets to other tasks. Incident commanders must be able to visualize this information in real time on a common operating platform. This capability could reduce the amount of time an incident commander spends analyzing vast amounts of incident data and situational awareness reports to focus on managing the response.

Current Capability: Research and responder input uncovered no known intelligent workflow systems focused on the emergency response mission. Task progress is typically communicated using hand-held radios or MDCs from responders in the field to incident commanders and dispatch operators. Some CAD systems are able to analyze response data to produce helpful information and statistics, such as average response time until units are on scene, but responders currently have no capability to automate or provide decision support to workflows.

Responder Goals:

- Identifies and collects key tasks associated with incident response for integration into an electronic workflow system
- Incorporates data from previous incidents for machine learning and prediction
- Integrates with logistics situational awareness systems
- Automates task management where possible to reduce responder interaction where applicable
- Tracks responders' previous system inputs
- Automates user choices or proposed next steps based on task progress
- Generates alerts to inform or predict the next actions that should be taken
- Includes customizable graphic displays
- Customizable to allow administrator to input jurisdiction-specific standard operating procedures
- Includes a confidence or quality control feature to assist decision-makers

State of Technology: Intelligent workflow systems are used extensively in other fields, for both automated and manual processes to capture and digitize processes and standard operating procedures and provide an audit trail of activities. Many of these systems are able to monitor the submission, processing and real-time tracking of requests. They can designate and prioritize the status of tasks (for example, assigned, past due, completed), provide alerts when processes are delayed or interrupted and provide graphic displays of workflows with real-time visualization.

Some of the commercially available incident management systems can provide commanders with support for workflow management and automate parts of the process, but these tools need to be customized for use at the jurisdictional level. For example, technologies are being developed that can help automate workflows based on the progress of tasks in the field and a specific jurisdiction's pre-planned standard operating procedures. The systems suggest courses of action that are aligned with local operating procedures, National Incident Management System (NIMS) and Incident Command System (ICS) processes and that incorporate FEMA's resource management life-cycle information. The workflow automation converts incoming messages from the field into action-based message types such as status update, request for action and resource request. These messages can then be tracked and managed within the system. Incident command can then make official requests and follow up to ensure tasks are being completed.

Potential Challenges:

- The ability to automate the content of notifications beyond binning into message categories is limited.
- Verifying that tasks are complete is still reliant on responder reporting. Some systems include the ability to upload images, but this functionality is not yet automated for responder applications.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

All-source Information Analysis System

Relevance: A catastrophic incident generates a lot of information that needs to be collected, analyzed and stored for decision support. This information is necessary for critical lifesaving and operational decisions, but it is transmitted in a multitude of different formats. Some require advanced knowledge or training to interpret. Response agencies will be held accountable for using this information, and it must be available in a comprehensible and concise format. Responders would like a common platform that can filter, aggregate and correlate data into an output that is relevant and usable for the decision-maker. Outputs and visualizations should be in a format that can translate the analysis of the data into actionable information.

Current Capability: Many response agencies use electronic incident management systems to support decision-making during response operations. The most commonly used systems utilize a dashboard system, which allows incident command to view different functions in a series of layers or tabs on the display. When this information is aggregated, incident commanders have a better common operating picture. However, they still lack the analytical and decision support modeling function requested by responders.

State and major urban area fusion centers provide additional capability for information integration and analysis. Fusion centers are collaborative efforts between multiple agencies to share information among federal, state, local and tribal organizations. The fusion centers are primarily focused on the analysis of threat-related information to prevent incidents but can be used to improve situational awareness and decision-making during response operations.

Responder Goals:

- Integrates a baseline set of business rules for every emergency management agency with the ability to customize for specific events or types of incidents
- Automatically filters, aggregates and correlates data
- Ability to graphically display and visualize data
- Includes predictive analysis to optimize courses of action (for example, rerouting assets, choosing to shelter versus evacuate)

- Aggregates data at a speed to inform real-time decision-making
- Integrates natural language processing to aggregate large amounts of text data to ease decision-making
- Customizable business rules for discipline-specific needs
- Filters information to ensure relevant, actionable information
- Includes a customizable graphical user interface (GUI)
- Includes next-step suggestions or considerations based on analytic outputs

State of Technology: Integrated tools that provide all-source information management, analysis and decision support either are in development or require customization, testing and evaluation before being used by emergency responders. Existing COTS systems do not meet the responder requirements, which include real-time aggregation, analysis and optimization of decision-making with predictive analyses. Most existing systems can automate functions for ingesting and mashing data but are very limited with regard to analysis and decision support. In addition, many of these functions are not rapid and require special programming support from developers.

The volume of incoming data increases during times of crisis, and systems need to be designed to rapidly detect changes in the data patterns and trending topics as events unfold. These technologies should provide meaningful analysis of streaming social media and other data to the end user in real time. To this end, DARPA has been developing a tool called Insight to consume and process information and provide mission-relevant, timely insights to incident commanders.[60] The goal of this program is to use technology and automation to enhance an individual's ability to support real-time operations with actionable data. Insight is designed to receive, index and store incoming data from multiple sources and analyze and correlate that information. Furthermore, DARPA is working to incorporate behavioral learning and prediction algorithms to help analysts discover and identify potential threats and corresponding activities.

Natural language processing (NLP) can assist analysts in understanding the content of social media data for the purposes of sentiment analysis, topic modeling, trend analysis and social network analysis. NLP uses machine learning algorithms to enable software to derive meaning from a user's input. The ability to use NLP lends itself to many different system features such as custom alerts, changes

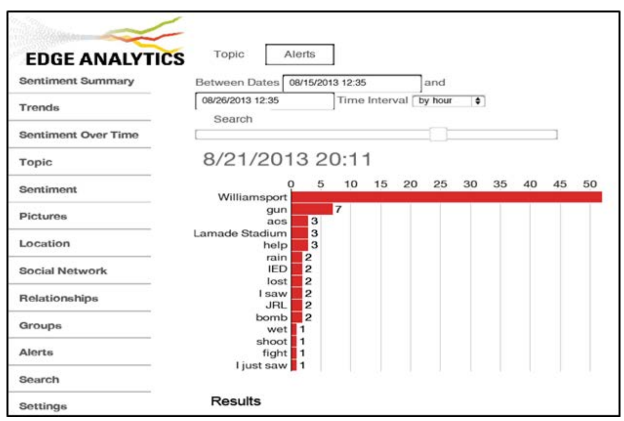

Figure 15. Edge Analytics Interface

[60] "INSIGHT," DARPA: Information Innovation Office, last updated: n.d., http://www.darpa.mil/Our_Work/I2O/Programs/Insight.aspx.

in data patterns, understanding local context, sentiment analysis and topic modeling.

Although real-time analytics technologies are still maturing, many of the features that emergency responders desire (such as sentiment analysis, filtering based on geolocation, social network representations, identifying influencers, custom alerting, trend and pattern analysis and topic modeling) already exist. An example of this is shown in figure 15 using a tool called Edge Analytics (EA). EA was initially developed by a DOD Federally Funded Research and Development Center (FFRDC) and has been piloted in various environments to conduct social media analytics. Figure 15 displays EA's real-time filtering and topic modeling capabilities. Advancements are still necessary in the areas of data fusion, natural language processing and real-time analysis to create a robust all-source analysis tool. These research areas are currently in development.

Potential Challenges:

- The appropriate entity to provide governance and maintenance support for an all-source information analysis system is undetermined.
- The accuracy of machine learning and NLP needs improvement.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Real-time Predictive Analysis and Modeling

Relevance: Response agencies conduct pre-planning efforts and exercises to improve their ability to respond to an incident before it happens. From these activities and past operations, they are able to predict certain factors in how an incident might unfold. However, there are many incident-specific variables that significantly impact incident action planning, including the population of the affected area, the existing and evolving hazards posed by the type of incident and the presence of other effects or hazards. There are ongoing and well-established efforts by the federal government to conduct predictive analysis for various types of threats including hurricane, flood and earthquake modeling. However, the emergency response community is lacking a baseline, customizable, all-hazards predictive analytic approach and integration strategy. Responders would like the ability to easily integrate incident-specific information with available models into decision-making processes in near real time.

Current Capability: There are many sophisticated models that can estimate effects related to natural and man-made incidents, including hurricanes, wildland fires, earthquakes, disease outbreaks, evacuations and population behaviors. Generally, each of these models is developed by different organizations or agencies working from disparate information sources. One example of modeling software used to estimate natural events is from the National Hurricane Center (NHC). This software creates hurricane track and intensity models and is used to inform emergency response efforts. NHC is an example of a modeling source that incorporates historical data and real-time information to develop alerts, warnings, forecasts and predictive analyses that help inform decision-making related to potential weather threats.

Some of these models can be accessed through an integrated suite called Standard Unified Modeling, Mapping, and Integration Toolkit (SUMMIT). The goal of SUMMIT is to create a collaborative environment that links the leading modeling and simulation tools and data to help emergency responders train for and respond to incidents.[61] SUMMIT has been used to support federal, state, regional and local exercises and operational planning efforts.

Another modeling resource for emergency responders is the DHS-led Interagency Modeling and Atmospheric Assessment Center (IMAAC). The IMAAC coordinates and disseminates federal atmospheric dispersion modeling and other hazard-prediction products.[62] These products provide information during actual or potential incidents involving hazmat releases.[63] The IMAAC provides emergency responders with predictions of hazards associated with atmospheric releases to aid in the decision-making process to protect the public and the environment.[64]

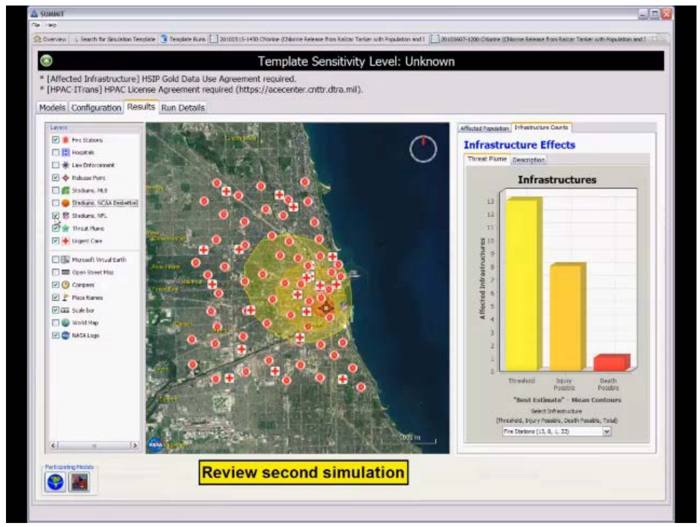

Figure 16. Standard Unified Modeling, Mapping, and Integration Toolkit

Responder Goals:

- Enhances model fidelity for threats such as chemical, biological, epidemiological, radiological, EMP, nuclear, explosives, fire and population dispersion.
- Incorporates high-performance analytics modeling of multiple data streams
- Conducts predictive analysis for specific incidents in near real time (for example, within one hour)

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[61] "SUMMIT," DHS, last updated: n.d., https://dhs-summit.us.

[62] "Interagency Modeling and Atmospheric Assessment Center," DHS, last updated: October 25, 2013, http://www.dhs.gov/imaac.

[63] Ibid.

[64] Ibid.

- Integrates outputs into decision support tools and existing electronic situational awareness tools
- Enhances social network analysis
- Improves the fidelity and validity of data
- Generates and runs customized stochastic models[65]

State of Technology: Operations research and the science of simulating scenarios to inform decisions have been around for decades. Modeling has been used for predictive analysis for large and small events and continues to evolve in many different industries, including the military, space exploration, weather forecasting, and homeland security. The Department of Energy national laboratories have done extensive modeling in various areas that have application to catastrophic disaster response including fallout, blast effects in an urban environment, mass sheltering and evacuation and EMP effects from a nuclear event. These models are not operational at the local responder level to help inform immediate response actions.

To this end, S&T, in conjunction with FEMA and in collaboration with Sandia National Laboratories, is developing a geo-agile platform called SUMMIT that enables responders to use and integrate models to improve response planning, training, and exercises.[66] The tool has already been used in various international, national and regional exercise scenarios. Eventually, the goal is to utilize this suite of models to inform decision-making during response operations for catastrophic incidents. The SUMMIT framework is described as platform-neutral, which allows users to access the models from a Web browser and mobile applications.

SUMMIT is deployed through FEMA's National Exercise and Simulation Center (NESC) to provide state-of-the-art modeling and simulation capabilities to support national, federal, state, local and tribal exercises. Once SUMMIT has undergone the Software Engineering Life Cycle (SELC), Security and Compliance transition process through DHS S&T, the emergency management community will be able to utilize the tool. During this transition period, research and development efforts will continue to advance SUMMIT capabilities in preparation for future deployments to the FEMA NESC.[67]

[65] Stochastic models include at least one random variable. Stochastic models are used to estimate the probability of different outcomes.

[66] "SUMMIT," DHS, last updated: n.d., https://dhs-summit.us.

[67] Jalal Mapar, Keith Holtermann, et al., "The Role of Integrated Modeling and Simulation in Disaster Preparedness and Emergency Preparedness and Response: The SUMMIT Platform", Department of Homeland Security, 2012.

Potential Challenges:

Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

- Responders would like model projections and updates in real time. Delays from real time can be caused by interruptions in the currency and quality of sensor data and other pertinent information, some of which comes from third parties.
- Enhancements of model projections require continuous and real-time updates of sensor data from the incident scene. Communication system failures following a catastrophic event may constrain the transmission of sensor data.

Incident-scene Information Recognition and Pattern Analysis

Relevance: Responders must quickly make informed decisions based on credible incident-scene information, reports from the field, and historical data. The sheer volume of information that needs to be considered and analyzed can present challenges, especially during a catastrophic event. This RTO is related to a response organization's ability to identify specific information being developed on the incident scene and conduct pattern analysis to validate and inform tactical decision-making. This type of analysis can improve situational awareness and help forecast an incident's evolution. The evolution of an incident dictates what, where, and when additional resources should be deployed.

Current Capability: Human initiative and analysis are the principal tools utilized for this capability. This type of information recognition and pattern analysis is done in some law enforcement agencies with the integration of sensor technologies, such as light detection and ranging (LIDAR), geotagging or ground sensors, to monitor specific locations. However, it is not widely used by the responder community. Joint fusion centers act as one resource to encourage data aggregation and information sharing among agencies. Responders in the field employ methods such as predictive policing and social network monitoring depending on the initiative of the agency.[68] Data synthesis and analysis systems currently exist, but they have not been specifically customized for and used by the response community.

Responder Goals:

- Collects incident-specific information to provide enhanced situational awareness
- Analyzes information to provide predictive clues as to what cascading effects of the incident may occur
- Rapidly analyzes aggregated incident-related data

[68] Predictive policing is a forecasting technique to identify likely targets for police intervention. These analytic techniques are typically statistical predictions and quantitative in nature.

- Fuses data streams across various information sources (including soft and hard sensors)[69]
- Collects and analyzes metadata of streaming information
- Integrates information protocols and agreements
- Calculates a level of confidence in data
- Includes multiple sources of validated information
- Displays trend data statistically and across the incident timeline

State of Technology: The development of a disaster management system that can detect trends and patterns has been a topic of interest in the technology community over the last decade. Technologies exist that can identify trends over space and time, monitor resources and displays results for a specific geographic area. However, none fully address responder requirements for an all-inclusive incident scene trend and pattern analysis tool.

DHS has invested in several infrastructure protection and disaster management projects that relate to this RTO with regard to collection, analysis and visualization.[70] Specifically, advancements are being made to develop tools that rapidly collect, process, present and understand massive amounts of data from multiple sources, including database information, message traffic, text documents, imagery, video, sensor, and instrumentation data from an incident scene. These analytical tools deal with large amounts of dynamic, streaming data and enable real-time understanding and decision-making. However, they still require a significant amount of developer knowledge and skills to operate. A combination of these technologies will enable the creation of new analytic techniques for a responder to develop situational awareness, whether they are in the field or at the command center.

Potential Challenges:

- The ability to validate information from the incident scene in real time can become an issue, particularly if responders will be using this information to inform response operations.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

[69] Soft sensors include data streams that are available to the public (for example, Twitter). Hard sensors include data streams that are not public information (for example, radiological and biological sensor data).

[70] "Infrastructure Protection and Disaster Management Projects," DHS, last updated: December 27, 2012, http://www.dhs.gov/infrastructure-protection-and-disaster-management-projects.

Core Requirements Standard for Response-related Software Applications

Relevance: Responders have multiple concerns about the response-related applications they currently use. For example, they are concerned that the applications may not properly protect their personal information, may not be available at critical times or may not provide technically accurate information. A core requirements standard would create an open standard where developers are able to build applications for the response community that meet a set of minimum requirements. These requirements might include levels of encryption, offline access and verified enrollment, among many others. Development of a core requirements standard would not require all software developers to adhere to the standard, but emergency responders would be aware of which applications did incorporate the standard and could make an informed choice of applications based on this information.

Current Capability: Emergency responders have access to hundreds of software applications, but there is not a core requirement standard that must be incorporated into response-related applications. Essentially, applications are developed by individual entities, and it is the responsibility of the responder to ensure the validity and functionality of actual applications. While responders are experts in their discipline, they may not be able to verify the level of security of these applications or whether they were developed based on the latest science, models and algorithms needed to produce the most accurate information.

Responder Goals:

- Core set of standards that response-related software applications should meet
- Reduces variation between devices
- Standards that address user validation, data standards and validation, functionality validation, operational suitability, ease of use, data security, compatibility and transferability, adaptability for discipline and jurisdictional needs, communication standards and scalability (catastrophic versus daily use)

State of Technology: Requirements standards for applications provide the documentation for developers that govern data outputs (in other words, all measurements must be provided using metric designations). They ensure that data are presented to the user in the format that is expected. The intended audience for an application requirements standard would be the application developer, but the standard would be developed in conjunction with the response community. Such standards are developed routinely and are not technically challenging.

There are several requirements standards pertinent to information exchange that are relevant to the development of an applications standard. The National Information Exchange Model (NIEM) provides a framework for Extensible Markup Language (XML)-based effective and efficient information sharing across all levels of government and private industry. There are multiple schemas within NIEM, especially the support schemas, which apply to application development.[71] In addition, the Unified CAD Functional Requirements document identifies a comprehensive set of functional specifications for CAD systems.[72]

The concept of recognizing components that meet standard requirements is used in other sectors. For example, the DHS SAFETY Act certification and the U.S. Environmental Protection Agency's (EPA) Energy Star designation provide recognition of compliance with standard requirements. Compliance with these standards provides incentives to manufacturers such as protection from liability and the availability of tax incentives for consumers. A similar designation could also be displayed on all response-related applications that follow the standard requirements.

Potential Challenges:

- None identified

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Software Development Kit for Integration of Response-related Software Applications

Relevance: A software development kit (SDK) is a set of software tools that allow for the development of applications for a specific platform or software package. A response-related SDK would be used by software developers tasked to develop applications for the response community. An SDK is necessary to ensure that response-related applications are available on common platforms, as responders do not want an application that is available on only one of the common platforms.

Current Capability: Research and responder input uncovered no known SDK or hosted set of services readily available for the adoption of responder-related applications.

Responder Goals:

- Identifies the necessary and optional common feature sets for response-related applications
- Provides protocols and common features for use of responder-related applications on common platforms

[71] "National Information Exchange Model," National Institutes of Health, last updated: n.d., https://www.niem.gov/Pages/default.aspx.

[72] *Unified CAD Functional Requirements* (APCO International, IJIS Institute, UCAD Project Committee, August 2012), http://www.ijis.org/docs/Unified_CAD_Functional_Requirements_FINAL.pdf.

- Backend that can be leveraged by existing and future responder applications to address common backend functionality (for example, registration, user validation, content security, data sharing)

State of Technology: Developing an application requires four steps. First, a developer identifies the necessary features of the application, commonly called a feature set. Second, software developers code the features. Third, developers expose features that will be seen by the user through APIs. APIs allow a developer to provide functionality to users without giving them full access to information on the application. For example, if an application provides encrypted messaging or a secure login, there is protected information that is not shared with all users. All applications that are developed for use on iPhone, Android and Web-based platforms must adhere to a set of stated requirements. Some of these requirements mandate a certain programming language, while others govern the interface design. These requirements are typically contained in an SDK. In the fourth step, the SDK is built on top of the APIs to ensure that the application can reach the most readily used platforms. An SDK would contain all of the features that responder-related applications should provide.

Backend services support specific user requirements such as registration, content administration and user data-sharing services. Developers of new responder applications currently need to "recreate the wheel" and develop unique solutions to address backend services. For example, each application developer must develop the means to validate whether the user is a responder (or otherwise authorized to use the application). The S&T-funded First Responder Support Tools (FiRST) is one application that provides backend services to support user registration, content administration and user data-sharing services; however, these backend services are not available for use with other applications. Although not technically challenging, there is currently no hosted set of common services that can be adopted by responder-related applications or an SDK to support the adoption of core requirements.

Potential Challenges:

- The appropriate entity to provide responsible ownership and maintenance of an SDK and response-related common services is unknown.

Anticipated Benefits	
Responder Safety	
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Platform for User Evaluation of Response-related Applications

Relevance: Many of the applications developed for responders are tailored to provide specific recommendations or guidelines to improve the safety of responders or the population (for example, bomb standoff distances). It is essential that these applications provide information and outputs that are accurate based on up-to-date science and official operating procedures. These applications also must be tested to perform as designed and function in realistic conditions. User reviews in a traditional app store (or other review forums) are often unregulated where individuals are able to post positive or negative reviews and ratings without verification that they have purchased or used the application. Responders believe the sensitive and critical nature of the response-related applications requires input from verified responder users. Therefore, responders would like a mechanism where they can purchase, rate and review the response-related applications. These reviews could include a standard set of criteria by which applications can be "certified" for use, such as data inputs, content outputs, usability and functionality. Responders desire a combination of a Consumer Reports™-style repository with the functionality of a traditional app store in a private forum.

