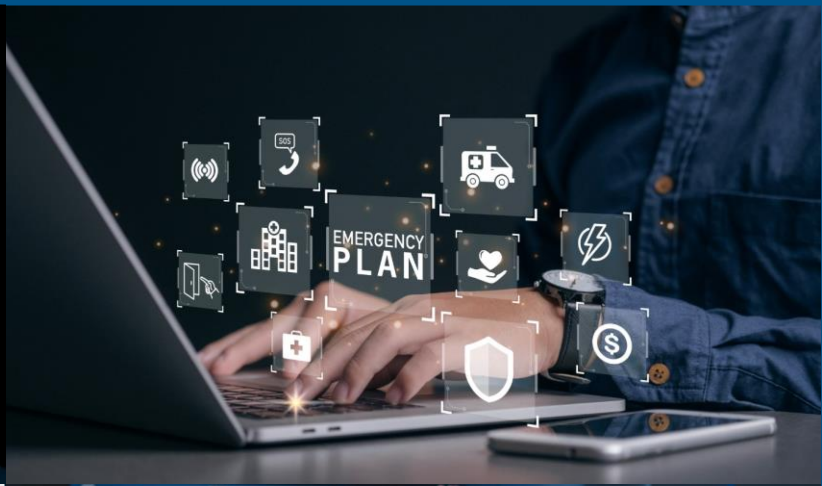

Emergency Management of Tomorrow Research Final Summary Report

July 2024

Science and Technology

This report was prepared for the U.S. Department of Homeland Security under a Work-for-Others Agreement with the U.S. Department of Energy, contract DE-AC05-76RL01830, IA 70RSAT23KPM000025.

Pacific Northwest
NATIONAL LABORATORY

PNNL-36203

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July 2024

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U.S. DEPARTMENT OF ENERGY

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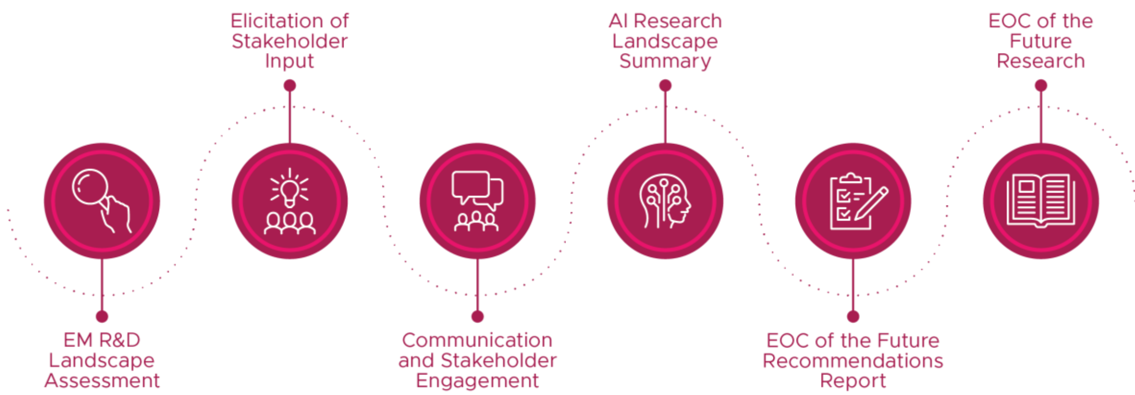
Pacific Northwest National Laboratory
Richland, Washington 99354

About the Emergency Management of Tomorrow Research

The Department of Homeland Security (DHS) Science and Technology Directorate (S&T) is partnering with Pacific Northwest National Laboratory (PNNL) to execute the Emergency Management (EM) of Tomorrow Research (EMOTR) program to identify current EM research and development (R&D), elicit capability needs from EM practitioners, and identify where technology, such as artificial intelligence (AI), may benefit the future of EM and emergency operations centers (EOCs).

This report details the insights gained from a series of landscape assessments and EM community outreach designed to inform future R&D and investments for the EM community. Feedback from this effort will help shape future research, analysis, and recommendations. To learn more about EMOTR and access copies of the activity reports, visit https://www.dhs.gov/science-and-technology/EM.



This report is intended for individuals looking to invest in EOCs and those interested in a comprehensive breakdown of the high-level opportunities emerging in EM technology development and deployment. The target audience includes the public and private sectors and academia, who seek to explore and capitalize on the advancements and potential within this critical field.

Summary

The EM threat landscape is evolving at an unprecedented pace due to challenges like climate change, urbanization, and technological advancements. This shifting landscape requires a dynamic and adaptable approach to EM, leveraging new technologies and integrating existing R&D from academic and government institutions. However, no single federal agency has the sole responsibility to deliver this task for the broad public safety community.

To address this challenge, DHS S&T partnered with PNNL to execute the EMOTR program to assess the EM and AI research landscape, elicit capability needs from EM stakeholders, and conduct validation exercises to identify where technology, such as AI, can benefit the future of EM and EOCs. Together, these efforts navigated the complexities of EM and AI to identify emerging trends, potential challenges, and strategic pathways to guide future investments based on current assessments and projected needs.