Current Capability: Responders currently purchase applications through traditional app stores or through vendor websites. There is no formalized approach for end-user evaluation of response-related software applications. This is currently done by word of mouth between responders and is very ad hoc. Online forums contain reviews of some applications, and traditional app stores contain reviews and ratings of functionality, but neither the identity of the reviewer nor the verification of purchase is required or available. Some app stores provide verification that the app contains no malicious code, but the validation does not relate to the content or functionality.

Responder Requirements:

- Non-anonymous platform for use review (attributed with name, discipline, rank, location, etc.)
- Includes a mechanism to directly purchase response-related applications
- Compares applications based on qualitative and quantitative factors
- Develops criteria for a "responder-approved" application, including compliance with core requirements and minimum threshold of validated user reviews and ratings
- Designates an entity to issue an "approved" software application list

State of Technology: Private business-to-business (B2B) sites currently exist that restrict the purchase and review of applications to a defined set of users. Subject matter experts who participated in the interview process stated that there are no technical barriers to creating a protected forum for responder review and purchase of applications. The Responder Knowledge Base (RKB) used to provide a forum for users to provide reviews on response-related equipment, but that functionality is no longer available.

Potential Challenges:

- State and local policies may govern the use of certain applications on agency-purchased equipment. Although an important factor in a purchase decision, it is not feasible to capture and maintain information about these policies for all agencies and jurisdictions.

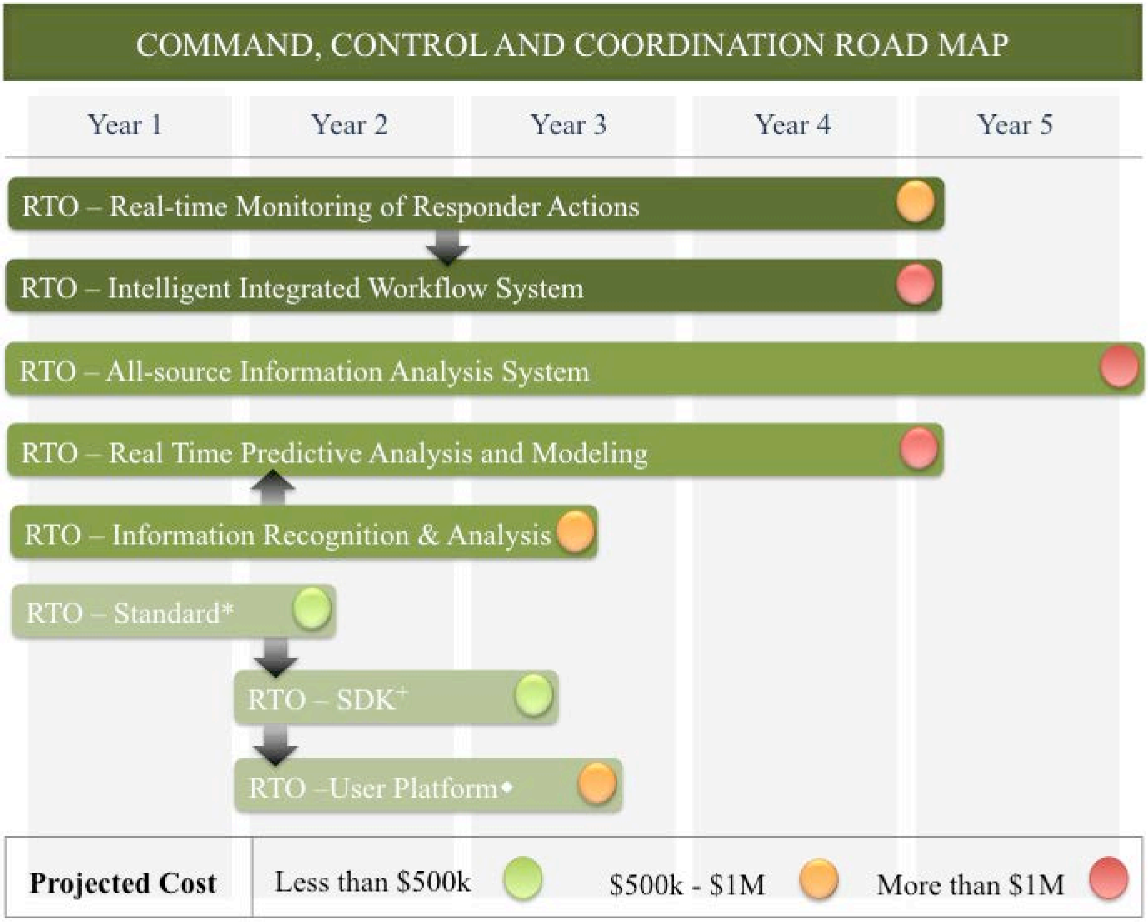
Anticipated Benefits	
Responder Safety	
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

- There are legal liability concerns if user reviews are seen to constitute a recommendation or to represent the opinion of the responder's agency instead of a personal opinion.

Command, Control and Coordination Path Forward:

Subject matter experts identified the following technology programs as necessary to meet some or all of the responder goals listed in the command, control and coordination RTOs above.

- Develop a system to collect automated data and tactical inputs from responders in real time
- Integrate responder geolocation and communication technologies into common operating platforms
- Develop an emergency response workflow of response tasks and objectives
- Develop a workflow system to ingest remote tactical monitoring inputs and customize to execute "intelligent" predictive analysis algorithms
- Establish a program to extract usable data from multiple sources (traditional and nontraditional) and develop machine learning algorithms to produce visualizations of actionable information
- Transition models used in training exercises for rapid deployment and use during response activities
- Develop a platform with integrated sensors and other data streams to collect, mash, analyze and display incident scene information
- Create a requirements standard that defines the format for data and outputs in responder-related applications
- Develop platform-specific SDKs that govern the development of response-related applications
- Create a developer portal with a common backend for user authentication
- Design and manage a forum for review, comparison and purchase of response-related applications



* Core Requirements Standard for Response-related Software Applications
\+ Software Development Kit for Integration of Response-related Software Applications
◆ Platform for User Evaluation of Response-related Applications

Figure 17. Command, Control and Coordination Technology Road Map

Responder health, safety and performance is defined as the ability to identify hazards to public safety personnel and develop appropriate mitigations to reduce morbidity and mortality associated with response activities.

There is one capability statement in this domain:

Protective clothing and equipment for all responders that protects against multiple hazards

The purpose of protective clothing and equipment is to shield responders from injury while operating efficiently in hazardous environments and provide the highest level of protection against a range of possible threats.[73] Body protection against individual threats has improved over the last decade; however, it has largely remained limited to the discipline-specific threats that are most likely to be encountered. This stovepiped approach to PPE development and implementation poses several issues. Most notably, responders face a myriad of known and unknown threats during incident response. Therefore, emergency responders often find themselves in situations where they are not outfitted with the best PPE available against the possible range of threats. This approach also does not provide efficient levels of protection across the body and does not allow response agencies to capitalize on economies of scale in purchasing. Responders who participated in PR4 workshops consistently expressed a desire for a modular system built upon a duty uniform that provides limited protection and physiological benefits (for example, moisture wicking) in combination with a series of modular, mission-specific layers to provide specialized protection.

A systems or modular approach allows emergency responders to move beyond a "one size fits all" solution and allows for the customization of their PPE ensemble in varied response environments. This provides several advantages, including preserving comfort and flexibility until the situation demands the next level of protection be employed. This helps ensure that responders are not in the position of choosing between their safety or mission effectiveness. Further, the use of modular layers has the potential to be the most cost-effective option, because only certain layers may become damaged or be in need of decontamination following an incident.

[73] The responders who participated in PR4 focused on body protection from all hazards. However, some reviewers of this document commented that respiratory protection may be more important than protective clothing and ensembles. Respiratory protection (in other words, SCBA, air-purifying respirators, powered air-purifying respirators, escape masks) is not addressed in this document, but has been consistently identified among the priorities in previous Project Responder reports and represents a significant focus of standards and technology development.

Subject matter experts identified five RTOs that correspond with this capability:

- Duty Uniform with Limited Protection Across Threat Spectrum
- Modular Mission-specific Protective Layers
- Wearable Materials and Systems That Can Be Easily Decontaminated
- Wearable Integrated Sensors
- Multi-threat Performance and Testing Standards for a Modular PPE System

Duty Uniform with Limited Protection across Threat Spectrum

Relevance: The duty uniform is the standard clothing ensemble worn by responders on a daily basis. In many cases, particularly for law enforcement officers and emergency medical technicians (EMTs), it may be the only clothing worn while on duty. The development of a PPE duty uniform that provides limited protection against a range of hazards is a well-established need with the emergency responder community. Responders function in unpredictable environments and may encounter threats before they can don the most appropriate PPE. Ideally, the duty uniform should help protect responders against the most likely threats encountered, including fire, blood-borne pathogens, extreme weather and projectiles. Additional layers can subsequently be donned, systematically and incrementally increasing the threat protection for the emergency responder.

Current Capability: While there are variances in color and style among disciplines and agencies, the duty uniform is generally made of cotton, wool or polyester. These uniforms provide little, if any, protection against hazards. For example, EMTs report an increase in Methicillin-resistant Staphylococcus Aureus (MRSA) infections on their knees and elbows from moving bedridden patients. Their duty uniforms provide no barrier against these bacteria. Further, the uniforms themselves could cause additional injury. Responders cited multiple instances where polyester uniforms have melted onto the wearer after being exposed to toxic chemicals or high heat. Duty uniforms in the fire service are often composed, in part, of flame-resistant polymers, which provide some additional protection from thermal, chemical and radiological hazards. Many responders wear a T-shirt and other undergarments under their duty uniform. Some commercially available T-shirts have moisture wicking functionality that helps the responder feel cooler, drier and more comfortable during operations. However, commercially available pieces do not adhere to existing uniform standards.

Responder Goals:

- Integrates into a modular PPE system
- Provides basic protection from most likely encountered threats (for example, fire, blood-borne pathogens, weather extremes, contamination, slashing)
- Provides increased localized protection as needed (for example, knees, forearms)
- Enhances comfort (for example, body temperature regulation, moisture wicking)

- Provides an affordable option that can be utilized across disciplines
- Enhances, does not degrade, responder performance
- Balances wearability, comfort, durability and dexterity
- Accommodates differences in gender and body size
- Able to be laundered repeatedly and frequently
- Ensures visual appearance is still in line with discipline and public image

State of Technology: Efforts are underway to achieve advances in functional design for responder garments. Researchers are developing distributed protection that provides enhancements where most needed (for example, reinforcements to elbow and knee areas), improved placement of pockets and other components to minimize bulk and enhance functionality and the integration of passive and active polymers into the material. Passive polymers are chemical compounds that provide a constant set of properties to the garment and could be applied as a coating to reduce the permeability of the material. Active polymers provide, receive and respond to signals from their environment and could enable a garment to change color based on physical conditions, such as exposure to toxins.

There is no single material that meets all of the goals listed above. However, there are opportunities to integrate innovative materials with improvements in functional design to provide advances that responders are looking for as part of a duty uniform. Unitary knits allow for the construction of garments with no seams or variance in thickness; 3-D weaving allows for lightweight molded and shaped fabric panels that use ultra-high-performance fibers; phase-change materials are able to store or release heat for the wearer; and shape memory alloys expand or contract based on exposure and then return to their original shape when heated.

Potential Challenges:

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	
Multi-incident Utility	❖

- Responders rely on the comfort, flexibility and functionality of their duty uniform and do not want these attributes sacrificed for greater levels of protection.
- There is no standard for a modular PPE system, and response agencies may be unwilling to purchase an ensemble that does not meet applicable standards.
- Manufacturers will need to develop training curricula regarding expected levels of protection and limitations of enhanced duty uniforms.
- Some of the modular systems used in other fields are expensive on a per unit basis (in excess of several thousand dollars for standard components). If responder modular components are priced similarly, this could be cost prohibitive for many departments.

Modular Mission-specific Protective Layers

Relevance: Responders don additional garments to protect themselves against specific threats. Firefighters, for example, use an ensemble of a thermal-resistant jacket, pants and boots called “turnout” or “bunker” gear. Many law enforcement officers regularly wear ballistic vests over their duty uniform to protect against projectiles. Responders who participated in the PR4 process consistently expressed a desire for a modular system built upon a duty uniform that would provide limited protection with a series of modular, mission-specific layers.

Current Capability: The current approach to developing and utilizing PPE is highly discipline-specific and is not currently viewed as a systems (or modular) approach. This stovepiped approach to PPE development and implementation poses several issues. Most notably, responders face a myriad of known and unknown threats that may not be within their discipline. This means that emergency responders may find themselves in situations where they are not outfitted with the best possible PPE available against the possible range of threats. In addition, current PPE often unnecessarily exceeds the recommended protection factor, in some areas by 400 percent, while still leaving other areas of the body under-protected. This occurs because of the way in which current PPE is layered, the inability to systematically employ the concept of localized protection and the manner in which PPE is evaluated.

Figure 18. Firefighter Turnout Gear

Localized protection integrates selective areas of the modular PPE in which critical additional protection is most needed. For example, additional localized protection may be added at the arms and chest, rather than the whole garment. Localized protection also includes the selective use of advanced material technologies, such as superhydrophobic finishes. These finishes provide the ability to absorb or draw off liquids, such as sweat. The selective use of localized protection, including advanced material technologies, can dramatically decrease cost and increase wearability.

Currently, PPE evaluation to assess the level of the protection factor is done at the component (individual piece) level. However, there is a need to transition to an approach that produces a modular PPE ensemble that can be holistically evaluated for overall protection. This would enable emergency responders to both understand how they can incrementally increase their protection factors by adding layers and understand the limitations of the PPE.

Responder Goals:

- Integrates into a modular PPE system
- Easily donned and removed

- Includes next-to-skin layers and outer layers to provide varying levels of protection as needed
- Uses a universal interface between layers (in other words, no proprietary interfaces that require responders to purchase all modules from the same manufacturer)
- Enhances comfort (for example, body temperature regulation, moisture wicking)
- Provides an affordable option that can be utilized across disciplines
- Enhances responder performance
- Balances wearability, comfort, durability and dexterity
- Accommodates differences in gender and body size
- Easily maintained, stored and decontaminated, and has a long shelf-life
- Ensures visual appearance corresponds with discipline and public image

Figure 19. Layers of the ECWCS

State of Technology: Subject matter experts reported that many of the mission-specific garments that responders use are technically mature, with incremental improvements possible to reduce weight and thickness. Advances can be made in the definition and development of a responder-specific modular PPE system. Modular garment systems are generally designed around three primary layers: a base or next-to-skin layer that is designed to wick moisture away from the body; an insulation layer that provides volume and allows warm air to be trapped between the body and the outer garment; and the outer shell layer that protects the wearer from the elements. Additional layers and accessories can be added to increase protection or versatility.

The U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC) designed the Extended Climate Warfighter Clothing System (ECWCS) as a modular ensemble for variable combat conditions. Now in its third generation, it includes seven layers of clothing, from lightweight undergarments to extreme cold/wet weather jackets and trousers.[74] The Flame Resistant Environmental Ensemble (FREE) is a PPE system that provides complete fire-resistant protection for the Army. In combination with additional outer layers, it builds on a fire-resistant base layer that provides moisture wicking to ensure comfort and breathability in all climates.[75]

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[74] "Extended Climate Warfighter Clothing System," U.S. Army Natick Soldier Research, Development and Engineering Center, http://www.military.com/equipment/extended-climate-warfighter-clothing-system-gen-iii.

[75] "Fire Resistant Environmental Ensemble (FREE)," ADS, http://adsinc.com/equipment/free.

In the commercial arena, multiple manufacturers are developing modular ensembles that allow the wearer to vary his or her level of protection. Advanced hunting apparel, for example, includes a system of multiple pieces that help regulate body temperature, wick moisture, protect against environmental elements and provide insulation. Some of the garments are composed of high-performance layers and membranes that provide liquid barriers and antimicrobial properties. Several of these systems are transitioned from combat gear developed for the U.S. military.

Sporting apparel companies currently produce garments worn next to the skin that provide moisture wicking functionality. These garments help to keep moisture from collecting near the wearer's skin and do not absorb the moisture itself. This helps the wearer feel cooler, drier and more comfortable during physically demanding operations. However, the materials developed for sporting apparel do not adhere to existing uniform standards required for emergency responder PPE.

Potential Challenges:

- Modular layers must be designed to meet operational conditions of the incident scene, which may vary from warfighters to responders.
- There is no standard for a modular PPE system, and response agencies may be unwilling to purchase an ensemble that does not meet applicable standards.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	
Multi-incident Utility	❖

Wearable Materials and Systems That Can Be Easily Decontaminated

Relevance: Each of the response disciplines faces different primary hazards. Law enforcement often responds to clandestine narcotics laboratories; EMS personnel are exposed to a spectrum of biological hazards; hazmat teams face numerous chemical and incendiary threats; and firefighters are exposed to unknown hazards, as they often do not know what is present on the fire ground. During response operations, PPE is exposed to multiple agents, toxins and contaminants, many of which adhere to or absorb into the materials. If the contaminants are not removed, the clothing may pose an ongoing hazard to the responder during later uses. The contaminant and the properties of the garment determine whether the garment can be decontaminated, as well as the correct process to do so.

Current Capability: Decontamination involves in-station laundering or sending the PPE to an alternate site for cleaning. Often, public safety agencies decide to dispose of contaminated items rather than risk additional exposure, despite the high costs of repurchase. This is primarily because they are not familiar with the appropriate decontamination techniques or do not fully trust that the process will keep the responder safe. Determining what type of decontamination strategy to employ is at the agency's discretion and is dependent on its experience and level of risk aversion. This subjectivity can be costly, especially when decisions are made to throw the equipment away or decontaminate them at an off-site location. Responders have limited nondestructive techniques for testing the exposure levels of their PPE. They often are unable to identify all contaminants absorbed into their garments and do not know what decontamination processes are necessary. They also remain uncertain whether decontamination was effective in removing all contaminants. In addition, PPE exposed to certain hazards (for example, asbestos, HIV, MRSA) carry an additional stigma and are more likely to be disposed of, regardless of whether decontamination procedures are available.

Responder Goals:

- Materials that resist absorption of contaminants (for example, coatings)
- Materials that more easily release contaminants
- Materials that indicate the level of contamination
- Garments that can more easily be decontaminated in the station

State of Technology: The potential exists to reduce the contamination on PPE through the application of coatings or treatments during manufacturing. The ability of a liquid to be absorbed into a fabric is dependent on the contact angle of the droplet. Superhydrophobic surfaces resist absorption because the angle created between the surface and the liquid causes droplets to roll off. Superhydrophobic nanoparticles can be applied as a coating to a garment, allowing contaminants to roll off. This creates a self-cleaning property. Use of these finishes in textiles has been demonstrated. The Alinghi sailing team used superhydrophobic jackets that had a microparticle treatment applied during the manufacturing process to increase water repellency during the 2010 America's Cup. Research in this area has primarily focused on absorption of liquids, but Subject matter experts stated that additional work is necessary for particle resistance.

Applying finishes to clothing is an established field, but many advances in this field have not been adapted to responder PPE. Ongoing research is focused on applying advanced textiles to meet responder needs. Recent successes include a hazmat boot made of new textile materials and surface treatments that can be fully decontaminated in the station. The boots are made, in part, of a leather material that repels toxic chemicals. It is possible that finishes could also be reapplied during the decontamination process, actually extending the usable life and protection provided by PPE.

Responders need to understand whether their PPE can be decontaminated for subsequent use or disposed of because the hazards cannot be removed. Responders also need to understand the appropriate methods for decontamination. As stated above, responders believe that they do not have clear guidance about decontamination protocols and procedures. The Technical Support Working Group (TSWG) of the Combating Terrorism Technical Support Office (CTTSO) is currently funding a project to create a decision tool for responders that would enable them to identify the appropriate means for decontamination. This does not address the ability of materials to be decontaminated but should provide advancement in the standardization and reduction of subjectivity in decontamination decisions.

One key factor for this RTO is that there are limited guidelines for maximum skin exposure to contaminants. All current guidelines are based on inhalation exposure. The absence of guidelines results in a de facto "no permissible exposure" limit, despite the fact that the inherent barrier properties of human skin can tolerate much higher concentrations of exposure. DOD has identified skin-exposure levels for chemical and biological warfare agents, but there are no guidelines for emergency response. Subject matter experts reported that compliance with existing standards and guidelines creates a paradigm of providing a greater level of protection than may be necessary, causing trade-offs that reduce comfort, functionality and the ability to decontaminate. They stressed the need for the development of responder-appropriate skin exposure guidelines to facilitate the identification of decontamination protocols for PPE.

Potential Challenges:

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

- The lack of skin exposure guidelines inhibits the development of decontamination protocols that provide appropriate levels of protection for responders.
- The lack of nondestructive sampling techniques prevents responders from being able to identify all hazards present on garments.
- It may be difficult to overcome psychological resistance to wearing garments that were previously contaminated, especially for certain hazards.

Wearable Integrated Sensors

Relevance: Responders experience significant physiological stress during response operations. In addition, they can be exposed to a myriad of hazards. Sensors can be used to monitor responders and relay important physiological and operational data to incident command. Specifically, sensors attached to or carried by responders can provide command with information about their individual health status (for example, responder inactive, physiological factors exceeding set parameters) and specific threats and hazards on the incident scene. Improved awareness of these factors helps incident command make decisions that increase the safety of responders and the population. This RTO focuses on sensors integrated into responder garments or body-worn equipment and does not address hand-held hazard detection devices.

Current Capability: The use of wearable sensors by the response community is limited. Other than specialized units, law enforcement and EMS personnel have no existing sensor systems or physiological monitoring devices integrated into their garments. Most firefighters use a PASS device that provides an audible alert when the firefighter is immobile. The PASS device is integrated into the firefighters' SCBA system.

Other sensors are available, but are not universally used within the fire service, including those capable of monitoring responder heart rate, blood pressure and oxygen levels. Other sensors monitor lack of oxygen, carbon dioxide levels, radiation, temperature and combustible gases. Additionally, there are sensors currently available to monitor general disaster environment elements, such as temperature and smoke presence and position. These sensors often adhere to the outside of responders' PPE. However, sensors that are externally placed are often damaged or rendered unusable during response operations due to the conditions of the response environment. In addition, the sensors do not necessarily provide immediate or actionable information based on the data collected.

Responder Goals:

- Integrates sensors into PPE rather than adhering sensors externally
- Enhances the robustness of sensors, including protection from common threats (for example, chemical, thermal)
- Generates data outputs that provide direct operational relevance
- Provides sufficient SWP without a net increase in the weight of the total PPE ensemble
- Ensures ease in calibration
- Further develops biological hazard detection capability
- Wearable sensors that can be laundered and decontaminated frequently
- Relays information in real time to incident command, caches data when connectivity is offline and automatically forwards when connection is restored

State of Technology: A wearable sensor system has three components: the sensor, the transmission of data measured by the sensor and the display that translates data into actionable information.[76] Many of the sensors identified by the response community have already been developed for other applications. Over the past decade, NASA has been developing and refining the Lifeguard system to monitor the health of astronauts during space flight missions. The Lifeguard system monitors vital signs (in other words, electrocardiogram, temperature, heart rate, respiratory rate, oxygen saturation and blood pressure) and transmits the data wirelessly to a portable base station. Multiple commercial entities are designing and producing compression clothing that has sensors woven into the fabric. These products were initially designed for athletes (for example, a shirt with an integrated bioharness was worn by participants in the 2011 National Football League Combine), but the applications are expanding into other fields.

There are a number of systems in development that are specifically designed to monitor the physiological signs of responders. The Wearable Advanced Sensor Platform (WASP)

[76] "In-Q-Tel Quarterly: What Are Wearables?,,"Zephyr Technology Corporation, last updated: n.d., http://zephyranywhere.com/press/in-q-tel-quarterly-what-are-wearables/.

system includes a flame-resistant T-shirt worn next to the skin. Physiological sensors mounted on an embedded strap track heart rate, heart rate variability, respiration rate, activity levels, posture and other factors. The system transmits data via Bluetooth over commonly used responder radios, cellphones and Wi-Fi networks. There is a portable command station that analyzes the physiological response of individual responders over time. A multi-disciplinary team funded by the U.S. Army NSRDEC is developing WASP.

The Center for Nanotechnology at NASA's Ames Research Center recently developed flexible textiles woven with computer memory. This material could be integrated into a wearable sensor system for the response community, advancing data processing. It could allow sensor readings to be compared with baseline physiological data, allowing for user-specific alerts.

Potential Challenges:

- The FDA regulates sensors that measure some medical data and may have regulatory authority over a wearable sensor system designed for responders.
- The fidelity of physiological measurements is significantly improved when compared with user-specific baseline data. However, it would be a significant and costly effort to gather baseline data on all responders across multiple conditions.
- There may be significant resistance by responders to wearing a device that may cause them to be removed from the incident scene due to physiological measurements.
- The transition from laboratory conditions to real-world operating environments is critical to ensure that accuracy and functionality is maintained.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Multi-threat Performance and Testing Standards for a Modular PPE System

Relevance: A number of performance and testing standards apply to the PPE worn and used by emergency responders. These standards are in place to ensure minimum levels of protection, consistency in performance and uniform testing criteria. Multiple standards development agencies have authored these standards, obtaining input from responders, associations and manufacturers. Response agencies often place greater trust in materials and equipment that meet these standards, and grant funding is often tied to purchasing equipment that complies with applicable standards. In addition, some states have adopted and enforced select PPE standards as law. Responders stated the need for performance and testing standards for a modular PPE ensemble.

Current Capability: No standards currently exist for multi-threat performance and testing of modular PPE system. While performance and testing standards exist for individual items of PPE, there are concerns that some do not reflect actual operational conditions, are not based on performance criteria or do not address technological advancements. The NFPA has two noted standards that relate to body protection for responders, but not necessarily modular PPE: NFPA 1971 and NFPA 1975.[77]

NFPA 1971 is the standard for protective ensembles for structural firefighting and proximity firefighting. This standard "protects firefighting personnel by establishing minimum levels of protection from thermal, physical, environmental, and blood borne pathogen hazards encountered during structural and proximity firefighting operations."[78]

Figure 20. NFPA Standards Manuals

NFPA 1975 is the standard for station/work uniforms for emergency services. This standard "safeguards emergency services personnel on the job by establishing requirements for flame-resistant station uniform clothing that won't cause or exacerbate burn injury."[79]

Existing standards may not be adaptable to a modular PPE system, however. NFPA 1971, for example, assumes the responder has no garments on below the structural firefighting garments (turnout gear) and does not account for the incremental increases in protection from multiple layers.

Responder Goals:

- Performance and testing standards that account for a modular PPE system
- Common interface for integration of modular PPE component
- Operationally appropriate performance and testing criteria
- Includes recommendations for the retirement of systems

State of Technology: The standards development process and revision cycle do not represent a technical challenge. The design of a modular PPE system and development of prototype ensemble pieces is a prerequisite for the development of this standard.

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[77] Two other standards NFPA 1977 (Standard on Protective Clothing and Equipment for Wildland Fire Fighting) and NFPA 1951 (Standard on Protective Ensembles for Technical Rescue Incidents) have some relevance to this RTO, but are not addressed here in detail.

[78] "NFPA 1971: Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting 2013 Edition," National Fire Protection Association, http://www.nfpa.org/catalog/product.asp?link_type=buy_box&pid=197113&icid=A647.

[79] "NFPA 1975: Standard on Station/Work Uniforms for Emergency Services, 2014 Edition," National Fire Protection Association, http://www.nfpa.org/catalog/product.asp?link_type=buy_box&pid=197514&icid=A647.

Potential Challenges:

- Introducing a new standard can be difficult if there is only one entity producing a prototype because there is limited opportunity for reproducibility of findings or inter-lab testing.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	
Multi-incident Utility	❖

Responder Health, Safety and Performance Path Forward:

Subject matter experts identified the following technology programs as necessary to meet some or all of the responder goals listed in the responder health, safety and performance RTOs above.

- Design a duty uniform that can be used across disciplines and that provides a defined level of protection from identified hazards
- Develop a modular PPE system incorporating next-to-skin layers, duty uniform layers, mission-specific layers and environmental layers that work together
- Develop a cleaning extraction program, initially focusing on a small number of the most common contaminants (six to ten) to evaluate optimal methods for extracting contaminants
- Develop a prototype garment (for example, vest) as a proof of concept for field performance testing and evaluation of wearable integrated sensors
- Develop performance and testing standards for a modular PPE system inclusive of a next-to-skin layer, a duty uniform layer and functional layers

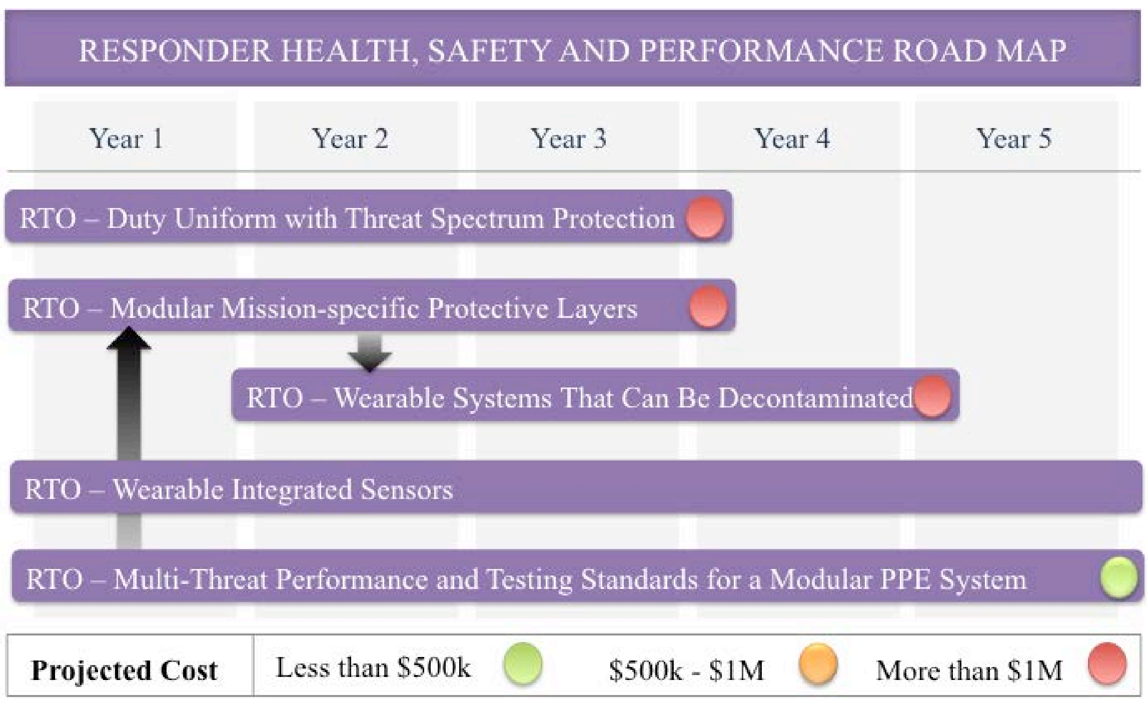

Figure 21. Responder Health, Safety and Performance Technology Road Map

Logistics and resource management is defined as the ability to identify, acquire, track and distribute mission-specific equipment, supplies and personnel in support of catastrophic incident response.

There are two capability statements in this domain:

The ability to identify in real time what resources are available to support a response (including resources not traditionally involved in response), what their capabilities are and where they are, in real time

Catastrophic incident response typically involves the participation of a large number of federal, state and local response agencies; National Guard units; volunteer organizations; and private individuals. Each participating party has resources available to it. It is difficult for the logistics section within incident command to understand which resources are needed, which resources are available to meet those needs and the proximity of those resources. Each agency or organization generally maintains a separate list of assets and is not able to readily share resource data with incident command. Additionally, incident managers may have limited information regarding nontraditional or specialized resources that are available or are operating on-scene. Responders would like a logistics management system that allows resource data to be exchanged and provides a clear resource-related common operating picture. This capability need is focused on the availability of resources for response operations.

Subject matter experts identified two RTOs that correspond with this capability:

- Integrated Logistics Management System
- Data Ownership and Exchange Standards

The ability to monitor in real time the status of resources and their functionality in current conditions

Many resources are brought to bear to support incident response operations, including personnel, supplies and equipment needed to stabilize the area, mitigate additional consequences, protect responders and the public and restore the use of critical resources. It is difficult for the logistics section in incident command to understand which resources are on-scene, who is using them, when they need maintenance or rehabilitation, when they are available for subsequent use or tasking and how the resources can be identified and returned to their home agency. Many of the requirements for this capability can be addressed with the development of a resource management system as mentioned above. However, data concerning the functionality of specific resources could improve the incident command's ability to make resource allocation decisions. This capability need is focused on the management of resources already on the incident scene.

Subject matter experts identified one additional RTO that corresponds with this capability:

- Remote Collection of Resource Data

Integrated Logistics Management System

Relevance: Logistics involves the procurement, transportation, storage and maintenance of resources. A logistics management system provides automation and organization of these processes. When applied to catastrophic incident response, it includes tracking the movement of inbound units, ordering new equipment, staging supplies, ensuring the functionality of on-scene equipment and predicting future event needs. Responders would like an integrated logistics management system (ILMS) that illustrates the resources that are available to support a response, the specifications of those resources and where they are located in real time, regardless of the incident's size. They would also like an integrated picture of the status of all resources at the incident scene, regardless of jurisdiction or discipline.

Current Capability: The logistics section is responsible for managing resources during incident response. The logistics section chief and staff are tasked with requesting resources, managing staging and distribution of resources on the scene and maintaining the functionality of those resources. Responding agencies frequently rely on static, outdated spreadsheets to identify the resources available to support a response, making it difficult for the logistics section to develop a clear picture of available resources. In addition, there is inadequate visibility into the status of inbound units or equipment. Responders reported that on-scene staging is frequently ad hoc, with limited predefined organization for placement of resources when they arrive. The use and status of equipment is often managed through paper check-out cards. Sharing resources often relies on having an emergency mutual aid compact in place. It is also difficult to share resource information when the data formats of resource databases are incompatible. The logistics chief can use situational awareness software to request resources and see inventories, but the data cannot be shared with other users to create an integrated picture.

FEMA uses a Logistics Supply Chain Management System (LSCMS) during federal emergencies to track shipments from distribution centers to the federal staging area. A logistics chief places a request into the system, and FEMA supply chain managers validate the order and decide where it will be sourced. If the item needs to be transported from a FEMA warehouse, it is fitted with a GPS transponder that allows the user to track its movement. The logistics chief must place a second order to move the resources from the staging area to the incident scene. At this time, LSCMS cannot be used to track some larger items (for example, vehicles) and is only available to approved users at the state and federal levels.

There are a number of other systems to manage resources on the incident scene, but they are generally task- or region-specific. For example, some jurisdictions use a Medical Emergency Response Center (MERC) to manage the availability of hospital beds and specialized care; the Texas Regional Resource Network (TRRN) was developed for the Governor's Division of Emergency Management to track the state's emergency response-related resources within the state; and the National Wildfire Coordinating Group developed the Resource Ordering and Status System (ROSS) to track all tactical, logistical, service and support resources. All of these systems provide significant improvements in resource management, but the utility and functionality are not universal among response agencies.

Responder Goals:

- Integration of systems to aggregate existing resource information, process resource requests, track the logistics process and record necessary financial information
- Tracks inventory levels, available suppliers and resources, qualified response personnel and transport and distribution information in real time
- Graphic display of real-time resource status at the incident scene (for example, fuel levels, battery life)
- Generates alerts when disposable supplies hit predetermined levels or automatic reordering of supplies given preset parameters
- Models burn rates on a range of resources
- Generates alerts for incompatibility of supply components
- Generates alerts when a resource is scarce on a local, regional or national basis
- Integration of supply chain and product integrity
- Compatibility between incident-related decision support and management systems and financial management requirements or systems
- Resilient stand-alone system that is not reliant on the Internet to function
- Operates using multiple platforms
- Provides visibility of resources at all levels (for example, federal, state, local and private sector)

State of Technology: Commercial logistics management systems address many of the responder goals listed above. These systems focus primarily on supply chain management and provide visibility into the status and transportation of ordered items. Consumers also enjoy advances in this area. As an example, an individual can order, pay for and watch the approach of a requested item (for example, a taxi cab) in real time using an application on his or her smartphone. Much of this utility has not been transitioned to emergency response needs, but several efforts are in development. For example, commercial developers are creating a software application that tracks the movement of inbound personnel. The application can notify a responder that he or she has been activated and can then track inbound movement to the incident scene using cellular and wireless networks.

The National Guard Bureau developed the Civil Support Team Information Management System (CIMS) to coordinate the command and management needs of Civil Support Teams (CSTs). One component of CIMS focuses on logistics. The system is tied to a database of equipment with associated costs. It allows the CST to track individual pieces of equipment by serial number to the user. The system then categorizes the disposition of equipment (for example, lost, returned, damaged, non-recoverable, disposed of) after an incident to support financial accounting. CIMS supports emergency response operations but is not available to the civilian response community.

Potential Challenges:

- Entering inventory data is time consuming, and it is difficult to ensure that the information is current. ILMS will not be as useful if the data is not maintained.
- Data and resource typing remains an issue despite expansion of the NIMS classification of types and resources. If agencies do not use the same naming conventions when entering resources into a repository, an integrated system will be less effective in identifying all of the resources available to support the response.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Data Ownership and Exchange Standards

Relevance: Data exchange is the process of sending and receiving data so that the information content or meaning assigned to the data is not altered during the transmission.[80] When large numbers of agencies come together to respond to a catastrophic incident, there is no common picture of the resources available to support response operations. The logistics section relies on inventories provided in multiple data formats, many of which cannot be integrated automatically. In a basic example, two spreadsheets may contain the same types of data, but if the column headings are not the same, merging the data can be problematic. This problem grows in proportion to the number of agencies that arrive to support the response. Data ownership and exchange standards govern how information is distributed and provide a common structure, or schema, so that information contained in the data set can be integrated seamlessly. This will provide the logistics section with a unified picture of all resources available to support the response.

Current Capability: Each response agency maintains its own inventory of assets. This inventory is often recorded in simple spreadsheets or documents. Other agencies enter resource data into commonly used situational awareness software. Some regional entities developed data-sharing protocols for resource data. Additionally, response agencies may

[80] "Data Exchange," Organization for Economic Cooperation and Development, last updated: June 2013, http://stats.oecd.org/glossary/detail.asp?ID=1355.

not be willing to share all of their assets to support the response. An agency may need to retain some assets to cover routine operations, may be unwilling to commit all available assets for fear that the items will not be returned or may want to provide only specific types of resources to the response.

As mentioned in the "Core Requirements Standard for Responder-Related Software Applications" RTO above, there are several requirements standards pertinent to information exchange. That NIEM provides a framework for XML-based effective and efficient information sharing across all levels of government and private industry. In addition, the Unified CAD Functional Requirements document identifies a comprehensive set of functional specifications for CAD systems.

Responder Goals:

- A schema that defines the format and structure for sharing resource data
- Originator of data retains ownership (read-only for users of the data)
- Nonproprietary solutions
- Accommodates different platforms, browsers, combinations and software upgrades
- Addresses firewalls and other network security
- Secure and encrypted system
- Low transition barriers or incentives for participation
- Intuitive to use
- Simple governance structures

State of Technology: The development of data exchange and ownership schema is not technically challenging, and there are multiple examples in the commercial domain as well as the federal government. The U.S. military developed the DOD Architecture Framework (DoDAF) to facilitate information sharing across the department. Within DoDAF, the Meta Model (DM2) provides information needed to collect, organize and store data in a way that is easily understood.[81] The DM2 has three levels: a conceptual data model that defines the high-level data constructs in nontechnical terms; a logical data model (LDM), which adds the technical attributes; and a physical exchange specification (PES) that defines how data will be exchanged.[82] The LDM generates the PES schema definitions in XML, which is a neutral format for sharing data.

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[81] "DoD Architecture Framework Version 2.02," U.S. Department of Defense, Chief Information Officer, last updated: n.d., http://dodcio.defense.gov/TodayinCIO/DoDArchitectureFramework/dodaf20_background.aspx,.

[82] "DoDAF Meta Model (DM2)," U.S. Department of Defense, Chief Information Officer, last updated: n.d., http://dodcio.defense.gov/TodayinCIO/DoDArchitectureFramework/dodaf20_dm2.aspx.

Through the Health Information Technology for Economic and Clinical Health (HITECH) Act in 2009, Congress mandated the use of electronic health records (instead of paper records) for medical practitioners who provide Medicare and Medicaid services. In response, health information exchanges have been created to facilitate the secure sharing of electronic patient files. As part of the federal health architecture, the U.S. Department of Health and Human Services developed a Nationwide Health Information Network (NwHIN) that provides common specifications, standards and governance that enable secure health information exchange.[83]

Potential Challenges:

- As mentioned above, some agencies may be unwilling to share resource data in a digital format.
- The cost and complexity of transferring existing resource data into the format governed by the schema may be a significant barrier to transition.

Anticipated Benefits	
Responder Safety	
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Remote Collection of Resource Data

Relevance: The functional status of equipment is an important factor in the success of response operations. Generators may run out of gasoline, chain saw blades become dull or broken, SCBA tanks run out of oxygen and medical treatment supplies are consumed. Responders would like the ability to remotely track on-scene resources for improved situational awareness of the equipment already deployed and its status. Graphically displayed location of resources, status updates and usage alerts can be extremely helpful to inform logistics and resource allocation decisions. This RTO pertains to the equipment used or worn by responders and does not include physiological monitors that measure the health status of personnel.

Current Capability: On-scene resources are generally managed through ICS form 219 (more commonly known as T-cards), which record the status and location of equipment on the incident scene. T-cards include a set of eight status cards that are color-coded based on the type of resource (for example, equipment is recorded on a yellow card, while helicopters are recorded on a blue card). Responders write on the T-card both the time they are checking the equipment in and out and the location they intend to use the resource. The anticipated location of personnel teams or crews is also recorded on T-cards.

Response agencies use dispatch systems to deploy units or response vehicles (commonly called apparatus) to meet response needs. Some systems have the ability to graphically

[83] "Nationwide Health Information Network," HealthIT.gov, last updated: n.d., http://www.healthit.gov/policy-researchers-implementers/nationwide-health-information-network-nwhin.

display the location of a particular apparatus. Responders use ratio relay to verbally communicate resource information and needs from on-scene. Many hospital systems are able to automatically track the use of supplies and automatically order new supplies when inventories are reduced to preset levels.