Envisioning EM and EOCs of the Future

Analysis of the EMOTR findings defined several EM and EOC of the Future recommendations, focused on the following:

- AI, automation, and human-machine teaming
- Data and information sharing
- Situational awareness
- Technology integration and interoperability
- Virtual capacity scaling
- Workforce development

Synthesis of the EMOTR findings resulted in a series of recommendations to inform future EM R&D and technology investments. Potential near-term opportunities to consider include:

- Defining open architecture standards and best practices as a reference guide for local jurisdictions to begin laying the groundwork for data and information sharing.
- Developing operationally secure requirements for deploying AI-enabled productivity applications (e.g., converting situation reports to slides/videos, deconflicting situational awareness information) in EOCs.
- Creating AI and other emerging technology training modules and certifications for EM.
- Engaging more frequently and intentionally with students and early-career professionals.
- Advancing AI-enabled productivity applications to benefit tasks such as generating after-action reports, automating queries and status during an emergency, and producing press reports.
- Developing risk models for optimal asset deployment, in which modern risk modeling methods paired with optimization can guide the deployment of assets in a risk-optimal way.
- Embedding AI for alternative data streams, leveraging modern contrastive learning and neural architectures to enable a unified approach for all data types.

This report features a high-level summary and analysis of the EMOTR observations and provides DHS S&T and other EM stakeholders with forward-looking recommendations for integrating emerging technologies, including AI, to transform the future of EM and EOCs.

Detailed reports from each EMOTR activity are available at https://www.dhs.gov/science-and-technology/EM.

Acknowledgments

The PNNL team would like to thank the many collaborators and other stakeholders who joined in this effort.

We are thankful to the participants of the EMOTR interviews, roundtables, and focus groups. Special recognition goes to the Boulder County Sheriff's Office for hosting the in-person focus group and to our roundtable presenters: Mark Sloan, Homeland Security and Emergency Management Coordinator, Harris County; Dr. Hannah Walsh, Subproject Manager, NASA Ames Research Center; Dr. Ranjana Mehta, NeuroErgonomics Lab, University of Wisconsin-Madison College of Engineering; and Dr. Hemant Purohit, Humanitarian Informatics Lab, School of Computing, George Mason University.

We acknowledge the State University of New York at Albany College of Emergency Preparedness, Homeland Security, and Cybersecurity for their critical partnership in the AI Research Landscape Assessment, expert validation, and ideation work. In particular, we recognize Dean Bob Griffin for his continued support to the EMOTR partnership; Alex Greer, PhD, and Eric Best, PhD, for their insightful discussions and organization of faculty validation sessions; and Brandon Behlendorf, PhD, and his team at the Center for Advanced Red Teaming for organizing a successful sandpit exercise with students.

We also extend our gratitude to the host cities, organizations, and personnel who contributed to the success of the EMOTR tabletop exercises, with a special thanks to Ruhamah Bauman, Jill Misiewicz, Wisconsin Emergency Management, the Joint Force Headquarters, Wisconsin State Emergency Operations Center, Emily Martuscello and the Dartmouth Hitchcock Clinics from the City of Nashua, and Curry Mayer from the Seattle Office of Emergency Management and the Seattle Emergency Operations Center. We also extend our thanks to the National Emergency Management Association and International Association of Emergency Managers for their support and insights.

Acronyms and Abbreviations

AI	Artificial Intelligence
DHS	Department of Homeland Security
EM	Emergency Management
EMOTR	Emergency Management of Tomorrow Research
EOC	Emergency Operations Center
ML	Machine Learning
PNNL	Pacific Northwest National Laboratory
R&D	Research and Development
S&T	Science and Technology
UAlbany	University of Albany

Contents

1.0 Introduction

The emergency management (EM) threat landscape is evolving at an unprecedented pace due to challenges like climate change, urbanization, and technological advancements. This shifting landscape requires a dynamic and adaptable approach to EM, leveraging new technologies and integrating existing research and development (R&D) from academic and government institutions with EM capabilities. New and novel approaches are needed to address the highly federated nature of EM; however, unlike other domains, no one federal agency has the sole responsibility to provide such tools and technologies for the broad public safety community.

The Department of Homeland Security (DHS) Science and Technology Directorate (S&T) partnered with Pacific Northwest National Laboratory (PNNL) to execute the EM of Tomorrow Research (EMOTR) program to assess current research in EM, elicit capability needs from EM stakeholders, and identify where technology, such as artificial intelligence (AI), may benefit the future of EM and emergency operations centers (EOCs).

Through the activities outlined in this report and summarized in Figure 1, EMOTR has provided insights and recommendations to improve effectiveness, enable efficiencies, foster innovation, and enhance collaboration to bolster the future of EM and EOCs. Findings from this report can assist DHS S&T and other EM stakeholders in decision-making for future EM R&D and technology investments.

The Vision: The Future of AI and EM

Amid today’s technological evolution, new tools and capabilities have emerged as crucial assets, reshaping EM with innovative solutions that can enhance preparedness, response, and recovery. However, the full potential of these advancements rests in their seamless integration with existing systems and capabilities, often bound by policy, procedure, privacy, and funding barriers. By aligning R&D and technology solutions with the specific needs of the EM community, we can collaboratively develop solutions that address critical gaps and fortify operational resilience. EMOTR takes on this challenge with an R&D- and end-user-informed approach to examine the EM and AI R&D landscape and enable a well-structured EM research agenda that can drive force-multiplying integration of science and technology to enhance the future of EM and EOCs.

Figure 1. EMOTR Approach

2.0 Methodology

EMOTR leveraged an iterative methodology to identify, vet, and communicate EM technology gaps, capability needs, and R&D priorities to inform decision-making and investments for the future of EM and EOCs. Each activity built on its predecessors and enabled its successors by continuously refining priorities as they were elicited, vetted, and validated through structured landscape assessments, stakeholder elicitation activities, capability analyses, and validation exercises.

"Emergency managers play a crucial role in mitigating multiple types of casualties and economic losses, while grappling with the daunting task of safeguarding their communities against unprecedented and escalating threats, ranging from severe weather events to cyberattacks on our critical infrastructure. This research is aimed at providing local and state emergency managers with scientific advancements and technologies, empowering them to adapt and scale their capabilities for the challenges of tomorrow."