Responder Goals:

- Identifies resource status (in other words, online, offline, in use, idle), functionality (for example, maintenance requirements, resupply needs) and location (in three dimensions)
- Transmits resource status data to incident command
- Integrates into larger Logistics Management System
- Graphic display of real-time status, functionality and location on a GIS-enabled platform
- Compares resource data against typical, optimal and emergency operating parameters and consumption rates
- Generates alerts when disposable supplies hit predetermined levels and automatic reordering of supplies given preset parameters
- Generates alerts when maintenance and resupply are needed
- Automatic population of financial accounting forms
- Two-way functionality and communication between field and command (in other words, the ability to "command" equipment to reduce consumption rates as necessary)
- Tags or chips attached to equipment should be ruggedized to withstand the heat, humidity, debris or other environmental conditions on an incident scene

State of Technology: Remote site monitoring involves tracking the status of equipment at distant locations. It is done regularly in multiple industries, such as railways and utilities. It is even possible for the manufacturer to remotely diagnose problems occurring in household appliances. Remote site monitoring relies on remote telemetry units (RTUs) that assess functionality, collect system alarms and monitor the environment for critical factors. The data are then aggregated and displayed for the user.

The field of human-machine interface (HMI) design is focused on the interaction between users and mechanical systems. A number of commercially available remote HMI systems are designed to allow users to monitor the status of machines and even control the machine from a smartphone or tablet. These systems use sensor data to provide a graphic display of supply levels, operating parameters and other factors. Although these systems are not focused on response equipment, the technology could be transitioned to meet responder needs.

Fleet tracking and management systems are commercially available that use sensors to track vehicles (using GPS) and report their location, extract vehicle status information, relay maintenance and diagnostic information and transmit alerts and notifications to and from the driver. These systems are in use by some public safety agencies but have not been adopted across the nation.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Potential Challenges:

- A solution to this RTO may present another big data problem as many assets on the incident scene transmit status data in real time.

Logistics and Resource Management Path Forward:

Subject matter experts identified the following technology programs as necessary to meet some or all of the responder goals listed in the logistics and resource management RTOs above.

- Develop a comprehensive public safety logistics management system that addresses resource availability and on-scene resource status
- Develop an open API for the integration of resource data
- Design a standard data collection and transmission HMI appropriate for response resources

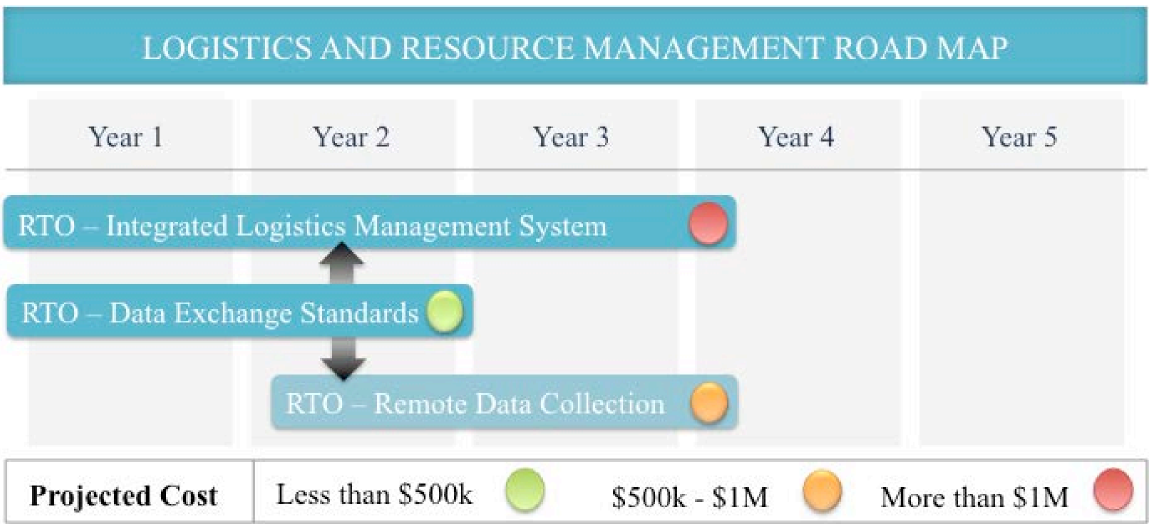

Figure 22. Logistics and Resource Management Technology Road Map

Casualty management is the ability to provide rapid and effective search and rescue, medical response, prophylaxis and decontamination for large numbers of incident casualties and identify appropriate sheltering, transportation and destination options.[84]

There is one capability statement in the casualty management domain:

The ability to remotely scan an incident scene for signs of life and decomposition to identify and locate casualties and fatalities

The purpose of search and rescue is to locate and extricate victims who may be trapped. This mission is primarily achieved by organized search and rescue teams but is also performed by other responders, volunteers or even victims themselves. The search and rescue process can be labor intensive and time consuming, with activities including (1) locating and verifying the presence of a victim; (2) performing necessary stabilization of the surrounding structures or debris; (3) removing the victim; and (4) performing initial medical stabilization efforts. Deceased victims are generally removed following the immediate active search and rescue efforts for living victims.

There are several reasons why responders would like to be able to *remotely* detect the presence of casualties on the incident scene. First, there may be areas that are hazardous for responders to enter (such as a radiological or chemical environment or if a structure is unstable). Incident command would like to confirm the presence of living victims in a geographic area before they deploy their personnel into a potentially dangerous environment. Second, a catastrophic incident scene may be geographically expansive, making it very time consuming to search for individuals in every structure or building. Third, current search and rescue protocols require the location of a victim to be verified by touching or hearing the voice of the individual. Therefore, if a person is unconscious, he or she will not be able to signal to responders. If responders could determine whether there are injured or trapped individuals from a standoff distance, they would be able to locate and rescue victims more quickly, improving their chance of survival. Likewise, responders would be able to more quickly retrieve deceased victims to enable processing (for example, autopsy, identification) and disposition (for example, burial, cremation), as well as decrease health hazards from decomposing remains.

Subject matter experts identified six RTOs that correspond with this capability:

- Remote Sign of Life and Death Detection
- Incident-specific Casualty Modeling and Prediction
- Data Integration and Decision Support for Casualty Detection
- Indoor Casualty Geolocation
- Outdoor Casualty Geolocation
- Subsurface Maritime Casualty Geolocation

[84] A casualty is defined as a person, living or deceased, who has been directly affected by an incident.

Remote Sign of Life and Death Detection

Relevance: A key factor in remotely locating individuals is the ability to detect signs of life (for example, heartbeat, respiration, body heat) or death (for example, gases emitted by decomposing remains). Responders would like positive verification of the existence and location of casualties to improve the efficiency and effectiveness of their search and rescue efforts by focusing on verified locations. They would also like to obtain this verification from a standoff distance to improve the safety of those engaged in the process.

Current Capability: Responders currently use several methods to remotely identify the existence and location of casualties. The options include the use of animals, sensors and camera systems. Animals are primarily used to detect human scent or movement. Dogs are predominantly employed, but others include bees, sea lions and dolphins. Sensors that detect living victims include heat-sensing forward-looking infrared (FLIR) or multi-spectral cameras, ground-penetrating radar (GPR), carbon dioxide detectors and acoustic equipment that can detect signs of life or movement. These sensors are frequently mounted on aircraft, boats, vehicles or robots. Side-scan sonar is used to detect the presence of remains in water. GPR can also be used to detect the presence of remains underground.

Responder Goals:

- Displays the location of signs of life/death on a GIS platform
- Distinguishes between signs of life and signs of decomposition
- Identifies signs of life up to 100 feet below ground
- Differentiates the number of victims in a given location
- Authenticates the identification of victims
- Scalable and adjustable to meet the parameters of the incident scene
- Incorporates survival factors (for example, exposure, dose, weather factors)
- Transmits data in real time

State of Technology: Recent advances have been made in the ability to remotely determine whether living victims are trapped within a structure. As an example, S&T funded the development of the Finding Individuals for Disaster and Emergency Response (FINDER) system. FINDER uses low-power continuous microwave radar technology to detect movements as small as a millimeter within a standing or damaged structure. Algorithms translate this movement to identify respiration and the heartbeat of victims. The system then creates a Keyhole Markup Language (KML) file that can be uploaded to create a GIS display. The equipment is relatively small (approximately the size of a pelican case) and works with a laptop or tablet. Recent tests demonstrated that FINDER was able to locate victims to within five to six feet from a standoff distance of up to 40 feet from the structure. The algorithms can differentiate between human and animal heartbeats and respiration within most parameters.[85] Prototypes of FINDER are currently being tested in the field. This program transitions work completed by NASA's Jet Propulsion Laboratory (JPL) for DOD to detect heartbeats in battlefield applications. In-progress refinements to the system include adding the ability to specify the scan range and working to integrate the device with other platforms, possibly unmanned aerial or ground systems. Additional work is being done to try to identify victims by differentiating between different heartbeat signatures to compare with an exemplar and identify trapped victims.

HSSAI research indicates several approaches are currently being explored to remotely detect the "smell of death." The development of synthetic nose hairs to detect the gases emitted by decomposing bodies and the use of lasers and remote sensing platforms to identify these gases are the subject of ongoing research efforts.

Interview participants also stated that additional advances in remote detection of signs of life or decomposition are possible through the miniaturization of sensors and their integration with small, hand-launched UASs. Efforts to miniaturize sensors are underway for other applications, but Subject matter experts stated they could be easily transitioned to create an integrated standoff system to detect signs of life and decomposition.

Potential Challenges:

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

- Participants stated there are no technological or regulatory barriers for remote sign-of-life detection.
- Advances in technology may result in changes in tactics, techniques and procedures. Responders may put more faith in current processes that rely on the experience of search personnel.
- UASs need expanded approval by the FAA for increased use in public safety missions.

Incident-specific Casualty Modeling and Prediction

Relevance: To deploy search and rescue personnel more effectively, incident command needs an accurate estimate of how many casualties to expect, the location of the injured and deceased and an estimated time window to rescue a casualty before he or she dies. These projections may be based on various incident-specific variables, including the population of the affected area at the time of the incident (due to variances in population at different times of the day), the size and scope of the incident and the presence of hazards and threats. This information will allow for a more informed requisition and

[85] The FINDER algorithms are able to differentiate between human and animal signatures except in those instances where they are similar. For example, a large dog and a small child have similar heart and respiration rates.

deployment of resources, allocation of victims to functioning health care facilities and establishment of priorities for search and rescue operations.

Current Capability: Tools for casualty modeling and prediction rely heavily on subject matter expertise and census data input. Models and prediction technology are often incident- or domain-specific. For example, there are several models currently employed in the public health arena, including ones that predict the epidemiological impact of communicable diseases. Others provide specific trauma care predictions. Incident-specific modeling exists for weather events (e.g., hurricanes, tornados), which can provide input to casualty-specific modeling tools. Responders also utilize traffic flow and community GIS data when available, although data accuracy is a concern.

Responder Goals:

- Generates probable locations and estimates of casualties based on specific characteristics of the incident
- Integrates information on areas of high-density population in the affected area or path of the incident
- Displays information and analysis on a GIS platform

State of Technology: There are several software applications available to project incident casualties, but they are generally not used by state and local response agencies because of significant training requirements. The Hazard Prediction and Assessment Capability (HPAC) modeling tool, developed by DTRA, models the dispersion of chemical, biological and radiological materials through the atmosphere and predicts casualties based on these calculations. The Consequence Assessment Tool Set (CATS) is another tool that calculates risks to the exposed population using inputs such as HPAC data and other model outputs.

There are other hazard-specific casualty models that can be applied to emergency response. For example, the U.S. Geological Survey developed the Prompt Assessment of Global Earthquakes for Response (PAGER) system that uses global earthquake fatality and loss models to estimate casualties from earthquakes.

Potential Challenges:

- Accurate census data on affected populations at the time of the incident are not always available. Some jurisdictions have overall population estimates for set times throughout the day, but the specificity requested as part of this RTO is not data that are traditionally collected by jurisdictions.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Data Integration and Decision Support for Casualty Detection

Relevance: There are multiple factors that influence the number of persons directly impacted by an incident, including their ability to be rescued, survivability and vulnerability to additional threats. Examples include time of day, weather elements, condition of transportation routes and other critical resources and likelihood of secondary hazards. Incident command needs the ability to integrate available data and information to deploy responders more effectively, including search and rescue teams, to those areas designated as a priority for casualty location and removal. Outputs of this RTO would also allow incident command to equip responders with the appropriate PPE, rescue gear, transportation and evacuation vehicles and medical supplies.

Current Capability: The preponderance of this capability is based on the experience of incident command staff. Responders cited there was no decision support capability focused on casualty detection. Systems exist that provide multi-layer integration of pertinent data, but there are no applications or modules in those systems that focus specifically on casualty detection.

Responder Goals:

- Provides guidance on the location of potential casualties and the resource requirements to remove them from the affected area
- Graphically displays data and recommendations on GIS-enabled maps at a street-level scale
- Integrates key data sources, specifically including:
  - Location of CIKR within the projected area or path (for example, schools, hospitals)
  - Location of known and vulnerable hazards
  - Ongoing community events and activities
  - Location and information about special needs populations (for example, the number of bottled-oxygen-dependent persons)
  - Projected weather forecasts and data
  - Real-time traffic data showing congestion on critical transportation routes
  - Resource availability and specialized capabilities of hospitals and medical centers
- Integrates pre-event and incident-specific risk assessments

State of Technology: Recent efforts to fuse incident-related information have been applied specifically to the integration of search-related data. Using systems transitioned from a DARPA effort to provide information collection and sharing capabilities for warfighters, incident command is able to see the location of all search teams on the incident scene. In the field, teams are able to collect observations and information during the search (in multiple formats, including video files) and the data are visible to all users.

This capability is currently used by the U.S. Army and is being transitioned to public safety missions.

Potential Challenges:

- Data on special needs populations are not centrally collected by most jurisdictions. When collected, the information is not necessarily integrated with electronic situational awareness systems.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Indoor Casualty Geolocation

Relevance: Natural disasters and explosive events can cause extensive damage to structures, trapping people or rendering them incapable of leaving the scene or receiving medical attention. Likewise, chemical or biological events may leave victims incapacitated and unable to help themselves. This RTO is focused on the ability to identify the location of victims in three dimensions inside standing structures and below ground level. A key consideration for this RTO is that the victims are not wearing a tagging device to aid in the identification of their location. The indoor location of casualties is more difficult than the outdoor location, because GPS does not currently function effectively indoors and building materials shield the body from other sensors.

Current Capability: Responders have several options for locating responders inside structures or below ground. As described in the “Remote Sign of Life/Death Detection” RTO, responders use animals and multiple sensor platforms—including multi-spectral and infrared cameras, microphones, radar and sonar—to detect casualties. These sensors can be attached to manned or unmanned platforms. There are commercially available comprehensive systems developed specifically to detect and locate victims inside buildings; however, these systems generally use networked microphones or GPR to detect movement and vibrations of victims. Using this technology is labor intensive and depends heavily on responder experience and expertise.

In some instances, responders have demonstrated the use of smartphone technologies to identify the number or location of victims. Search teams use this technique to “ping” cellphones to obtain a head count of potential casualties or identify approximate locations. This capability is generally available in the short term, as most phones have a 24- to 48-hour battery life.

Responder Goals:

- Precisely locates victims (including latitude, longitude and height or depth) within one foot, up to 100 feet below ground
- Graphically displays data and recommendations on GIS-enabled maps at a street-level scale
- Transmits location data to incident command in real time

- Differentiates between single and multiple individuals, humans and animals, living and deceased
- Locates casualties from a standoff distance
- Includes confidence levels or margin of error (for example, person located at specific coordinates, margin of error within three to five feet)
- Operates continuously for a minimum of 12 to 24 hours

State of Technology: As described above, the S&T-funded FINDER system will allow responders to remotely determine whether living victims are trapped within a structure. Once the technology is commercially licensed and refined, search teams will be able to identify the location of individual physiological indicators within approximately five feet.

The potential exists to locate individuals using components or signals from personal cellphones. Most cellphones, particularly more advanced smartphones, are enabled to transmit a GPS location. Specific applications allow the user, or others, to find the approximate location of the phone as long as the location-tracking feature is on. The phone location is determined via the GPS signal in combination with triangulation data from nearby cellular towers. If these towers are damaged by the incident, or if bandwidth is overloaded by other communications, this capability may be degraded. Geolocation using cellphone tracking is restricted within buildings due to GPS signal blockage and provides limited data on height or depth.

Project Tango, a multi-entity collaboration, may address some of these deficiencies. The goal of Project Tango is to track the 3-D motion of a mobile device. Sensors in the device take millions of measurements each second to create a 3-D map of the space around the user.[86] The system uses simultaneous location and mapping (SLAM) technology originally developed for the U.S. military to track friendly forces. The system has the potential to locate devices enabled with this technology to within centimeters, including height or depth. Subject matter experts who participated in this study stated that phones enabled with this capability may be available in the near term.

Additional advances in this capability can be achieved through the integration of existing sensors onto alternate platforms such as UASs or UGVs. See the "Remote Monitoring of Threats and Hazards" RTO for a detailed description of the use of these platforms for emergency response missions.

[86] "Project Tango," Google, last updated: n.d., https://www.google.com/atap/projecttango/.

Potential Challenges:

- Current limitations on the use of UASs and UGVs prevent the deployment of search-related sensors on these platforms.
- The limited functionality of GPS within buildings hinders the use of devices that transmit GPS data.
- The use of personal devices to identify and locate individuals has several challenges. First, recurrent pinging drains the battery on these devices, diminishing the window that they can be used for geolocation. Second, many persons carry multiple devices, which may provide an inaccurate count of potential victims.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Outdoor Casualty Geolocation

Relevance: Casualties may be dispersed across large geographic areas following a catastrophic incident. For example, a tsunami or tornado can disperse casualties over many square miles, and an airline disaster could create a significantly large debris field.[87] Therefore, searchers need to identify the location of casualties across expansive areas and across varied terrain. As with the “Indoor Casualty Geolocation” RTO, the victims are assumed not to be wearing devices that aid in location identification, although personal property (for example, smartphones) may be used for detection. This RTO also addresses the location of casualties on the surface of bodies of water.[88]

Current Capability: Because outdoor geolocation is not bound by the same structural impediments as indoor geolocation, responders have more options at their disposal. In addition to the baseline capabilities used for indoor geolocation, responders may also use aerial line-of-sight searches, sensors (for example, FLIR) attached to airborne platforms and UGVs, satellite and aerial imagery and GPS locators. The technologies used for finding victims on the surface of bodies of water are similar to those for outdoor geolocation on land, although equipment may be mounted on marine vehicles.

Responder Goals:

- Precisely locates victims within one foot

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[87] The ground search area for the Columbia space shuttle disaster covered a 25,000-square-mile search area. The terrain of this search area included four national forests, two large bodies of water and large portions of land uninhabited and inaccessible by paved roads. While this is three times larger than most other National Transportation Safety Board investigations, it illustrates the expansive nature of potential search and rescue efforts.

[88] Subsurface casualties are covered in the following RTO: “Subsurface Maritime Casualty Geolocation.”

- Graphically displays data and recommendations on GIS-enabled maps at a street-level scale
- Transmits data in real time to incident command
- Differentiates between single or multiple individuals, humans and animals, living and deceased
- Locates casualties from a standoff distance
- Includes confidence levels or margin of error (for example, person located at specific coordinates, margin of error within three to five feet)
- Operates continuously for a minimum of 12 to 24 hours
- Incorporates terrain information

State of Technology: As discussed in the preceding RTO, many of the advances in search technology could result in the integration of sensors with advanced platforms. Subject matter experts interviewed for this study discussed the potential for integrating advanced sensors on UAS and UGVs. For example, Predator-sized UAS fitted with FLIR can be used to search wide areas. However, restrictions on where UAS can fly, the size of UAS used for domestic missions and the design and use of robots and other UGVs hinder advancement in this area.

Responders can use the electronic devices on victims for outdoor location, much more effectively than for indoor location. The transmission of GPS coordinates in cellular telephones, in combination with triangulation of proximity to cellular towers, can provide responders with a more accurate location. This capability can be used to query the cellphones of specific individuals who may be missing or can be targeted across a specific area to determine how many “pings” are returned and therefore approximate the number of victims. Advances in SLAM capabilities will provide significantly more data and could allow geolocation to within centimeters.

Potential Challenges:

- Current limitations on the use of UASs and UGVs prevent the deployment of search-related sensors on these platforms.
- As mentioned in the RTO above, the use of personal devices to identify and locate individuals presents several issues, including battery life and the potential for inaccurate victim counts.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Subsurface Maritime Casualty Geolocation

Relevance: Catastrophic incidents that occur in, over or near water can result in victims being trapped below the surface. Underwater geolocation involves different challenges than location on the surface: water conditions (for example, currents, floating debris) and depth often impair visibility; the survivability of victims is significantly diminished if they are trapped below the surface; water can mask signs of life and decomposition; and flow can transport victims over long distances. This RTO addresses only the location of casualties below the surface of the water.

Current Capability: Specially trained and equipped search and rescue dive teams currently exist to perform this function. Searches are carried out in specific patterns (for example, circular, spiral box). Team members on the surface may help guide the searchers if the water is clear. These teams use a variety of passive and active sonars. Sea mammals such as sea lions and dolphins are occasionally used to assist search and rescue teams. Technology currently used for underwater search and rescue also includes cameras, microphones and self-initiating GPS locators. The U.S. Coast Guard also employs water-current mapping and models using dummies and dye packs to help with underwater searches.

Responder Goals:

- Precisely locate victims within one foot
- Graphically displays data and recommendations on GIS-enabled maps
- Transmits location data to incident command in real time
- Differentiates between single and multiple individuals, humans and animals, living and deceased
- Locates casualties from a standoff distance
- Includes confidence levels or margin of error (for example, person located at specific coordinates, margin of error within three to five feet)

State of Technology: Remotely operated vehicles (ROVs) can conduct underwater searches without endangering the lives of divers. ROVs have multiple applications, primarily for offshore drilling, but the technology has recently adapted to underwater search and rescue. Responders used ROVs to search for victims of the South Korean ferry accident in April 2014.