- Dr. Dimitri Kusnezov, DHS Under Secretary for Science and Technology

The EMOTR methodology, outlined in Figure 2, combined several key activities to curate a comprehensive set of recommendations to inform future EM R&D and technology investments:

- **Landscape Assessments** – Used a suite of publication databases, key search terms, and analytical tools to review hundreds of resources (i.e., peer-reviewed articles, open-source publications) to build a foundational understanding of recent EM and AI R&D.
- **Stakeholder Elicitation** – Used a structured protocol to conduct stakeholder engagement sessions, including interviews, focus groups, roundtables, and a survey, to understand current practices, capability needs, and research priorities within EM.
- **Workflow Analysis** – Examined a variety of literature and EM emergency support functions to prioritize tasks befitting of or in need of technology enhancement.
- **Validation Exercises** – Engaged subject matter experts, university students, and EM practitioners in realistic scenarios to explore the feasibility of applying new and novel technologies to emergency operations.

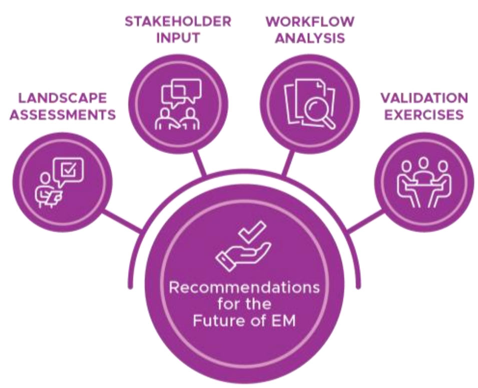


Figure 2. EMOTR Methodology

Detailed reports for each EMOTR activity are available at https://www.dhs.gov/science-and-technology/EM

3.0 Observations

EMOTR activities engaged the EM community nationwide and included the following (Figure 3):

- Connecting with more than 230 EM stakeholders spanning government, academic, and private EM organizations.
- Reviewing over 500 publications assessing the EM and AI R&D landscape.
- Hosting nearly 30 outreach activities, including interviews, focus groups, tabletop exercises (TTXs), roundtables, and a university student competition.

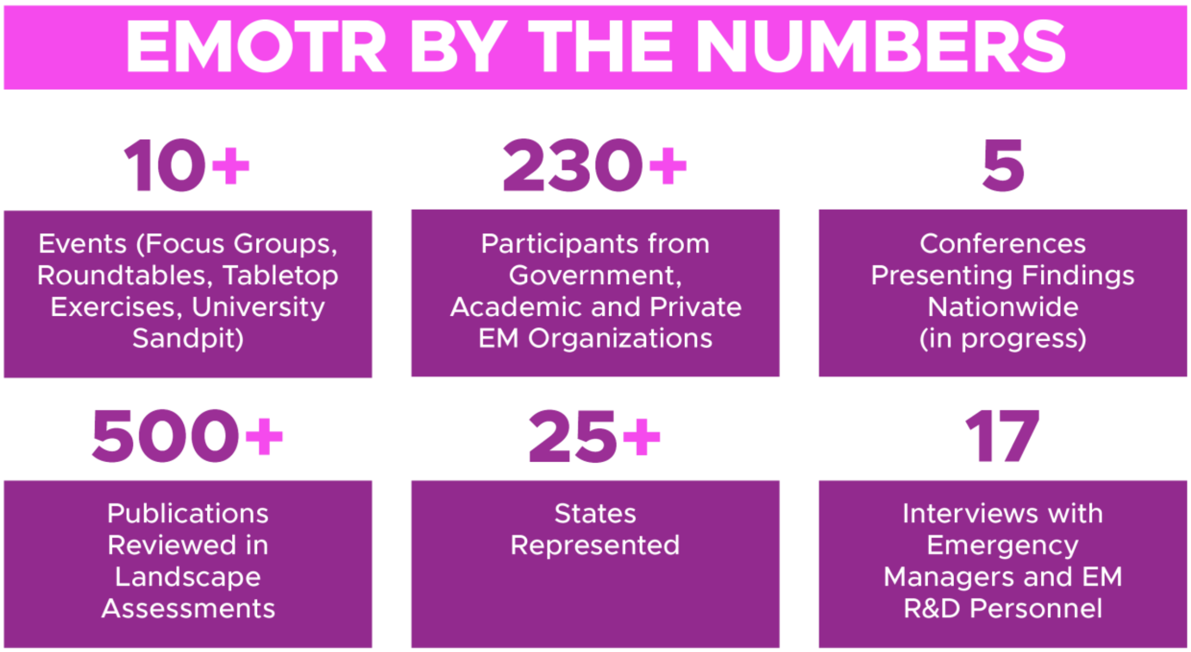


Figure 3. EMOTR Outreach

3.1 Landscape Assessments

3.1.1 Emergency Management Research and Development Landscape Assessment

EM R&D Landscape Assessment

Analysis of 300-plus peer-reviewed and open-source EM R&D-related publications identified recurring areas of EM capability needs being addressed by major R&D institutions:

- 3D geolocation
- Communications
- Data integration
- Threat and hazard detection/analysis
- Resource management/jurisdiction coordination

The EM R&D Landscape Assessment reviewed recent research (from 2017 to 2023) to evaluate current studies in EM and public safety and create an annotated bibliography highlighting collaborative opportunities and shared interests in EM research.[1] Figure 4 summarizes the EM R&D Landscape Assessment.