Potential Challenges:

- Water characteristics (for example, salinity, clarity, wave size) significantly impact the effectiveness of subsurface search efforts. There is limited ability to control these characteristics and improve search conditions.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	

Casualty Management Path Forward:

Subject matter experts identified the following technology programs as necessary to meet some or all of the responder goals listed in the casualty management RTOs above.

- Iterative design improvements for technologies in development and obtain special temporary authorization from the FCC for use of unlicensed spectrum for search and rescue training
- Develop algorithms that model casualty density and locations based on real-time incident data and specific to GIS-correlated segments of the population
- Develop algorithms that produce recommendations for search and rescue priorities and integrate with a comprehensive decision support system
- Continue development of SLAM technology to locate persons using personal hand-held devices
- Continue development of untethered ROV platform and sensor packages

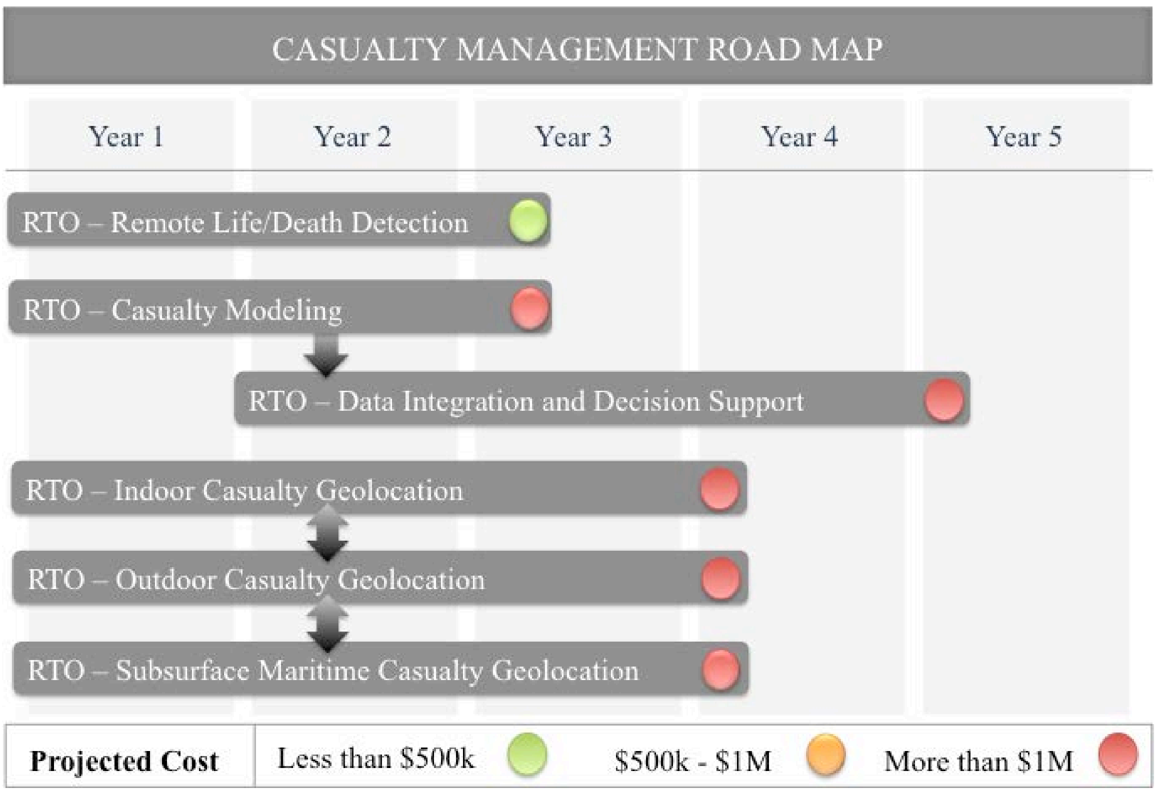

Figure 23. Casualty Management Technology Road Map

Training and exercise is defined as the ability to provide instruction on necessary skills for catastrophic incident response and coordinate and practice the implementation of plans and potential response prior to an incident.

There is one capability statement in this domain:

Readily accessible, high-fidelity simulation tools to support training and exercises in incident management and response

The efficacy of responders is improved through training and exercises. However, training and exercises for response to catastrophic incidents often fail to replicate operational needs and incident effects in a cost-effective manner. Issues with cost, participation and a lack of realism impact the efficiency and effectiveness of the full-scale live exercises held most frequently to prepare for large-scale incidents. Responders would like simulation capabilities that include realistic missions, tools and decision points. Such simulations could allow a large number of responders to train repeatedly and frequently and provide them the opportunity to test their performance in a wide variety of scenarios. Training could be conducted by a variable number of participants, from a single individual to thousands of responders in an agency or region. Virtual training and exercises cannot replace the valuable personal interactions that live training provides for emergency responders. However, virtual training does provide numerous opportunities to significantly reduce infrastructure, equipment and manpower costs and increase responder proficiency.

Subject matter experts identified four RTOs that correspond with this capability:

- Multi-user Virtual Simulation for Training and Exercise
- Artificial Intelligence for Responder Roles and Responsibilities
- Physics-based Operational Elements
- User-specific Simulation Control and Customization

Multi-user Virtual Simulation for Training and Exercise

Relevance: Responders would like high-fidelity virtual simulation tools that allow participants from multiple agencies, disciplines and jurisdictions to train for coordinated incident response. A virtual simulation platform can decrease the costs associated with planning and executing full-scale exercises; increase participation across shifts, stations, agencies, jurisdictions and levels of government; and decrease artificial constraints, such as compressed timetables and always-available resources, that hamper training and exercises today. This RTO is focused on a simulation environment that allows a number of users to engage in scenarios that improve or test the skills needed for emergency response. Other RTOs (see below) address realistic roles and responsibilities, operating conditions and control and customization.

Current Capability: The technology for multi-user virtual training and exercise is readily available through commercial massive multi-player online games. These games provide the immersive environment that responders believe they need, but few systems have been adapted to response needs. Responders cited several platforms currently used for virtual training and simulation. While some provide detailed and highly realistic training and exercise experiences, none provide the ability for geographically dispersed responders to participate in large-scale response scenarios. For example, scenarios may be presented in two dimensions, allowing users to see icons moving on a map, but do not create an immersive experience. Other systems require participants to travel offsite to a central location, limit the number of users or roles or present a limited number of specific scenarios.

Responder Goals:

- Allows single, multiple player and/or massive multiple player interoperability
- Simultaneous and seamless interaction between two or more communities, agencies or entities from dispersed geographic locations
- Nearly real-time, simultaneous interaction between the simulation and all players
- On- and offline capability
- Browser-neutral platform
- Open-source programming
- Scalable virtual space to allow short-duration mini-events through complex incidents
- Low- or no-risk environment for players, creating no public record
- Assesses results against identified scoring or evaluation systems
- Ability to demonstrate and verify competency
- Includes real-time, faster than real-time, fast forward and rewind options
- Includes audio, visual and tactile feedback
- Ability to inject changes into the scenario
- Includes deterministic and stochastic effects
- Includes standardized and user-defined metrics of performance
- Provides opportunity for individual and collective after-action reviews
- Provides in-play trainee feedback

State of Technology: There have been significant advancements in virtual training and exercise over the past several years. Several systems have been developed or transitioned specifically for the emergency response community.

The U.S. Army's Simulation and Training Technology Center (STTC) has extensive experience in the development of advanced simulation-based training for warfighters. DOD's Joint Improvised Explosive Device (IED) Defeat Organization funded an effort known as the Enhanced Dynamic Geo-Social Environment (EDGE) through STTC to train warfighters for counter-IED missions. DHS S&T is now leveraging EDGE to create a simulation platform for emergency responders.[89] The ongoing program recently completed a training platform for law enforcement, EMS, fire, unified command and dispatch to virtually train on a simulated active shooter response. The prototype is built on a well-known game engine that is also used in many consumer first-person shooter and online role-playing games. The goal of the program is to create a customizable, multi-player online game that is interoperable with multiple user interfaces.

DHS also funded a similar effort to develop training for EMS personnel. Zero Hour: America's Medic is a single-player immersive simulation tool for training in triage, treatment, and incident command.[90] Users can choose from multiple scenarios, including mass casualty chemical, biological and explosive incidents and natural disasters.

Several commercial entities also offer emergency response and disaster management virtual training platforms. Currently, providers offer either virtual training at the corporate location or on location in the community. These platforms meet many of the responder goals listed above and offer some capabilities that might enhance an online virtual training and exercise system. For example, some commercial providers include simulator elements, such as vehicle controls, that can enhance the training experience. While much of this virtual training is not within the domain of the online multi-player simulation that responders are looking for, there are multiple components that may be integrated.

Potential Challenges:

- Equipment owned by public safety agencies may be insufficient to run state-of-the art gaming engines. Subject matter experts stated that systems developed for the response community should assume the use of "trailing edge" hardware. Response agencies should not have to purchase new platforms to use the system.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

[89] "Training First Responders for Active Shooter Response," DHS, last updated: November 21, 2013, http://www.dhs.gov/st-snapshot-training-first-responders-active-shooter-response.

[90] "Zero Hour: America's Medic," Applied Research Associates, last updated: n.d., http://www.ara.com/Projects/p_zero_hour.htm.

Artificial Intelligence for Responder Roles and Responsibilities

Relevance: During simulated training and exercises, some of the roles of responders will need to be filled by simulated players. For example, if a single law enforcement agency would like to conduct an exercise, the simulation system will need to replicate the actions of firefighters and EMTs. The decisions and actions of virtual players must mirror those of a real-life responder. Players must be able to interact with simulated responders in the same manner that they do with real participants.

Current Capability: Simulated players are known as non-player characters (NPCs). They are constructed using artificial intelligence (AI) that mirrors the actions and decisions of other players. Commercial online games incorporate highly detailed simulated players, but development of NPCs that mimic responders has been limited.

Responder Goals:

- Ability to create a discipline-specific avatar that can interact with NPCs controlled by AI
- Development of NPCs representative of:
  - Traditional response agencies (fire, law enforcement and EMS)
  - Nontraditional entities (public health, hospital systems and nongovernmental organizations)
  - Hostile forces (for example, an active shooter)
  - Victims and members of the public
- Avatars that accurately represent a gender-specific human form
- Includes physical and mental stressors for players
- Ability for users to play the role of Mother Nature, hostile forces or victims
- Vertical integration and simulation of government roles
- Option for AI to assume role of users who leave the simulation

State of Technology: Subject matter experts report that the development of AI is one of the most complex areas in online simulation and gaming. NPCs have to not only mirror the actions of characters, but also correctly execute a range of decisions. For example, a simulated firefighter must make the same choice as a real firefighter when confronted with the choice between rescuing a baby on the third floor and responding to a fire on the second floor. NPCs that do not act appropriately can degrade the user experience in the training and exercise environment.

The complexity of NPC development depends on several factors. The first is whether the scenario is intended for part-task or full-task training and exercise. It is easier to develop a triage-only NPC for EMT training than one that mirrors the full knowledge and experience of the EMT. The more complex NPC can be used in a wider range of scenarios but is more difficult to develop. The second factor is whether the NPC will be used in a single-player environment or a multi-player environment. NPCs in single-player environments often act as "buddies" who provide advice and recommendations to players. NPCs in multi-player environments play a less prominent role. A third factor is the number of scenarios in the simulation environment. Responders perform different actions depending on the type of incident, which must be mirrored in the development of the NPC. For example, responders don different PPE when responding to a chemical spill than they do when rescuing trapped persons after a building collapse. The NPC must choose the correct actions that correspond with the scenario.

Potential Challenges:

- The level of detail embedded in the AI is a function of cost. Available funding largely dictates the realism that can be portrayed through the NPCs.

Anticipated Benefits	
Responder Safety	❖
Population Safety	
Consequence Mitigation	
Decision Support	❖
Multi-incident Utility	❖

Physics-based Operational Elements

Relevance: The virtual simulation environment must be built on appropriate models to replicate realistic responses and actions. Users will need to identify courses of action, make decisions and act on those decisions within the framework of the scenario. Responders cannot learn from training or exercise if the system does not generate realistic consequences of their actions. For example, virtual triage training for a mass casualty incident will not be effective if simulated victims do not have appropriate physiological responses. The scenario and environment should set the incident conditions to reinforce operational and management skills that will be necessary during a real-life incident response.

Current Capability: Some of the advanced simulation-based training available to responders incorporates physics-based models into the environment (for example, fire and smoke propagation models). In addition, several systems developed for mission-specific training rely on model outputs. For example, simulation-training systems for explosive ordnance disposal (EOD) rely on blast propagation models to govern results within the scenario.

Responder Goals:

- Realistically replicates all elements of incident response
- Realistically represents weather and incident effects
- Accurately portrays virtual objects, characters and environmental effects in three dimensions
- Capability to vary volume levels to reflect cause and proximity of sounds

- Developed with validated physics, chemistry, mathematics and biological models and algorithms
- Ability to input historical data to improve the accuracy of effects

State of Technology: It is possible to incorporate scientific models into simulated training and exercise environments. For example, one developer recently integrated a destruction model, tying the extent of a building collapse in the scenario to variable factors that can be manipulated in the environment. However, many physics-based effects in simulation environments are scripted based on data points and flow charts. For example, the flow rate of water through a fire hose can be accurately depicted in the game without the development of a comprehensive model. The development timetable is increased with the inclusion of physics-based elements. One commercial developer created a fully physics-based gaming system, but it took four years to complete development.

Potential Challenges:

- Coding and design errors in the representation of elements that have a varying value could prove detrimental to the efficacy of the training or exercise. Responders cautioned about the use of models unless validated by Subject matter experts.

Anticipated Benefits	
Responder Safety	❖
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

User-Specific Simulation Control and Customization

Relevance: The utility of virtual training and exercise systems is improved if responders are immersed in an environment that mirrors their own operating conditions. Individual participants, agencies and jurisdictions would like the ability to design and produce operationally realistic scenarios centered on their specific needs. Responders believe they will be better able to prepare for catastrophic incidents if they can use the geography of their own jurisdiction instead of a generic city. For example, a virtual exercise that simulates an explosion at a chemical plant will have a greater impact if responders are familiar with the critical infrastructure (for example, schools, hospitals) in the path of the chemical plume. The ability to customize the training and exercise scenarios will likewise help responders prepare for the incidents that they may be most likely to encounter.

Current Capability: Responders reported that they are largely unable to customize existing virtual training and exercise products. Classroom-based virtual training centers are an exception, as they allow users to choose from a selection of scenarios, environments and objects. There are image libraries of customized towns, municipalities, cities or localities for a limited number of locations that have been designed for large-scale exercises. To date, virtual training and exercise systems have not integrated these images. Existing simulation products generally contain a set number of universal scenarios and offer a geo-typical instead of a geo-specific environment.

Responder Goals:

- Ability for user to design training and exercise scenarios
- Includes geographically correct infrastructure and terrain features derived from GIS data
- Ability to incorporate jurisdiction-specific resources
- Presence of customizable skins (for example, coloring for uniforms, apparatus, buildings)
- Ability to add the location of community-specific known hazards into the virtual environment

State of Technology: Creating a geo-specific location for a virtual simulation requires 3-D digital renderings of the selected infrastructure in that community. It is not technically complex to create a 3-D rendering. One process for creating a rendering is to download street-level imagery, which is readily available online for large parts of the country at no cost. Multiple providers maintain repositories of digital image files for buildings and infrastructure in the United States. As an alternative to downloading imagery, a jurisdiction could purchase or rent a mobile LIDAR platform that could be driven through the community to obtain ground-level images. The USGS produces digital topographic maps of the United States, which are downloadable at no cost and can be integrated into a 3-D rendering of a community.[91] Location-specific images are uploaded to a software program that allows the user to produce a 3-D rendering, complete with accurate placement of exterior details (for example doors, windows). Some systems allow users to include a high-degree of specificity, including the composition of construction materials and the type of window glass on the structure. Some programs also allow users to extend the rendering to include the interior of a structure, allowing specific placement of walls, stairways, doors and even furniture. A jurisdiction can produce 3-D renderings at varying levels of detail.

A level designer integrates digital location data into the engine platform to create a polished visual display. This process is necessary to script how the AI elements will move within the environment.[92] Coding is necessary to define boundaries and movement parameters. For example, characters cannot walk through walls. Systems recently designed for DOD allow some scenario-editing capability, allowing users to define a set of variables, such as the number of players per team or real-time injections of scenario elements. However, the integration of customized or editable locations requires specialized skills.

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[91] "The National Map," U.S. Geological Survey, last updated February 27, 2014, http://nationalmap.gov.

[92] A script is a series of instructions written into software code that are used by another software program. The process of writing these instructions is called scripting.

Potential Challenges:

Anticipated Benefits	
Responder Safety	
Population Safety	❖
Consequence Mitigation	❖
Decision Support	❖
Multi-incident Utility	❖

- Each jurisdiction will likely have to bear the costs of creating a 3-D rendering of the infrastructure in its community.
- Although not technically complex, it is time-consuming and expensive to produce 3-D renderings. The combination of cost and duration of the project may limit the scope of the effort.
- Some jurisdictions may be able to afford “boutique” map development, which creates a customized rendering of a specific location within a simulation environment. High costs make this option unaffordable to all but the largest jurisdictions.

Training and Exercise Path Forward:

Subject matter experts identified the following technology programs as necessary to meet some or all of the responder goals listed in the training and exercise RTOs above.

- Continue development of multi-user simulation platform for emergency response-related training and exercises
- Develop an initial set of five NPCs per discipline to perform tasks or provide feedback in a virtual simulation environment
- Identify those elements of the simulation environment that have a varying value
- Develop an integration standard for geospecific 3-D digital renderings

* Physics-based Operational Elements
+ User-specific Simulation Control and Customization

Figure 24. Training and Exercise Technology Road Map

CONCLUSION

Technology Plan Summary

This document is the product of the PR4 effort. The purpose of this effort was to examine the state of science and technology for opportunities to address the highest-priority capability needs for emergency response to catastrophic incidents and to develop a plan to address those needs. Two important groups of people made the development of this plan possible.

The first are emergency responders, who respond to catastrophic and routine incidents and who ultimately will use these improved tools, equipment and systems. The responders who participated in PR4 were drawn from traditional and nontraditional public safety disciplines, jurisdictions diverse in size and location and multiple levels of government. The responders identified, described and prioritized the capability needs, and provided qualitative and quantitative goals for needed improvements in those capabilities.

The second group includes Subject matter experts from fields related to the capability needs. Subject matter experts from private industry, academia, federal research agencies and national laboratories participated in the data-gathering efforts. HSSAI spoke with individuals who gave generously of their time to discuss the state of technology and proposed development paths to address responder needs. HSSAI relied on the input and feedback of these groups to ensure that each RTO reflected operational considerations and each was based on an actionable and achievable technology path.

Capability Needs

This document identifies 14 capability needs that responders believe represent the highest priorities for improving their ability to respond to catastrophic incidents. Each of the capability needs may be improved, in whole or in part, through the application of technology solutions. The capability needs include enduring needs identified across the previous phases of Project Responder and emerging needs that will allow responders to leverage technological advances occurring in other fields. Responders prioritized these needs based on their impact on responder safety, population safety, consequence mitigation, decision-making and utility across multiple incidents.

Response Technology Objectives

This plan identifies 42 RTOs that address the PR4 capability needs. The RTOs translate the capability statements into actionable, technology-centric objectives. Each identifies a high-level technology solution (or part of a solution) designed to improve the capabilities of the response community. Each capability need has at least one corresponding RTO, and some RTOs can address multiple needs. The RTO descriptions include projects that represent a proposed path forward for increasing capability. The projects identified in this plan range from short-term initiatives, requiring less than six months of effort, to multi-year research and development programs that may cost tens of millions of dollars.

HSSAI’s analysis for PR4 indicates that many of the technologies already exist, though they may need to be customized to meet the operational needs of the response community. Unfortunately, this is not always an easy process. The varying operational environments of responders require tools and equipment that can operate in extreme conditions (for example, high temperatures and humidity, lack of reliable power and communications infrastructure) for extended periods of time. Technologies developed for other fields may need to be reengineered to function in these conditions, which often results in added weight and loss of functionality. In addition, a product designed or redesigned for responders may need to comply with a number of stringent performance and testing standards, some of which should be updated or rewritten to reflect advances in technology.

Key Finding

Many of the potential technology advances will not be possible without the ability to transmit and integrate multiple sources of data. Many of these advances are dependent on sensor systems that provide real-time data about the location of responders, victims, hazards, and resources, the monitoring of physiological data and the progress of activity on the incident scene. Leveraging this technology could significantly improve the safety of responders and the public. However, without a data communications infrastructure, sensors will be able to collect data but may not be able to transmit it to incident command. Further, without a system to integrate the data, decision-makers may not be able to effectively assimilate and understand the large amount of incoming data. For example, the ability to identify the position of a trapped responder in three dimensions, inside a building, is a useful capability only if that data can be quickly and clearly transmitted to the appropriate persons.

Path Forward

Since 2001, the Project Responder initiative has sought to identify and describe the multi-disciplinary capability needs of the response community. This is important because the unique structure of that community significantly influences the technology development and acquisition process. The response community is made up of thousands of career and volunteer agencies from multiple disciplines, each with different priorities and requirements. There is no central coordinating body to gather requirements, obtain economies of scale in procurement, or to fund the development of new capability needs. Since 2003, DHS has sponsored Project Responder to identify the areas where federal investment can make the greatest impact. This plan informs S&T as it makes investment decisions and proceeds with an acquisition strategy designed to address the enduring and emerging emergency response needs. The capability needs and the related RTOs also provide technologists with a vision toward which they can direct their efforts.