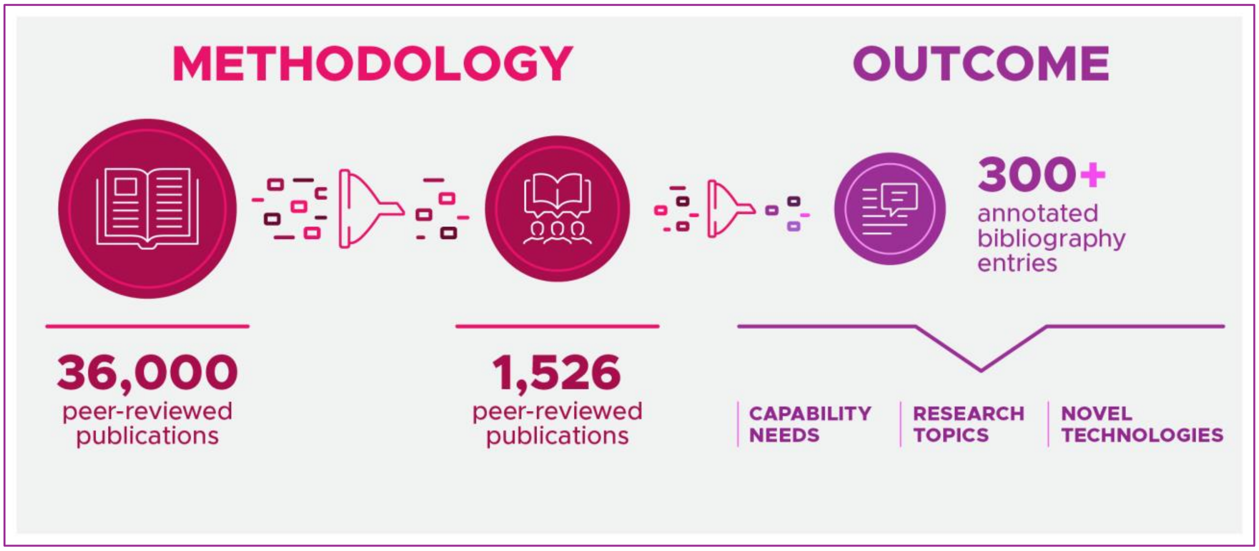


Figure 4. EM R&D Landscape Assessment

This assessment focused on open-source and peer-reviewed publications and U.S.-based projects, utilizing initiatives like the DHS S&T-funded Project Responder and the First Responder Roadmap, and examined applicability, interoperability, potential multi-use applications, and operational challenges. The assessment aimed to identify funded R&D addressing EM capability needs and overlapping research efforts. Results were categorized by EM capability needs, highlighting areas with high interoperability and implementation for further DHS consideration. Notable research within the EM capability needs is summarized in Table 1.

Table 1. Notable Research within EM Capability Needs

Notable Research within EM Capability Needs	
• Social media use in emergency response • Flood impact assessment • Citizen science • 3D building reconstruction • Reliable energy alternatives • Smart grid modeling	• Enhanced cellular networks for unmanned aerial system corridors • Satellite-integrated wireless systems • Internet-of-things dashboards for responder health • Deep-learning models for damage assessment

Findings were also organized by EM capability needs as identified by the landscape assessment, which addressed and ranked the needs in terms of interoperability and

[1] Sleiman, C., Thomas, K., Gray, J. Schroeder, J., Disney, M., Alsabagh, H., Ortega, S., Bartholomew, R., Lesperance, A. 2024. *Emergency Management of Tomorrow Research Landscape Assessment*. PNNL-35649. Richland, WA: Pacific Northwest National Laboratory.

implementation. Needs were plotted to visually compare research between and within the capability need categories. Research evaluated as high interoperability and implementation represented research where further investigation may determine if they would provide a solution on a national level. The research areas ranked with low interoperability or high impact from implementation barriers should be viewed as potential opportunities where collaboration or augmented efforts could lead to productive resolutions to barriers or improve interoperability. These areas of research included the following:

- 3D geolocation
- Communications
- Data integration
- Threat and hazard detection/analysis
- Resource management/jurisdiction coordination

3.1.2 Artificial Intelligence Research Landscape Assessment

AI Research Landscape Assessment

Through a targeted review and analysis of over 200 articles, the AI Research Landscape Assessment[1] identified a set of AI technologies and their potential application to EM. This set of AI technologies was curated and validated through discussions with emergency managers, university faculty, college students, national laboratory researchers, and federal staff. Ultimately, 13 technologies were identified that have a high probability of enhancing EM in the next decade (Table 2), including technology to support the following:

- AI-filtered domain awareness
- Communication
- Datasets, testbeds, and methodologies for training
- Disaster prediction
- Planning and productivity
- Resource and asset management
- Risk modeling
- Seamless information sharing

The AI Research Landscape Assessment summarized scholarly work at the intersection of EM and ML, as of May 2024. The assessment was approached from the perspective of a data scientist seeking to find application areas for AI in EM as opposed to that of an emergency manager, seeking to find data science techniques to solve specific problems. This approach allowed for matching of emerging machine learning (ML) techniques to multiple different EM problems. Likewise, technology adoption lags behind technology development. This approach also accounted for the faster pace of research in ML as compared to the adoption of technology in EM. Considering the rapid pace of technological advancement, it is imperative to periodically revisit understanding of current technologies, maintaining relevant knowledge amid constant innovation.

Ultimately, this assessment provided a current understanding of the most promising AI research as applied to EM, along with insights regarding how additional R&D could benefit EM in the future. This entailed the following:

- Reviewed more than 200 articles and created a tagged bibliography to encapsulate pertinent focus areas for the application of AI technologies to EM. Disaster prediction and measurement, decision optimality,[1] and social media understanding represented the most popular fields of study.