The identification of the capability needs and response technology objectives described in this plan are the first steps in providing emergency responders with the capabilities needed to more effectively respond to a catastrophic incident. The responder goals listed in this document provide a high-level overview of what the responders believe is necessary for capability improvement. The projected costs and timetables contained in the technology road maps describe resource requirements at a rough order of magnitude based on those high-level goals. Subject matter experts were hesitant to project time and resource requirements for the potential development programs without a complete description of functional and operational requirements and a defined timetable to meet objectives. For example, identifying overall development costs for an integrated logistics management system is difficult without a detailed understanding of the required inputs and outputs of the system.

There are two primary avenues that DHS can pursue to improve the capabilities of emergency responders based on the information presented in this plan. The first is the development of detailed requirements documents, preferably at the RTO level. The second option is the solicitation of development proposals from private industry, academia and national and federal laboratories that outline their solutions for addressing capability needs.

The first option entails a full requirements-identification process to pinpoint technical specifications. DHS could conduct or sponsor efforts to identify detailed quantitative and qualitative requirements. For example, this process should identify specific thermal loads or water resistance limits articulated by responders. The requirements process should also determine detailed milestones, metrics of success, and costs at a more programmatic level. The output of this process is often called an operational requirements document (ORD). DHS can then solicit proposals to meet the specific requirements described in the ORD.

In the absence of a full requirements analysis, the second option is the development of a statement of objectives (SOO). An SOO is used by DHS to describe a requirement at a higher level than an ORD. The SOO can provide technology developers with sufficient information to allow them to suggest programs that may address responder needs. Developers are not provided with the same depth of information, but are able to propose different solutions to address the capability need. Using the SOO process allows to assess the proposed programs against available budgets to make annual programming decisions.

As technology developers consider responder capability needs, the goals listed in this plan should not be viewed as a set of minimum essential elements that must all be satisfied before new capability is introduced. Responders agree that incremental change through spiral development would provide greater benefit than waiting until all requirements can be satisfied. Finally, technological advances should be integrated, to the extent possible, into all-hazards equipment that is used on a daily basis. Equipment that is used only for responding to and training for catastrophic events may not be used as effectively, if responders are unfamiliar with its operation.

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APPENDIX A. PROJECT RESPONDER 2001–2014

The Project Responder effort over the past decade can be divided into four distinct phases. The initial effort, from 2001 to 2004, was funded through a Department of Justice grant to the Oklahoma City National Memorial Institute for the Prevention of Terrorism. The original purpose of Project Responder was to identify operational needs, shortfalls, and priorities for response to catastrophic incidents and develop a technology investment plan to meet identified capability deficits. Shortly after inception, the focus of the effort was fundamentally shifted by the terrorist attacks of September 11, 2001. During development in the initial phase, emergency responders from multiple disciplines and a wide range of jurisdictions and locations participated in a series of interviews and responder workshops. The output of the data-gathering process was the development of a set of 12 capability areas that, as a whole, defined and described the requirements for response to a catastrophic terrorist event. The capability areas were referred to as National Terrorism Response Objectives. Following the identification of capability requirements, a second series of workshops queried technologists from national laboratories, academia and private industry to inform a national agenda for research and development and a corresponding set of road maps detailing new initiative designed to close gaps in emergency response capability.

The second phase of Project Responder was initiated in 2007 by the Department of Homeland Security (DHS) Science and Technology Directorate (S&T). The purpose of the follow-on effort was to examine changes in the emergency response effort since the first report and identify new and enduring capability priorities. Despite the short time frame between the first and second reports, significant shifts in the emergency response mission and needs occurred as a result of an increased focus on "all-hazards" (due in part to events like Hurricanes Katrina and Rita, failure of large-scale infrastructure like the I-35 bridge collapse, pandemic influenza, etc.) and the evolution of national response policy and doctrine with the release of the National Incident Management System and the National Response Plan (which was later revised as the National Response Framework). As a result, the second Project Responder report found significant changes to responder capability needs and related priorities. Emergency responders from a wide range of disciplines, jurisdictions and agencies participated in the effort through a series of interviews and workshops. The findings from the second Project Responder report, released in 2008, included a set of 15 capability priorities and associated challenges in training, technology, management and policy that responders felt constrained the further development of respective capabilities.

In 2011, a third Project Responder effort produced *Project Responder 3: Toward the First Responder of the Future*, examining capabilities needed to fill existing gaps and creating a vision of emergency response in the future. Project Responder 3 was funded by DHS, through a joint relationship between S&T's Support to the Homeland Security Enterprise and First Responders Group and the National Preparedness Directorate of the Federal Emergency Management Agency. In the years since the second Project Responder report was published, a number of economic, technological, infrastructural, and societal developments—as well as a change in the number and type of major incidents facing the nation—combined to change the response environment. DHS believed these changes warranted a reevaluation of capability gaps and resulting investment priorities. As with the two previous iterations, Project Responder 3 used facilitated discussions with a diverse set of responders throughout the United States to identify existing response capability gaps. Through these discussions, participants identified 40 capabilities needed to fill existing gaps. Among these 40 capabilities, responders identified a subset of 12 capabilities as those of the highest importance. Project Responder 3 also produced a compelling vision for potential capabilities that may be required in a future response environment, unconstrained by present-day resource or technical considerations.

PR4 is focused on examining the state of science and technology for opportunities to address the most persistent and highest priority capability needs and developing a plan to address those needs. PR4 continued the interactive discussions with emergency responders and subject matter experts to identify enduring and emerging capability needs; assess the state of science and technology to meet those needs; identify potential technology solutions; and develop road maps that illustrate a coherent technology path to addressing the high-priority needs.

Appendix B. Project Responder 4 Methodology

As described in the body of this plan, the methodology for this effort consisted of data gathering and analysis through four phases:

Phase 1: Identify and Validate Enduring and Emerging Capability Needs
Phase 2: Identify Technology Objectives
Phase 3: Identify Potential Science and Technology Solutions
Phase 4: Develop a Technology Plan and Road Maps

This appendix describes the methodology in greater detail with the goals for each phase, steps within each, and the activities needed to complete those steps.

Phase 1: Identify and Validate Enduring and Emerging Capability Needs

The phase 1 goal was to identify the capability needs that should be addressed in the plan and to validate those needs with a group of emergency responders. Phase 1 was completed using two steps: (1) identification of emerging and enduring needs, and (2) prioritization of capability needs.

For step 1, the Homeland Security Studies and Analysis Institute (HSSAI) facilitated a series of three virtual focus group meetings with emergency responders to determine and validate the set of capability needs to be addressed as part of Project Responder 4 (PR4).[93] The virtual meetings were held over a three-week period in August and September 2013. Participants included more than 75 members of both the First Responder Resource Group (FRRG) and InterAgency Board (IAB). During the virtual meetings, an HSSAI facilitator led participants through a review of the 40 capability needs identified in the Project Responder 3 report and discussed the capability needs that have been consistently rated as a high priority in previous Project Responder efforts. The HSSAI facilitator also asked participants to suggest new or evolving needs that have arisen or increased in priority because of technological advancements, social or cultural changes or other drivers. After analysis of the virtual meeting results, HSSAI identified 14 capability needs for assessment during PR4.

Fiscal considerations dictate that there will never be enough federal funding to address all emergency response capability needs.[94] It is necessary to prioritize among them to identify those where the need is greatest. For PR4, HSSAI wanted to identify those factors that make each capability a priority. HSSAI asked emergency responders from multiple disciplines to identify the factors that cause one capability to be ranked higher than another. The factors that emergency responders consider most heavily when prioritizing capabilities needs include the impact on responder safety, population safety,

[93] Virtual focus group meetings were held using a collaborative web-based system, allowing participants to review materials simultaneously, provide input and feedback verbally and through posted comments.

[94] The first *Project Responder National Technology Plan* identified 84 capability needs, many of which have received little or no funding for development or advancement.

consequence mitigation, decision-making and use across multiple incidents. HSSAI used these factors as the basis to develop an online prioritization tool.

In step 2, HSSAI developed an online tool that responders used to prioritize the PR4 capability needs and invited all members of the FRRG and IAB to participate. Participants rated the 14 PR4 capability needs according to overall priority, the factors identified above and the criticality of need.[95] The prioritization tool was distributed to all members of the FRRG and IAB. It was available over a two-week period. More than 125 responders participated, with a 90 percent response rate for each question.

Phase 2: Identify Technology Objectives

The phase 2 goal was to translate capability needs into technology objectives. Phase 2 entailed three steps: (1) data gathering to better understand the capability needs, (2) facilitation of a focus group meeting to identify draft response technology objectives (RTOs) and (3) facilitation of a workshop to identify responder goals for the RTOs.

It is not sufficient to simply state the emergency response capability needs. Without additional information, technology developers cannot move forward to make advancements. They need to understand the actual capability gaps—the difference between current capability and what responders believe is required to properly and successfully complete their tasks and mission. This requires a clear articulation of baseline capability—what responders have now—and quantitative and qualitative goals that describe what they believe is needed. In step 1 of phase 2, HSSAI facilitated discussions with members of the IAB's Strategic Planning Subgroup to gather initial data on baseline capabilities. Participants reviewed the 14 PR4 capability needs and provided information and data about their current capabilities (technology, policy, procedure and training) available for response operations.

RTOs translate responder capability needs into technology-centric objectives. In other words, an RTO should identify a high-level technology solution (or part of a solution) for a capability need. To develop the RTOs (step 2 of phase 2), HSSAI facilitated a focus group meeting in November 2013 between emergency responders with experience in catastrophic incident response and recognized technical subject matter experts in fields related to the capability needs. The purpose of the focus group was to identify the RTOs that correspond with the PR4 capability needs identified during phase 1. The HSSAI facilitator asked responders to describe each capability need in detail, explaining the operational issues that they face. Subject matter experts then translated those needs into technology objectives. The Subject matter experts identified 58 draft RTOs that correspond with the 14 PR4 capability needs during the focus group meeting.

It is difficult for Subject matter experts to identify a proposed path for improving capability unless they have a clear understanding of what the responders believe is needed. In March 2014 during step 3 of phase 2, HSSAI facilitated a workshop with 26 emergency responders. The workshop's purpose was for participants to characterize the tools they currently have available and to identify goals for each of the RTOs. HSSAI

[95] See Appendix C for a more detailed discussion of the PR4 prioritization process.

facilitators led participants through a detailed discussion of each RTO, asking them to comment on current capabilities, identify qualitative and quantitative goals and discuss potential challenges that might hinder development or adoption of new technologies. HSSAI invited participants from multiple disciplines, areas of the country and levels of government to obtain diverse points of view.

Phase 3: Identify Potential Science and Technology Solutions

The phase 3 goal was to evaluate the state of science and technology to identify potential technology solutions that meet responder needs. Phase 3 consisted of two steps: (1) data gathering and research on the technologies associated with the RTOs and (2) interviews with Subject matter experts.

Some RTOs require advancements in basic and applied research. Some RTOs necessitate new or continued development of existing technology programs, while others need only the transition of existing technology to the responder applications. In step 1 of phase 3, HSSAI researched the state of technology associated with the 58 RTOs to identify the use of similar technology in unrelated fields as well as ongoing research and development efforts. HSSAI analysts reviewed open source websites, publications, technical journals, conference proceedings, and other relevant sources. The purpose of this research was to provide contextual descriptions of the related technology and to identify Subject matter experts for the subsequent interview process.

In step 2, HSSAI engaged Subject matter experts from the national laboratories, academia, and private industry to provide input about each technology objective and to identify quantifiable development requirements. During a series of in-person and telephonic interviews, HSSAI asked the Subject matter experts to propose potential solutions for each RTO. In addition, HSSAI asked them to discuss anticipated costs and timelines and anticipated risks and challenges for the potential technology solutions. Subject matter experts were selected based on several factors including real-world experience, academic background, publishing credits and overall recognition within the domain. Based on the input of the Subject matter experts that some of the RTOs did not entail technology solutions, HSSAI reduced the number of RTOs from 58 to 42.

Phase 4: Develop a Technology Plan and Associated Road Maps

The goal of phase 4 was to assess and integrate the information from responders and Subject matter experts to identify actionable programs for increasing capability. Phase 4 entailed two steps: (1) characterization of proposed technology paths designed to improve capabilities, and (2) development of consolidated technology road maps within each domain.

In step 1 of phase 4, HSSAI assembled the inputs from the Subject matter experts and developed a coherent description of each RTO. Each RTO was described in terms of:

- Relevance: why advancements in the technology objective are necessary, including information on baseline capabilities and why the capabilities are currently insufficient;

- A program description: including the goals articulated by the responders during the workshop and a proposed path to achieve those goals based on the technologists' input; and
- State of technology: a description of the current maturity of the technology (in use and in development) and potential technology barriers that may inhibit further advancement.

In step 2 of phase 4, HSSAI developed a series of road maps that illustrate the projected timetables and estimated costs for each RTO. The road maps include new or transitioned technologies and knowledge products that can result in a measurable improvement in capability. HSSAI created one comprehensive road map for each domain.

HSSAI distributed a draft of the road map to and solicited comments and suggested edits from the FRG and all responders and Subject matter experts who participated in this effort. To the extent possible, HSSAI incorporated this feedback into the final version of this plan.

Appendix C. Project Responder 4 Prioritization Process and Results

In previous iterations of Project Responder, participants engaged in workshops to identify needed response capabilities and prioritize their importance. This approach was ideal because it provided a logical path to (1) learn what responders believe to be critical gaps in their ability to respond to catastrophic incidents, (2) identify specific capabilities required to meet these needs, and (3) prioritize these capability needs according to how urgent and important they are.

The Q methodology was well suited to rank order the large number of capabilities in previous Project Responder iterations. However, this technique is not suitable for understanding the underlying factors necessary to prioritize a small subset of enduring and emerging capability needs. The Homeland Security Studies and Analysis Institute (HSSAI) worked with survey experts to develop a uniform prioritization tool that is tailored to the subset of Project Responder 4 (PR4) capability needs. This approach analyzes specific factors that make each capability a priority. Knowing these factors will help guide investments to meet the highest-priority needs and improve catastrophic incident response.

This appendix provides a detailed discussion of the developmental steps and the implementation of the PR4 prioritization process.

Methodology

The prioritization process is a uniform method that emergency responders used to prioritize the PR4 capability needs. This process was developed and implemented using a four-step methodology, including (1) identification of prioritization variables, (2) development of a question set, (3) design of an online tool and (4) distribution and data collection.

Step 1: Identification of prioritization variables

To identify the factors that emergency responders use when ranking capability statements, HSSAI interviewed a group of responders from multiple response disciplines. Each responder was interviewed by telephone and asked to identify the factors he or she would consider when assessing the relative importance of a capability. To assist in the process, HSSAI used a small sample of capability statements to extract recurring factors in a consistent manner.[96] Responders were specifically asked to consider the sample

[96] Sample capability statements used to extract prioritization factors during the interviews include: 1) The ability to know the location of responders and their proximity to risks and hazards in real time; 2) The ability to identify what resources are available to support a response (including resources not traditionally involved in response), what their capabilities are and where they are, in real time; 3) The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground); and 4) The ability to remotely scan an incident scene for signs of life and decomposition to identify and locate casualties and fatalities.

capability statements to determine “what makes this capability a priority” and “what specific factors are considered when making this capability a priority.”

Responders identified six overarching variables that are considered when denoting a capability need as a priority. They stated that a capability would be prioritized higher if it accomplished one of the following:

1. Increased responder safety;
2. Increased the safety of the affected population;
3. Mitigated incident consequences;
4. Informed decision-making for incident management;
5. Improved the response for various types of incidents; or
6. Impacted the overall effectiveness or efficiency of the response.

Step 2: Question set development
The study team worked with a subject matter expert to develop a question set that would elicit the necessary information to prioritize the capability needs. The final question set included a series of questions for each capability to determine what makes it a priority. Participants were asked to rank each answer on a scale from 1 (lowest) to 7 (highest).

- How would improvements in this capability improve responder safety?
- How would improvements in this capability improve the safety of the affected population?
- How would improvements in this capability improve the ability to mitigate incident consequences?
- How would improvements in this capability improve decision-making for incident management?
- Can improvements in this capability be used in multiple types of incidents?
- Overall, how important a priority is this capability?

Responders were also asked to rank what they perceive to be the top three (in other words, most important) capability needs and the least critical capability need. Because priorities are subjective, HSSAI also developed questions to identify the discipline, level of government and jurisdiction of the participant.

Step 3: Online tool design
To conduct the assessment, the study team identified a customizable, online tool to walk responders through a uniform assessment of each capability statement. HSSAI used a research suite from Qualtrics.com that enabled the collection and analysis of responder provided data.

For each capability statement the tool provided a seven-point, Likert-style scale, with 7 representing the highest level of improvement for each priority. Below is an example of how the questions were presented to the responders.

Example

How would improvements in this capability improve ***responder safety***?

1 (not at all)	2	3	4	5	6	7 (a great deal)
○	○	○	○	○	○	○

Figure 25. Sample Question From Prioritization Process

Step 4: Distribution and data collection

HSSAI invited all members of the First Responder Resource Group (FRRG) and InterAgency Board (IAB) to prioritize the PR4 capability statements using the online tool. FRRG and IAB members received a link to access the tool. The prioritization tool was available from September 25 through October 7, 2013. A total of 135 emergency responders participated in the prioritization process.[97]

Responders from 31 states and multiple disciplines participated in the prioritization process.

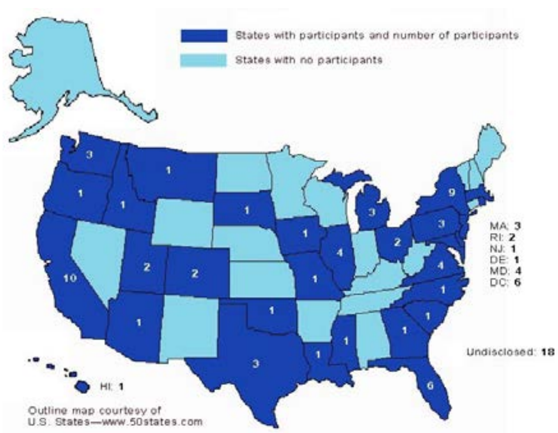

Figure 26. Prioritization Participation by State

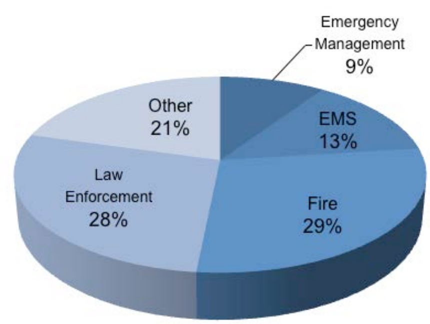

Figure 27. Prioritization Participation by Discipline

Results

The total mean score was collected for each of the questions in the prioritization process and analyzed by HSSAI.[98] The prioritization process results can be depicted in many

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[97] Although there were 135 participants, not all completed the prioritization process. Each question received between 117 and 128 responses (an average response rate of more than 90 percent). In total, 129 individuals completed the entire process.

[98] For the purposes of this study, the mean score is the average score of all the responses for a specific question.

different ways. The following sections are select tables and visual representations of the data that best reflect the objectives of this study.

The following table represents the top capabilities, based on the mean score of the combined responses to the priority questions for each capability statement.

Capability Need	Mean Score
The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)	6.3
The ability to know the location of responders and their proximity to risks and hazards in real time	6.1
The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time	6.0
The ability to rapidly identify hazardous agents and contaminants	5.9
The ability to remotely monitor the tactical actions and progress of all responders involved in the incident in real time	5.7
Protective clothing and equipment for all responders that protects against multiple hazards	5.4

Figure 28. Top Capability Needs Based on "Overall Priority"

Responders were asked to rank each capability need on a scale of 1 to 7; a ranking of 7 meant that achieving this capability would be the largest improvement to "overall impact" of a responder's ability to perform his or her job during a catastrophic incident. Figure 28 shows the top capability needs based on the overall mean score (in other words, combined average) for the responses to this question.

Most responders rated the following capability as having the greatest "overall impact" on their ability to respond to incidents.

- The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)

Capability in Rank Order	Priority Areas				
	RS	PS	MIC	DIM	CC
The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground	6.6	5.68	6.13	6.24	6.34
The ability to rapidly identify hazardous agents and contaminants	6.24	6.13	6.02	6.08	5.62

RS= Responder safety
PS= Population safety
MIC= Mitigate incident consequences
DIM= Decision-making for incident management
CC= Crosscutting capability
= Highest mean score for priority area

Figure 29. Top Capability Needs Per Variable

The mean scores shown in figure 29 provide additional insight as to why each of the top capability needs is a priority. The following are the top three results for each priority area.

Most likely to improve **responder safety** during a catastrophic incident:

- The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)
- The ability to know the location of responders and their proximity to risks and hazards in real time
- The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time

Most likely to improve **population safety** during a catastrophic incident:

- The ability to rapidly identify hazardous agents and contaminants
- The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time
- The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)

Most likely to **mitigate consequences** during a catastrophic incident:

- The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)
- The ability to rapidly identify hazardous agents and contaminants
- The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time

Most likely to improve **decision-making for incident management** during a catastrophic incident:

- The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)
- The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time
- The ability to know the location of responders and their proximity to risks and hazards in real time

Most likely to **apply to multiple incident types** for catastrophic incident response:

- The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)
- The ability to know the location of responders and their proximity to risks and hazards in real time
- The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time

Additional metadata was collected for each participant, including his or her agency's city and state, level of government and emergency response discipline. Using specific metadata, such as response discipline, HSSAI was able to determine which disciplines ranked which capability needs highest. For example, the ability to know the location of responders and their proximity to risks and hazards in real time ranked highest among firefighters. The ability to incorporate information from multiple and nontraditional sources (for example, crowdsourcing and social media) into operations ranked higher among law enforcement personnel.