- Connected with various stakeholders, including emergency managers, university faculty, college students, national laboratory researchers, and federal staff, to curate and validate emerging technology concepts.
- Formulated a comprehensive summary of current research on AI's application in EM, including existing capability gaps for state, local, and related partner EM functions as well as research directions to harness advanced AI capabilities to address these gaps.

As a result, PNNL developed a refined list of AI technologies and AI-enabling technologies that exhibit a high likelihood of augmenting EM capabilities over the next decade. These technologies are summarized in Table 2. AI technologies that had consensus from AI and EM stakeholders as to their optimistic future in EM are labeled as highlighted technologies; enabling technologies are those that must be in place for the highlighted technologies to provide impact.

Table 2. Highlighted and Enabling Technologies

Highlighted Technologies	Enabling Technologies
• AI embedding for alternative data streams • AI-enabled disaster prediction and detection • AI-enabled planning • AI-enabled productivity applications • AI-enabled recovery and prediction • AI-filtered domain awareness • Modern optimization for asset deployment • Public-facing AI communication • Risk models for optimal asset deployment	• Governance and public perception of AI • Information technology infrastructure for AI • Modeling, simulation, and digital twins • Security of AI assets and data

Seven technologies had consensus, elicited via workshops and interviews with AI and EM stakeholders, as to their optimistic future in EM:

- AI-enabled disaster prediction and detection
- AI-enabled planning
- AI-enabled productivity applications
- AI-enabled recovery and prediction
- AI-filtered domain awareness
- Public-facing AI communication
- Risk models for optimal asset deployment.

Two additional technologies were included because of potential impact in the field, despite less interest from emergency managers:

- AI embedding for alternative data streams
- Modern optimization for asset deployment.

Four enabling technologies must be in place for the previous technologies to provide impact:

- Governance and public perception of AI
- Information technology infrastructure for AI

[1] *Decision optimality* is a mathematical process that helps organizations make the best possible decisions by optimizing input parameters and organizational rules or processes.

- Modeling, simulation, and digital twin
- Security of AI assets and data.

Detailed technology profiles for each highlighted and enabling technology, including technology readiness level, current status, and potential application to EM, are available by request to emotr@pnnl.gov.

3.1 Community Outreach

Eliciting Stakeholder Input

A series of interviews, focus groups, roundtables, and a survey elicited EM stakeholder priorities for EM today and in the future. Emerging themes focused on the following:

- Technology and technical capabilities – EOCs will need to harness real-time data streams from various sources (i.e., sensors, social media, satellite imagery) to enhance situational awareness and facilitate rapid decision-making.
- Structure and organization – EM must balance hybrid operations and overcome challenges in interoperability, flexibility, and scalability.
- Policy and operations – Information sharing, resource management, and situational awareness are a priority but face policy, funding, privacy, and trust barriers.
- Research and development – Human-centric R&D can explore balancing psychological impacts of high-stress environments and decision-making with AI tools.

3.1.1 Interviews, Focus Groups, Roundtables, and Surveys

EM stakeholder input was essential to underpinning the EMOTR findings with EM stakeholders' experiences in the field. Structured outreach activities—interviews, focus groups, roundtables, and a survey—elicited input from the EM stakeholder and R&D communities in a collaborative and interactive way. These structured engagements elicited feedback on EM-related technologies and operations, discussed how they are evolving, and gathered operational and researcher perspective on how they might impact EM today and in the future.

As of May 2024, this effort resulted in 17 interviews with emergency managers[1] and EM R&D personnel nationwide, two focus groups (in person in Boulder, CO, and virtual),[2] and four virtual roundtables.[3] Additionally, the survey was administered alongside the stakeholder events to supplement input with quantitative data. Together, these engagements were guided by previous and concurrent EMOTR activities to assess current research in the field of EM, elicit capability

[1] Ortega, S.R., Disney, M.V., Sleiman, C.M., Bartholomew, R.A., Lesperance, A.M., Barr, J.L., Gray, J., et al. 2024. *Emergency Management of Tomorrow Research – Current State of Practice: Information Sharing.* PNNL-35727. Richland, WA: Pacific Northwest National Laboratory.
[2] Ortega S.R., Disney, M.V., Sleiman, C.M., Betzsold, N.J., Bartholomew, R.A., Lesperance, A.M., Barr, J.L., Gray, J. 2024. *Emergency Management Research and Development Community Awareness*. PNNL-35880. Richland, WA: Pacific Northwest National Laboratory
[3] Ortega, S.R., Disney, M.V., Sleiman, C.M., Betzsold, N.J., Lesperance, A.M., Bartholomew, R.A., Barr, J.L., Gray, J. 2024. *Emergency Management Research and Development Community Coordination*. PNNL-35996. Richland, WA: Pacific Northwest National Laboratory.

needs from EM practitioners, and identify where technology, such as AI, may benefit the future of EM and EOCs. In particular, stakeholder input reflected what practitioners and researchers shared they believe the future of EM and EOCs will look like, envisioning a dynamic blend of hybrid, in-person, and virtual operations within EOCs, with the role of EMs evolving in response to the changing threat landscape.

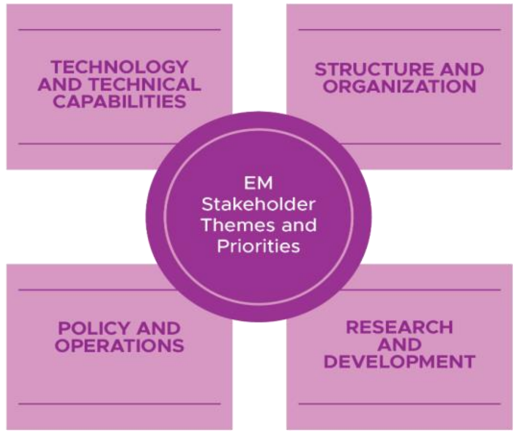


Figure 5. EM Stakeholder Priorities for the Future of EM

Themes and priorities that emerged from the interviews, focus groups, and roundtables are summarized below and in Figure 5:

- **Technology and Technical Capabilities** – According to EM personnel interviewed, the seamless integration of data analytics and AI will be paramount. The expectation is that EOCs will need to harness real-time data streams from various sources, including sensors, social media, and satellite imagery, to enhance situational awareness and facilitate rapid decision-making. Practitioners mentioned using AI algorithms to assist in predicting disaster patterns, optimizing resource allocation, simulating scenarios to test response strategies, and even as digital assistants to help inform decision-making.
- **Structure and Organization** – EM personnel shared that they anticipate a shift toward more decentralized and resilient EM frameworks. Instead of relying on centralized EOCs, networked approaches will be needed with distributed command centers and hybrid/virtual EOCs. These decentralized nodes will be interconnected through robust communication systems, enabling interoperability among different agencies and jurisdictions. These approaches will enhance flexibility and scalability, enabling a more adaptive response to dynamic and complex emergencies.
- **Policy and Operations** – While envisioning the EOC of the Future, several key themes emerged, primarily focused on enhancing information sharing, resource management, and situational awareness, which includes establishing robust validation processes for information, developing platforms for resource allocation, and creating protocols for seamless and secure information exchange across government entities. Overcoming barriers such as funding limitations and policy constraints, enhancing trust in new systems and AI, and balancing human-machine interactions to optimize decision-making is crucial. Other topics emphasized included leveraging existing technology like WebEOC (with modifications) and exploring AI solutions for planning, data analysis, and decision support.
- **EM Research** – EM-focused research personnel reflected on the future of EM research initiatives and highlighted several challenges and opportunities in line with the research areas of interest from the EM R&D Landscape Assessment. Challenges emerged in addressing misinformation on social media, maintaining data integrity and network security for AI/ML applications, and filling gaps in human-centric research for emergency response personnel. On the technology front, emphasis focused on leveraging AI/ML for crisis detection and communication improvement, including exploring applications in security and network analysis. However, challenges persist regarding data availability, particularly in the private sector where access is restricted. Current research strategies include further R&D efforts in emerging technologies like AI/ML, cloud solutions, unmanned aerial systems, and

human-centric approaches to EM, along with integrating cybersecurity and enhancing testing mechanisms, particularly in real-world emergencies. These efforts aim to enhance the adaptability and effectiveness of EOCs in handling future crises and are not all-encompassing of the current state of research in EM.

PNNL, with support from DHS S&T, administered a survey to supplement stakeholder input (i.e., interviews, focus groups, and roundtables) with quantitative data to better understand research needs and impacts within the EM community. This survey aimed to evaluate the current research and technology landscape in EM, including identifying the types and sources of research accessed by EM stakeholders in the field and determining how advancements in research and technology can enhance critical tasks in EM. The following is a summary of the survey results:

- **EM Research** – Participants indicated R&D in the areas of AI, response operations, and critical infrastructure was of most relevance to their discipline. Participants also indicated peer networks, conferences and workshops, and internet searches are their top resources for accessing research. This aligned with feedback from interviews that peer networks, conferences, and professional organizations are popular sources of information.
- **EM Technology and Tasks –** To better assess how EM tasks can benefit from new or enhanced science and technology, participants shared feedback regarding potential tools and operations. Key takeaways include:
    - Participants prioritized situational awareness and coordination and information sharing as EM tasks that could benefit from enhanced or new technology.
    - Participants prioritized situational awareness and predictive/forecasting tools as AI tools warranting further research and having the most potential impact on the future of EM.
    - Participants indicated chatbots and summarization tools as the most used AI tools in their discipline and cited biometric authentication and visualizations as tools of interest.
    - Lastly, when asked to envision the future of EOCs, many participants indicated they anticipated a hybrid environment, consistent with many previous EMOTR discussions.

3.1.2 Validation Exercises

Validating a Vision for the Future

In-person exercises with subject matter experts, university students, and EM practitioners validated EMOTR findings and defined EOC of the Future foundational concepts, including the following:

- AI automation and human-machine teaming
- Continuous, real-time situational awareness
- Forward-leaning workforce development
- Human-centered design of workspaces
- Hybrid EOC operations
- Next-generation data management
- Resilient system design
- Whole community approach

Figure 6. Sandpit Exercise at UAlbany

As the emerging technology gaps, capability needs, and R&D priorities began to collate into a vision for the EOC of the Future,[1] PNNL sought to validate this emerging vision through a series of validation exercises. The exercises were designed to ground truth that EMOTR findings were sound, feasible, and aligned with real-world EM operations, while also embracing the art of the possible. The following section summarizes EMOTR validation exercises, including expert validation, idea generation through university competitions, and TTXs.