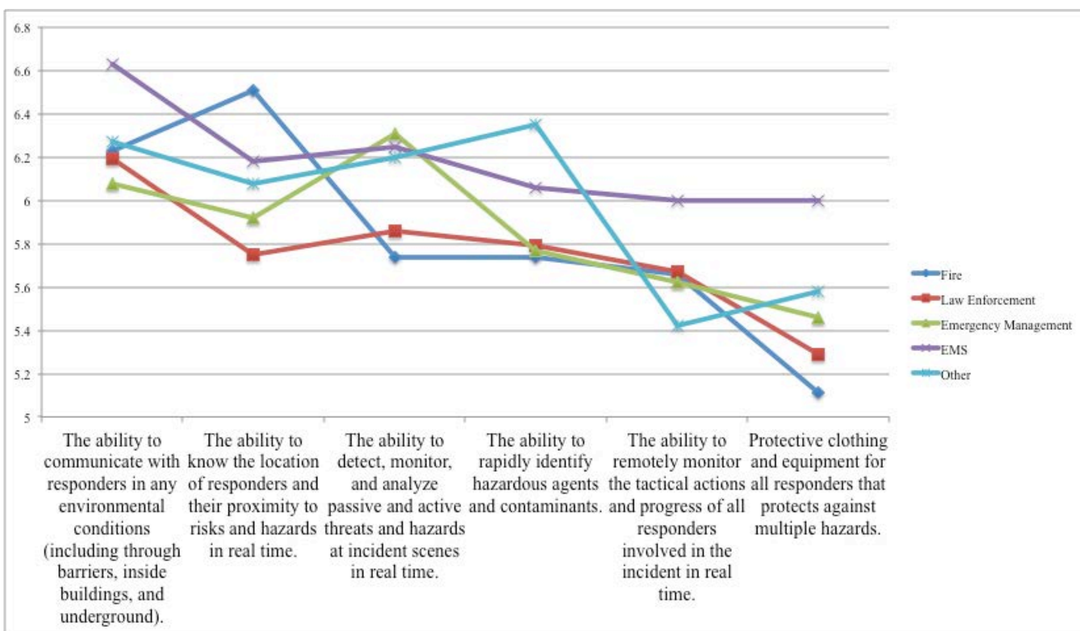

Figure 30. Top Capability Need by Discipline

Figure 30 shows how each discipline scored the top capability needs on a scale of 1 to 7. Each score depicted in the graphic is an average of the total responses from each discipline category for the top capability needs that would make the greatest impact on the overall response to a catastrophic incident.[99]

Top 3 Most Critical Capabilities	1	2	3	Total Votes
The ability to know the location of responders and their proximity to risks and hazards in real time	47	22	16	85
The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)	28	22	20	70
The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time	12	16	11	39
The ability to rapidly identify hazardous agents and contaminants	5	11	11	27
Protective clothing and equipment for all responders that protects against multiple hazards	7	9	4	20
Communications systems that are hands-free, ergonomically-optimized and can be integrated into personal protective equipment	2	10	6	18
The ability to incorporate information from multiple and nontraditional sources (for example, crowdsourcing and social media) into incident command operations	4	7	6	17
The ability to remotely monitor the tactical actions and progress of all responders involved in the incident in real time	3	3	11	17
The ability to remotely scan an incident scene for signs of life and decomposition to identify and locate casualties and fatalities	1	5	10	16
The ability to identify in real time what resources are available to support a response (including resources not traditionally involved in response), what their capabilities are and where they are, in real time	1	5	9	15
Readily accessible, high-fidelity simulation tools to support training and exercises in incident management and response	4	5	4	13
The ability to identify trends, patterns and important content from large volumes of information from multiple sources (including nontraditional sources) to support incident decision-making	2	4	6	12

[99] The 'other' discipline category consists of either retired, homeland security, federal agency or other emergency response professionals who are not affiliated with any of the other four categories (fire, law enforcement, emergency management and emergency medical services).

Top 3 Most Critical Capabilities	1	2	3	Total Votes
The ability to monitor in real time the status of resources and their functionality in current conditions	3	1	4	8
The ability to identify, assess and validate emergency-response-related software applications	2	0	0	2

Figure 31. Most Critical Capabilities

Participants were asked to consider all capability needs and rank the top three they felt were the most critical to achieve advances for catastrophic incident response. Participants selected a capability that was the single most (column 1), second most (column 2), and third most (column 3) critical. Figure 31 represents the responses ranked in order by the highest total votes per capability.

The following capabilities ranked the highest in order of votes for the single most critical capability need to address (column 1) as well as total number of votes for being either the first, second, or third most critical capability need:

- The ability to know the location of responders and their proximity to risks and hazards in real time
- The ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)
- The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time

Least Critical Capabilities	Votes	%
The ability to identify, assess and validate emergency-response-related software applications	70	59%
The ability to incorporate information from multiple and nontraditional sources (for example, crowdsourcing and social media) into incident command operations	10	9%
The ability to remotely scan an incident scene for signs of life and decomposition to identify and locate casualties and fatalities	9	8%

Figure 32. Least Critical Capability Needs

There is no doubt that all 14 capability needs are high priorities to the emergency response community; however, HSSAI asked participants to select the one capability they would consider being the least critical of the 14. Figure 32 shows three capabilities that were rated as least critical.

The majority of participants (59 percent) considered the following capability to be the least critical of the 14 capabilities:

- The ability to identify, assess and validate emergency response-related software applications

The following section examines each capability need independently and shows results using the mean score based on the seven-point scale for each variable.

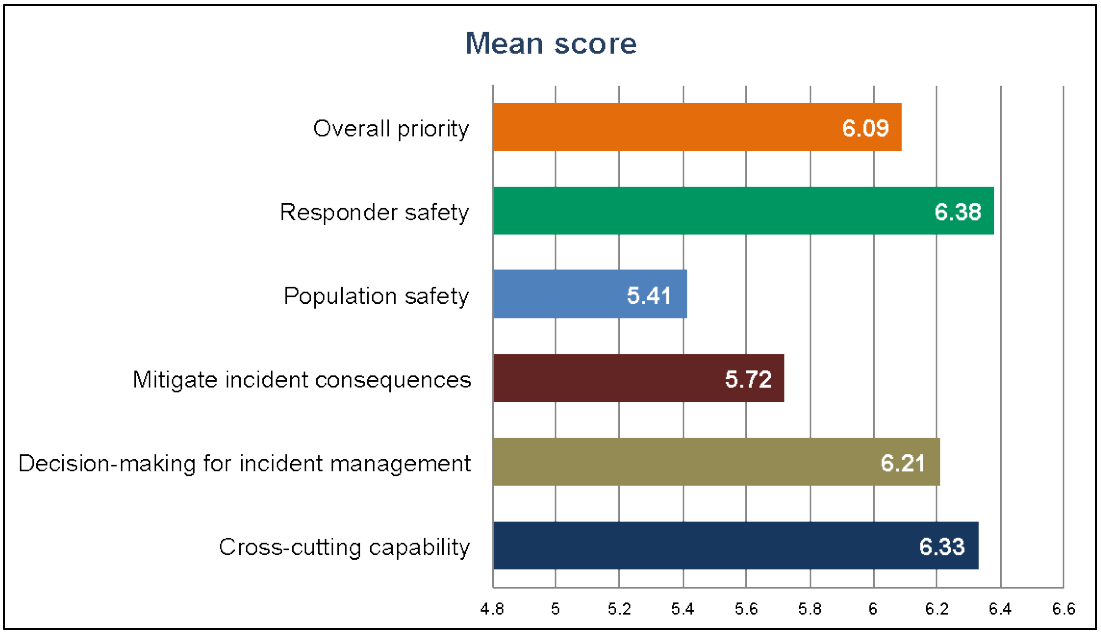

Figure 33. Mean Scores: ***ability to know the location of responders and their proximity to risks and hazards in real time***

Figure 34. Mean Scores: ***ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time***

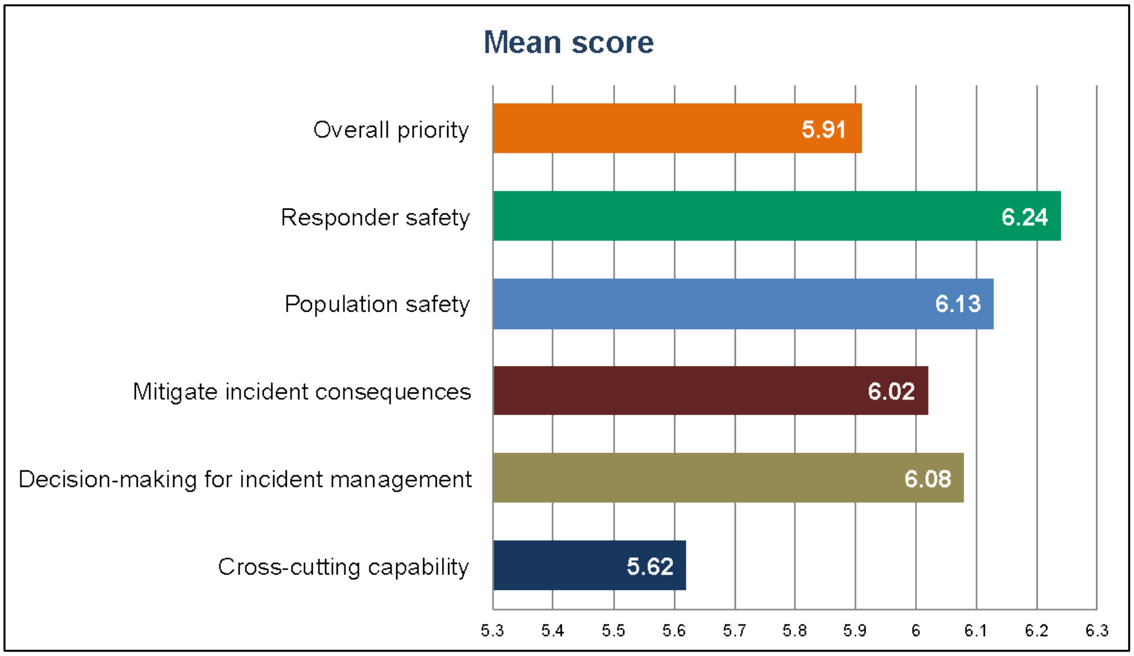

Figure 35. Mean Scores: ***ability to rapidly identify hazardous agents and contaminants***

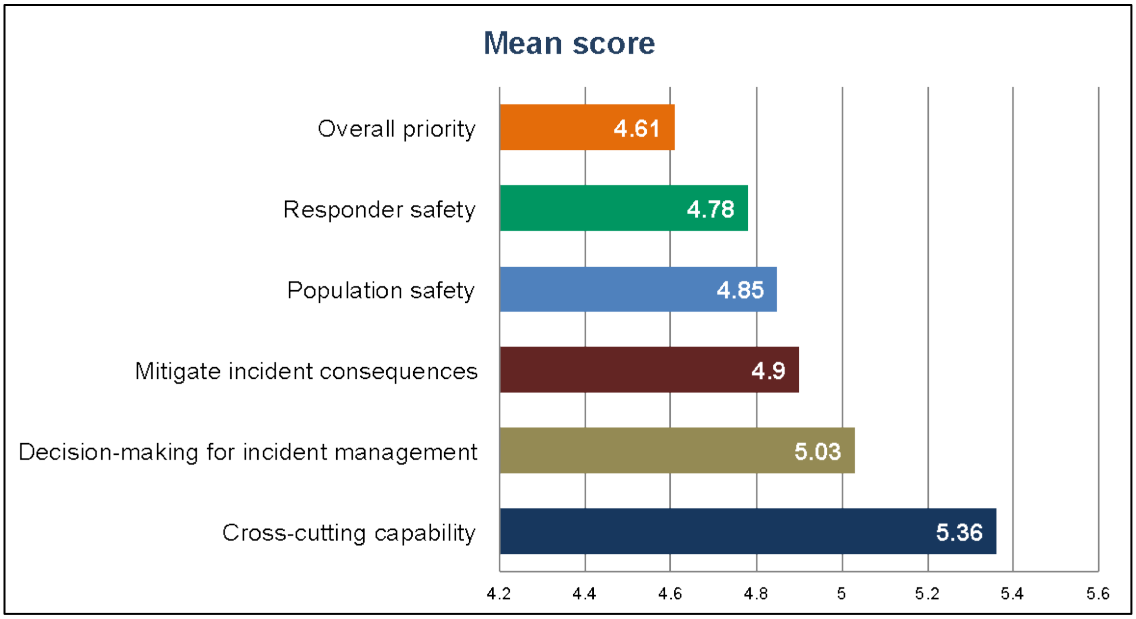

Figure 36. Mean Scores: ***ability to incorporate information from multiple and nontraditional sources (for example, crowdsourcing and social media) into incident command and operations***

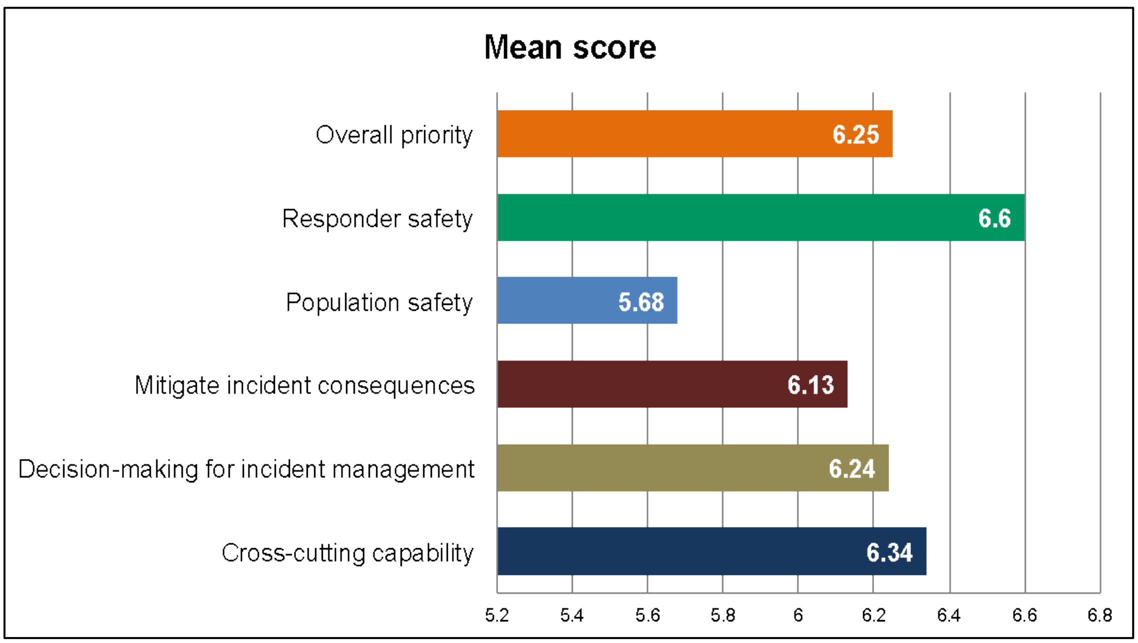

Figure 37. Mean Scores: ***ability to communicate with responders in any environmental conditions (including through barriers, inside buildings and underground)***

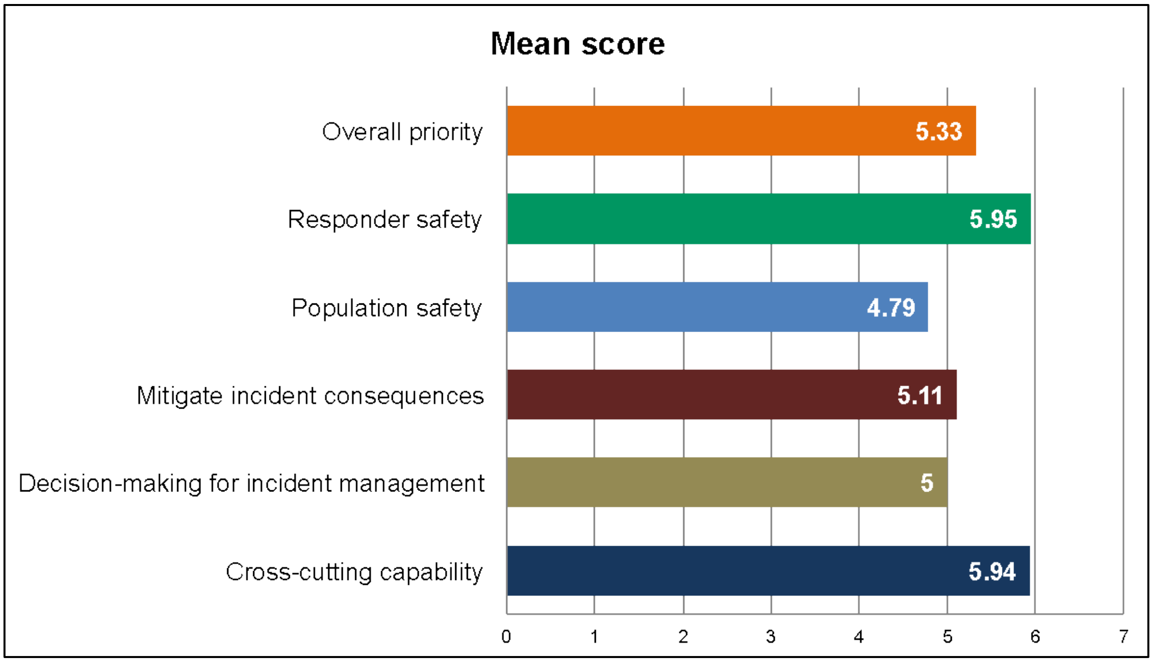

Figure 38. Mean Scores: ***communications systems that are hands-free, ergonomically optimized and can be integrated into personal protective equipment***

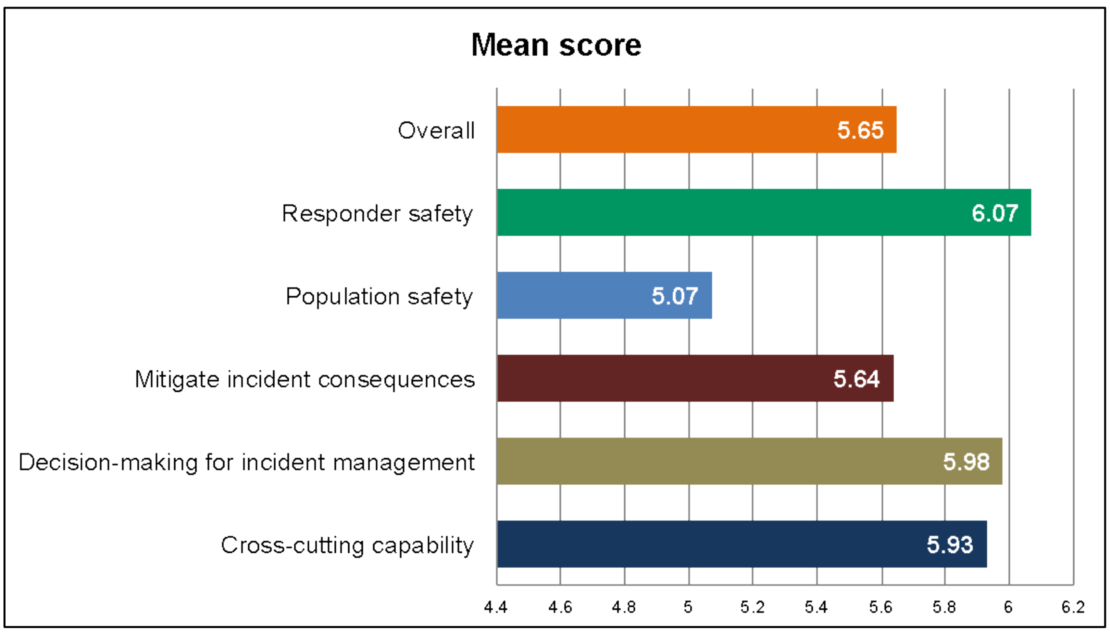

Figure 39. Mean Scores: ***ability to remotely monitor the tactical actions and progress of all responders involved in the incident in real time***

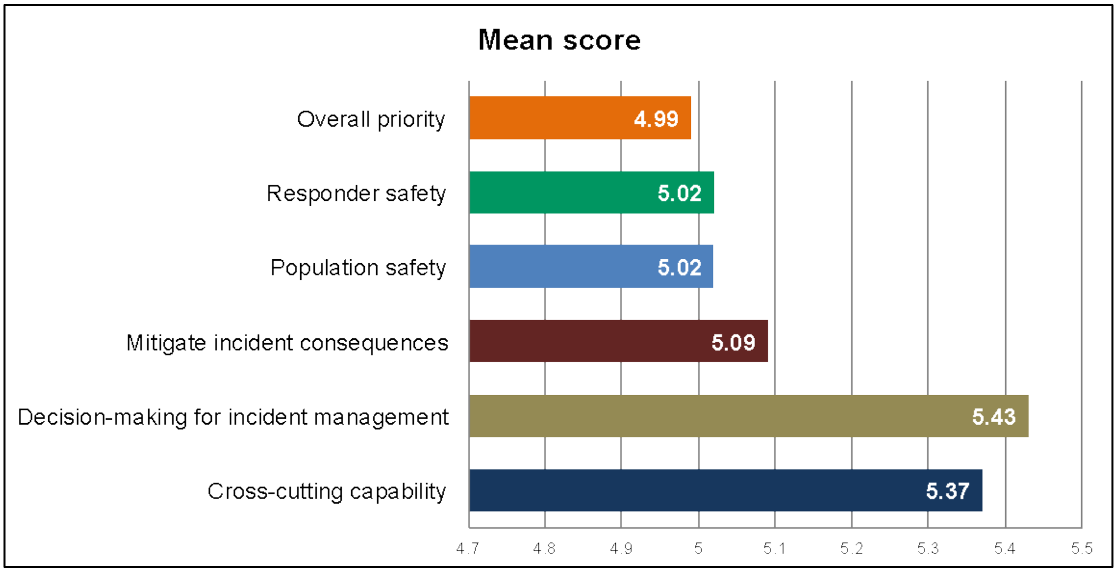

Figure 40. Mean Scores: ***ability to identify trends, patterns and important content from large volumes of information from multiple sources (including nontraditional sources) to support incident decision-making***

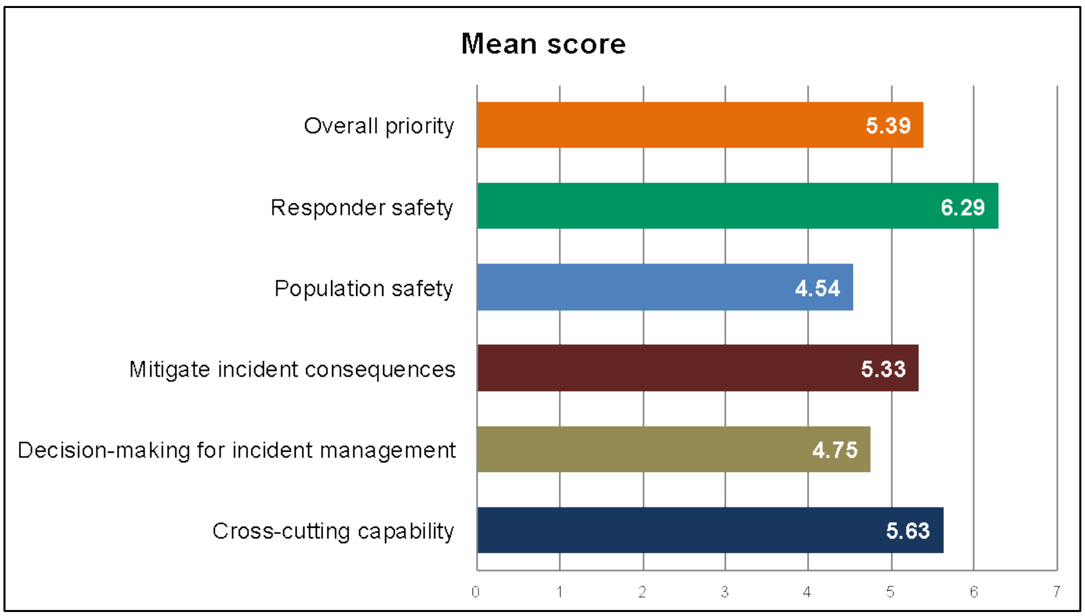

Figure 41. Mean Scores: ***protective clothing and equipment for all responders that protects against multiple hazards***

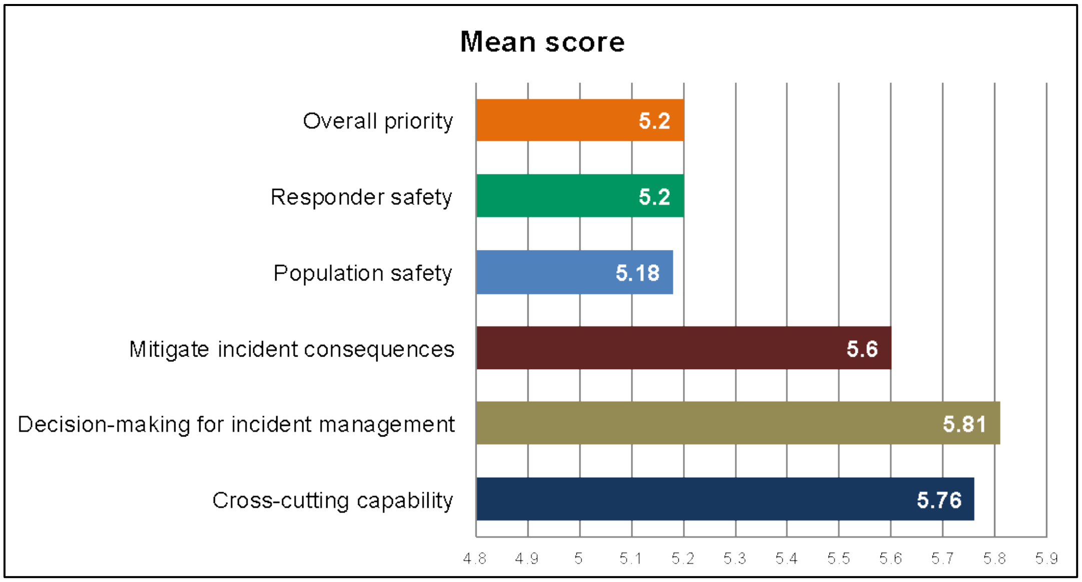

Figure 42. Mean Scores: ***ability to identify what resources are available to support a response (including resources not traditionally involved in response), what their capabilities are and where they are, in real time***

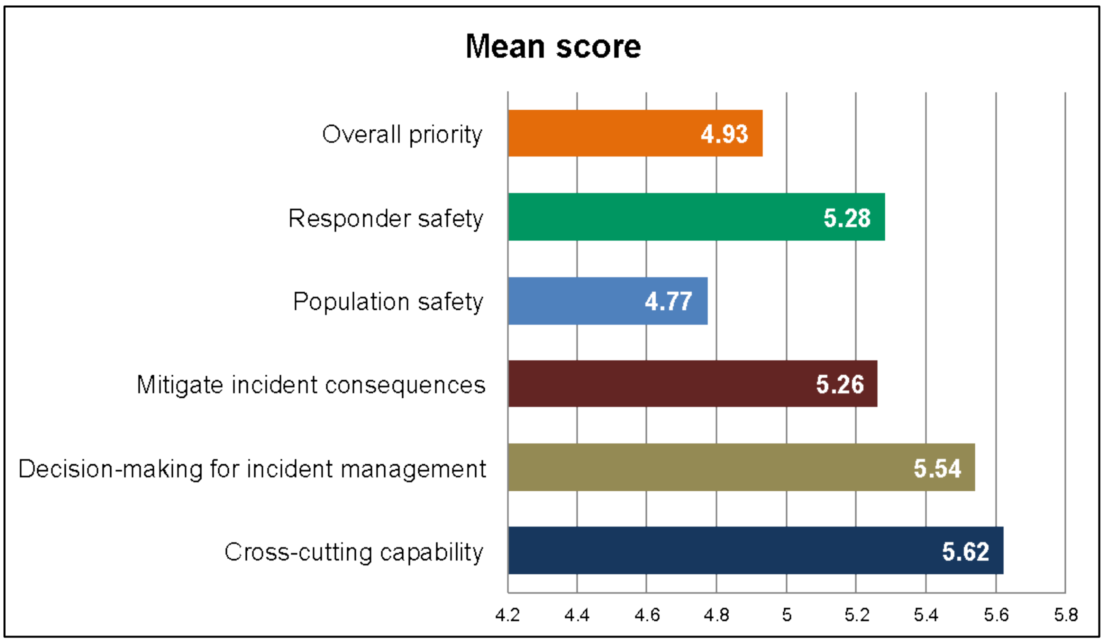

Figure 43. Mean Scores: ***ability to monitor the status of resources and their functionality in current conditions, in real time***

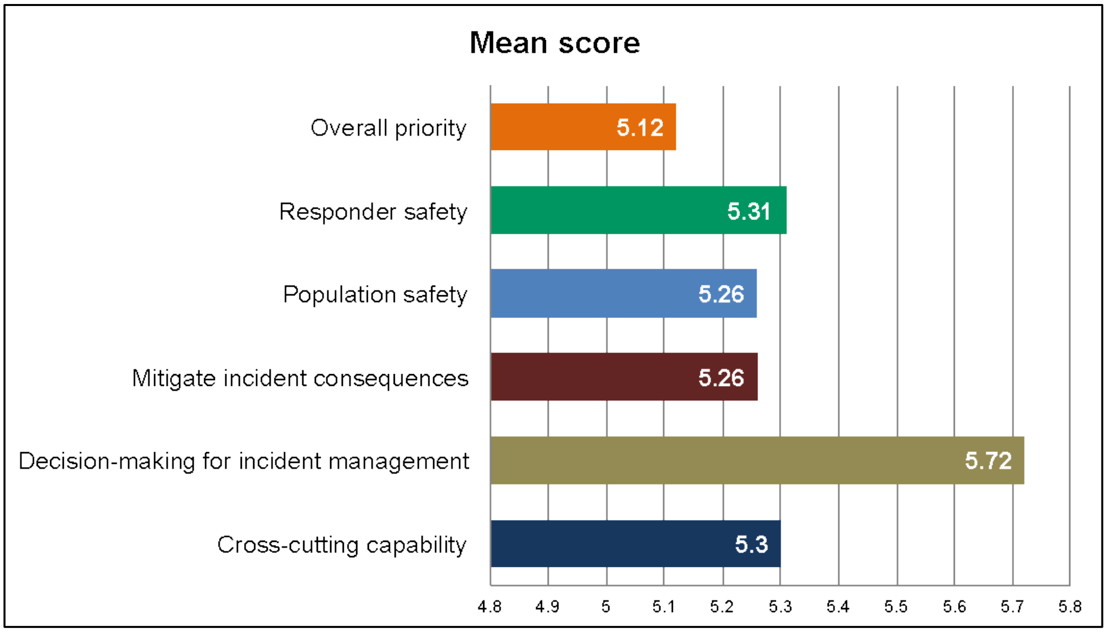

Figure 44. Mean Scores: ***ability to remotely scan an incident scene for signs of life and decomposition to identify and locate casualties and fatalities***

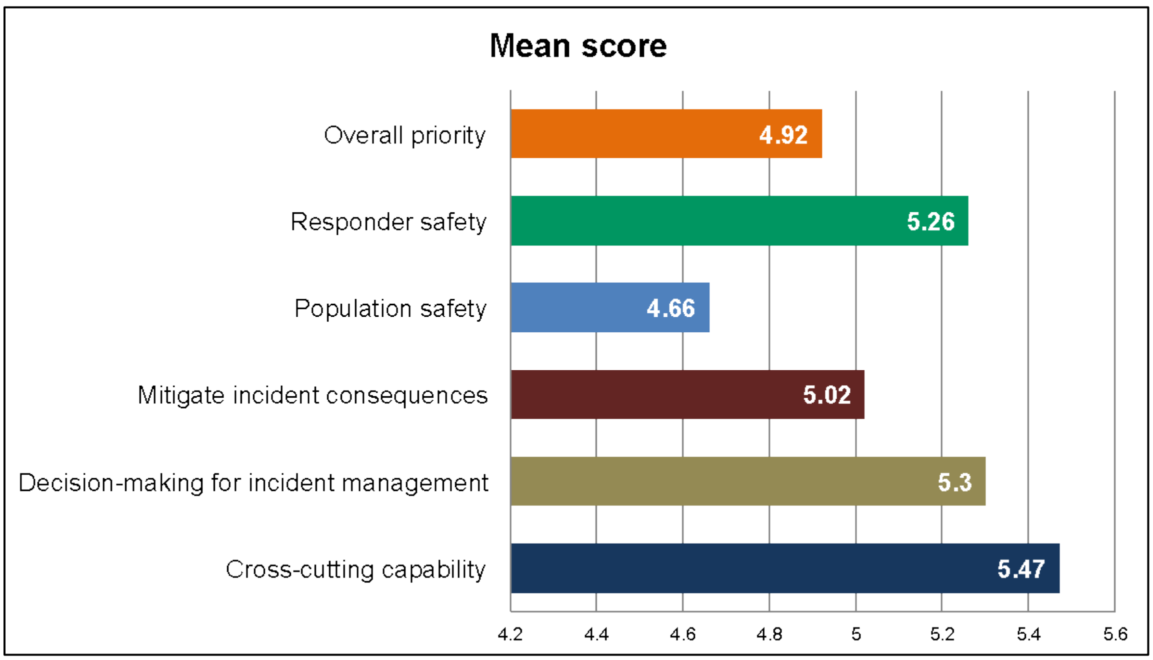

Figure 45. Mean Scores: ***readily accessible, high-fidelity simulation tools to support training and exercises in incident management and response***

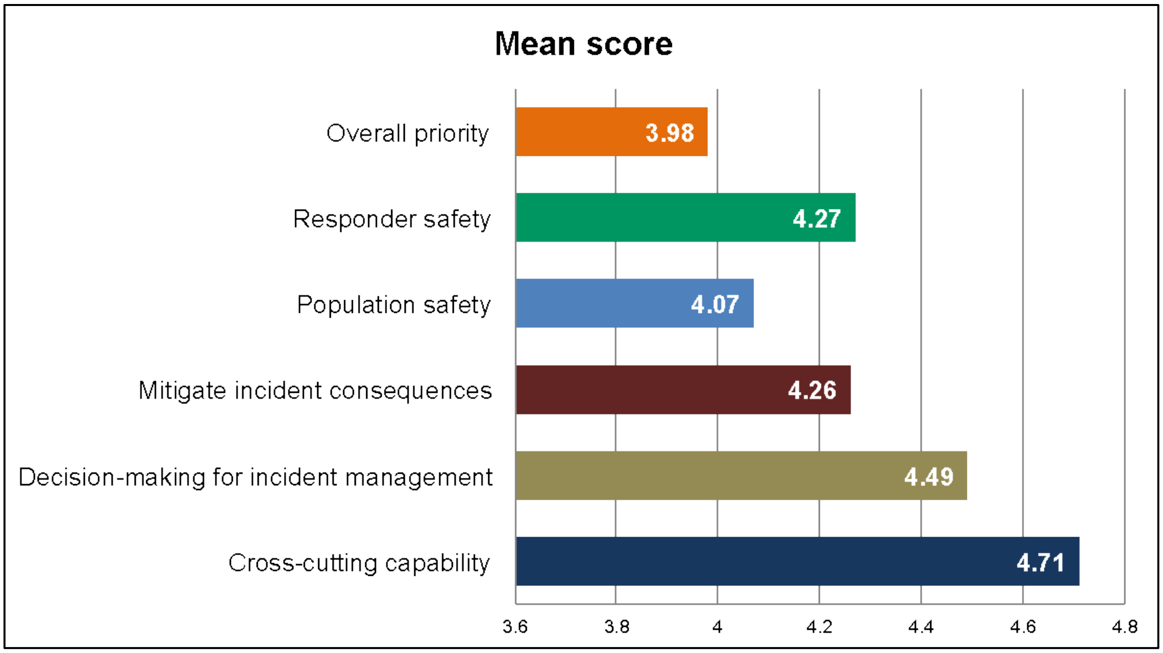

Figure 46. Mean Scores: ***ability to identify, assess and validate emergency response-related software applications***

Results of this prioritization process provide insight from responders on what the critical needs are for an effective response to a catastrophic incident. This insight should be used to help focus additional research and investment decisions for eventual technology development, transition and implementation. Particularly, the priorities shown in figure 30 for each discipline may be helpful for developers to understand who their primary customer may be for requirements generation and technology development. Other visualizations provided help decision-makers understand how the anticipated investments align with responder priorities.

Appendix D. Project Responder 4 Participants

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Name	Organization
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Name	Organization
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Name	Organization
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Appendix E. Acronyms

Acronym	Definition
AIS	Automatic Identification Systems
ANS	Adaptable Navigation Systems
AI	Artificial Intelligence
API	Application Programming Interface
ARGUS-IR	Autonomous Real-Time Ground Ubiquitous Surveillance - Infrared
ART	Adaptive RF Technology
AWARE	Advanced Wide FOV Architectures for Image Reconstruction and Exploitation
B2B	Business-to-Business
C3	Command, Control, and Coordination
CAD	Computer-Aided Dispatch
CAMEO	Computer-Aided Management of Emergency Operations
CATS	Consequence Assessment Tool Set
CCTV	Closed-Circuit Television
CIAB	Cell in a Box
CIKR	Critical Infrastructure and Key Resources
CIMS	Civil Support Team Information Management System
CMUVT	Compact Mid-Ultraviolet Technology
COLTS	Cell on Light Trucks
COP	Common Operating Picture
COTS	Commercial Off-the-Shelf
COWS	Cellular on Wheels
CSFV	Crowd Sourced Formal Verification
CST	Civil Support Teams
CTTSO	Office of Combating Terrorism Technical Support Office
D2P	Detect-to-Protect
DARPA	Defense Advanced Research Projects Agency
DBM	Distributed Battle Management
DHS	Department of Homeland Security
DM2	DoD Meta Model
DOD	Department of Defense
DoDAF	DoD Architecture Framework

Acronym	Definition
DTRA	Defense Threat Reduction Agency
EA	Edge Analytics
ECG	Electrocardiography
ECWCS	Extended Climate Warfighter Clothing System
EDGE	Enhanced Dynamic Geo-Social Environment
EGVs	Unmanned Ground Vehicles
EMP	Electromagnetic Pulse
EMS	Emergency Medical Services
EMT	Emergency Medical Technician
EOD	Explosive Ordnance Disposal
EPIRB	Emergency Position Indicating Radio Beacons
ERG	Emergency Response Guidebook
EXIF	Exchangeable Image File Format
FAA	Federal Aviation Administration
FBCB2/BFT	U.S. Army's Force XXI Battle Command Brigade-and-Below/Blue Force Tracking
FCC	Federal Communications Commission
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FFRDC	Federally Funded Research and Development Center
FINDER	Finding Individuals for Disaster and Emergency Response
FirstNet	First Responder Network Authority
FLIR	Forward-Looking Infrared
FREE	Flame Resistant Environmental Ensemble
FOV	Field of view
FRG	Support to the Homeland Security Enterprise and First Responders Group
FRRG	First Responder Resource Group
GLANSER	Geospatial Location Accountability and Navigation System for Emergency Responders
GPR	Ground-Penetrating Radar
GPS	Global Positioning System
GUI	Graphical User Interface
HAZMAT	Hazardous Materials
HITECH	Health Information Technology for Economic and Clinical Health

Acronym	Definition
HMI	Human-Machine Interface
HPAC	Hazard Prediction and Assessment Capability
HSARPA	Homeland Security Advanced Projects Agency
HSSAI	Homeland Security Studies and Analysis Institute
HUD	Heads Up Display
IAB	InterAgency Board
IBC	International Building Code
ICS	Incident Command System
IEC	International Electrotechnical Commission
ILMS	Integrated Logistics Management System
IMAAC	Interagency Modeling and Atmospheric Assessment Center
IMU	Inertial Measurement Units
ISO	International Organization for Standardization
IT	Information Technology
JPL	NASA Jet Propulsion Laboratory
JSON	Javascript Object Notation
KML	Keyhole Markup Language
KMZ	Keyhole Markup Language Zipped
LDM	Logical Data Model
LELs	Lower Explosive Limits
LIDAR	Light Detection and Ranging
LSCMS	Logistics Supply Chain Management System
LTE	Long Term Evolution
MDC	Mobile Data Computers
MERC	Medical Emergency Response Center
Micro-PNT	Micro-Technology for Positioning, Navigation and Timing
MIPT	Memorial Institute for the Prevention of Terrorism
MRSA	Methicillin-resistant Staphylococcus Aureus
NESC	National Exercise and Simulation Center
NFPA	National Fire Protection Association
NGA	National Geospatial Agency
NHC	National Hurricane Center
NIEM	National Information Exchange Model
NIMS	National Incident Management System

Acronym	Definition
NIST	National Institute of Standards and Technology
NLP	Natural Language Processing
NPC	Non-Player Characters
NPD	National Preparedness Directorate
NSRDC	U.S. Army Natick Soldier Research and Development Center
NTRO	National Terrorism Response Objectives
NwHIN	Nationwide Health Information Network
ORD	Operational Requirements Document
OSHA	Occupational Health and Safety Administration
PAGER	Prompt Assessment of Global Earthquakes for Response
PASS	Personal Alert Safety System
PES	Physical Exchange Specification
PHASER	Physiological Health Assessment System for Emergency Responders
PLB	Personal Locator Beacons
PPE	Personal Protective Equipment
PR3	Project Responder 3
PR4	Project Responder 4
RAN	Radio Access Network
RAPS	Robotic Aircraft for Public Safety
REMM	Radiation Emergency Medical Management
RF	Radio Frequency
RFID	Radio Frequency Identification
RKB	Responder Knowledge Base
ROSS	Resource Ordering and Status System
ROV	Remotely Operated Vehicles
RTO	Response Technology Objectives
S&T	Science and Technology Directorate
SAFER	Safer Warfighter Communications
SCBA	Self-Contained Breathing Apparatus
SDK	Software Development Kit
SELC	Software Engineering Lifecycle
SLAM	Uses Simultaneous Location and Mapping
SMS	Short Message Service
SOO	Statement of Objectives

Acronym	Definition
STA	Special Temporary Authorization
STTC	U.S. Army's Simulation and Training Technology Center
SUAS	Small Unmanned Aircraft Systems
SUMMIT	Standard Unified Modeling, Mapping, and Integration Toolkit
SWAT	Special Weapons and Tactics
TRRN	Texas Regional Resource Network
TSWG	Technical Support Working Group
TTP	Tactics, Techniques, and Procedures
UAS	Unmanned Aerial Systems
UHF	Ultra High Frequency
ULTRA-Vis	Urban Leader Tactical Response, Awareness and Visualization
USGS	United States Geological Survey
UV	Ultraviolet
VOCs	Volatile Organic Compounds
VoIP	Voice Over Internet Protocol
VoLTE	Voice Over Long Term Evolution
WASP	Wearable Advanced Sensor Platform
XML	Extensible Markup Language