- **Expert Validation** – To validate the identified technologies as well-aligned, non-trivial, and feasible, UAlbany College of Emergency Preparedness, Homeland Security, and Cybersecurity faculty and EM stakeholders from state agencies and city departments convened with the PNNL team to discuss the identified technologies from the AI Research Landscape Assessment. The faculty convened included those with expertise in EM, cybersecurity, ML, and traditional computer science. The EM stakeholders included representatives from the New York State Police, Albany Fire Department, and New York State’s Division of Homeland Security and Emergency Services. The group discussed the aforementioned 13 technology concepts through an activity categorizing each technology by its acceleration toward maturity and potential for new research. Those ratings were further evaluated for their fitness for DHS investment and potential impact on other industries. These sessions helped ground results in faculty and EM stakeholder-led feedback and included digressions that informed results for enabling technologies. Additionally, these sessions indicated imperfect alignment between the AI art-of-the-possible and emergency managers’ understanding of it, which presents an opportunity for further education.
- **University Sandpit** – To bolster the diversity of sources for review, PNNL partnered with UAlbany to engage a population less indoctrinated to the current state of practice in EM. A “sandpit” exercise was held at UAlbany, where UAlbany and Rensselaer Polytechnic Institute students competed to develop ideas to apply ML to an EOC (Figure 6). In this hackathon-style exercise, 17 student teams of 2-4 students each were introduced to the concept of an EOC and provided an exemplar emergency to seed their thinking. Students were asked to come up with a concept for ML use in such a situation that would improve EOC operations during the emergency. The students communicated their ideas through a three-minute, one-slide briefing and a two-page report presented to a panel of judges. The two best overall student teams and the most creative student team were awarded prizes. The student concepts aligned predominantly with the tag of decision optimality, which validated a previous conclusion in the AI Research Landscape Assessment that decision optimality is an unexpectedly visible and well-supported subfield at the intersection of AI and EM.

[1] Betzsold, N., Barr, J., Lesperance, A., R. Bartholomew, R., Ortega, S., Sleiman, C., Disney, M., Tietje, G. 2024. *Emergency Management of Tomorrow Research: Emergency Operations Center of the Future Recommendations*. PNNL-36082. Richland, WA: Pacific Northwest National Laboratory.

- **Tabletop Exercises** – Building on this validation approach, TTXs were conducted in Madison, WI; Nashua, NH; and Seattle, WA; and they engaged operational stakeholders in real-world scenarios to evaluate the potential impacts of new technologies on EM operations. This was achieved through a comprehensive assessment of current EOCs and other operations centers, identification of core future EOC concepts, and validation of these concepts and emerging technologies through TTXs. The TTXs convened emergency managers and first responders with diverse backgrounds; federal, state, and local EOC stakeholders; and academic researchers around an extreme, futuristic emergency scenario with a technological complication, as outlined in Figure 7.

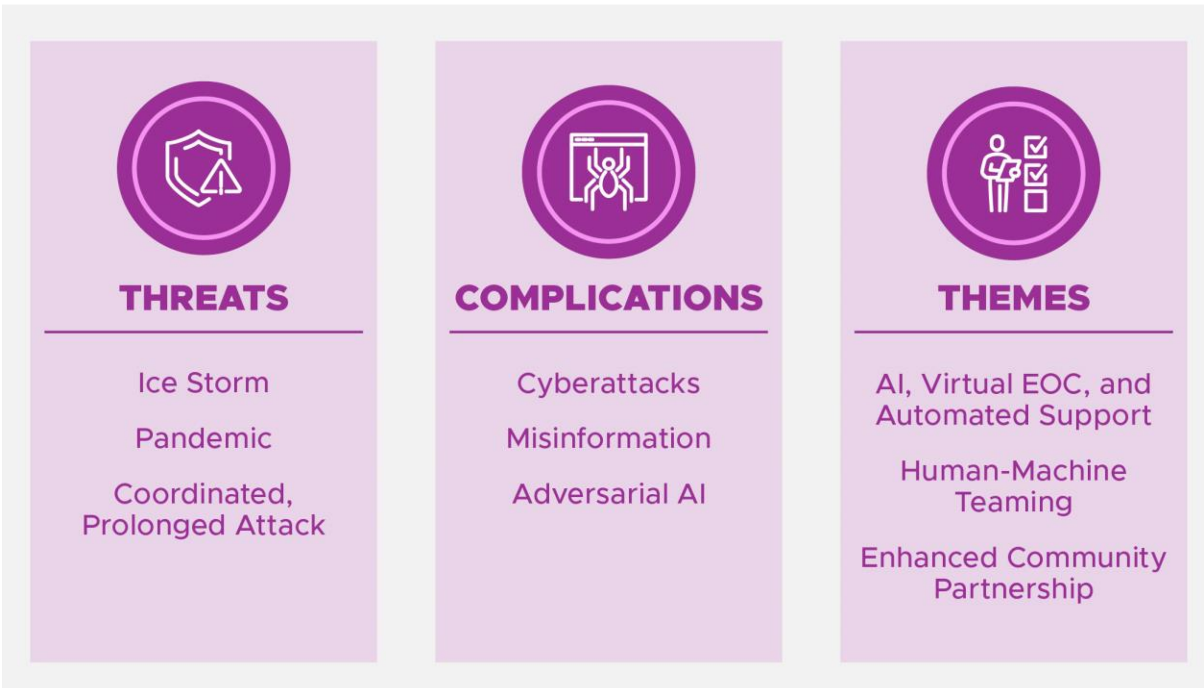


Figure 7. Tabletop Exercise Framework

By integrating the TTX feedback with previous EMOTR findings and priorities, foundational concepts for an EOC of the Future emerged, outlined in Table 3.

Table 3. EOC of the Future Foundational Concepts

EOC of the Future Foundational Concepts	
• Next-generation data management • Continuous, real-time situational awareness • AI automation and human-machine teaming[1] • Human-centered design of workspaces	• Hybrid EOC operations • Resilient system design • Whole community approach • Forward-leaning workforce development

[1] *Human-machine teaming* refers to the way in which humans collaborate and interact with technologies as they both perform functions toward achieving a common goal.

4.0 Recommendations

Envisioning EM and EOCs of the Future

Analysis of the EMOTR findings defined several EM and EOC of the Future recommendations, focused on the following:

- AI, automation, human-machine teaming
- Data and information sharing
- Situational awareness
- Technology integration and interoperability
- Virtual capacity scaling
- Workforce development

The following is a summary of key EM R&D and technology gaps, opportunities, and recommendations for future consideration, as identified through EMOTR landscape assessments and community outreach. Transcending all of the EMOTR findings—the combined results from the landscape assessments, stakeholder input, and validation exercises—was an emphasis on information sharing and the increasing role of AI. Information sharing will require data sharing agreements, varying dissemination formats and platforms, and information security plans. Given the rapid pace of its development in industry, operationalizing AI in EOCs and in EM more broadly will be a significant challenge, particularly if EM is not the primary application.

4.1 EM R&D Recommendations

Landscape assessments identified leading areas of EM research, potential areas of R&D overlap that may benefit from collaboration, and persistent stakeholder challenges that could benefit from additional R&D. To address these recommendations effectively, stakeholders should integrate the identified areas into comprehensive training programs and build strong communication channels between government, academic, and private sector representatives. Cross-sector engagement and education are vital for enhancing awareness and preparedness. At the same time, collaboration and coordination among all stakeholders are crucial for a unified and efficient response and adoption of new technologies. Continuous assessment and updating of the EM R&D landscape, alongside a commitment to resilience and sustainability, will help strategies remain relevant and effective in addressing evolving challenges. These recommended research areas are summarized in Table 4.

Table 4. Recommended R&D Areas of Interest

Leading Areas of Research	Opportunities for Collaboration	Stakeholder Challenges
• 3D geolocation • Communications • Data integration • Threat and hazard detection/analysis • Resource management/jurisdiction coordination • Disaster prediction and measurement • Decision optimality • Social media understanding	• Social media analytics • AI/ML • Community resilience • Satellite technology • Emergency response solutions • Critical infrastructure damage assessments	• Vetting and validating incoming information • Resource management • Situational awareness • Trust in technology, particularly human-machine teaming. • Integration and interoperability • Standardized protocols • Cloud-based systems to enhance usability and coordination

4.2 AI for EM Technology Recommendations

The AI Research Landscape Assessment curated a series of highlighted and enabling technologies that exhibit a high likelihood of augmenting EM capabilities over the next decade. These technologies were detailed in Table 2. Of the highlighted technologies, improvement may be made through private industry and other public sector investment (such as from the Department of Defense or the intelligence community). Near-term R&D opportunities include:

- AI embedding for alternative data streams
- AI-enabled productivity applications
- Risk models for optimal asset deployment.

However, AI embedding for alternative data streams and risk models for optimal asset deployment technologies have constraints and requirements specific to EM and may not progress without specific interest from the EM community. Additionally, governance and public perception of AI was identified as the most important enabling technology overall for AI, but security of AI assets and data was identified as the enabling technology with constraints and requirements most specific to the public sector, to DHS S&T, and to EM.

Some EM-specific barriers to adoption should be considered when evaluating these and other new AI technologies, such as the critical nature of EM applications. As coordinating agencies, EM organizations need to be aware of many domains and communicate with experts in all of them. This makes the negative outcomes from misclassifications or hallucinations much greater in EM than in many other fields and is likely to lead to slower adoption in the critical and regulated EM and EM-adjacent fields compared to organizations not focused on public safety. Additionally, emergency managers frequently must communicate with entire communities, including those that are not technologically literate, meaning that many market-based tools may be less useful.

4.3 EOC of the Future Recommendations

Analysis of the validation exercises, in combination with findings from the landscape assessments and stakeholder input, resulted in a series of recommendations for a next-generation EOC, outlined in Table 5. These recommendations are intended to help strengthen and reimagine the future emergency response structure in EOCs, informing future R&D and investment toward establishing a framework for a coordinated national approach to EM. Concept-based recommendations can be traced back to an EOC of the Future concept defined through landscape assessments and community outreach. Supplemental recommendations are those not directly linked to a single EOC of the Future concept but that will further support EMOTR findings and analysis. Notably, policy development will be associated with each of these emphasis areas to facilitate the successful transition to an EOC of the Future; policy needs or implications are not addressed in this report.

Table 5. EOC of the Future Recommendations

Concept-Based Recommendations	Supplemental Recommendations
• Build a solid data architecture foundation. • Promote continuous awareness and operations. • Develop AI to become an EOC digital teammate. • Meet the needs of the individual operator. • Leverage digital tools to transcend physical boundaries. • Adopt a layered approach to technology integration and EOC functionality. • Crowdsource EM information gathering and response capabilities. • Attract, train, and retain emergency managers of the future.	• Exchange lessons learned with other federal agencies in developing open architecture. • Assess potential cascading impacts of EOC of the Future realization. • Stand up an EM-focused innovation testbed. • Develop an AI-Ready Workforce curriculum. • Create and engage with spaces for students and early-career professionals.

4.4 Near-Term Opportunities

Based on the recommendations, potential near-term opportunities (e.g., 1-3 years) for achieving EM and EOC of the Future concepts include:

- Defining open architecture standards and best practices as a reference guide for local jurisdictions to begin laying the groundwork for data and information sharing.
- Developing operationally secure requirements for deploying AI-enabled productivity applications (e.g., converting situation reports to slides/videos, deconflicting situational awareness information) in EOCs.
- Creating AI and other emerging technology training modules and certifications for EM.
- Engaging more frequently and intentionally with students and early-career professionals on careers in EM and EOCs of the Future.
- Advancing AI-enabled productivity applications to support AI for administrative tasks such as knowledge summarization, report writing, SQL query writing, and code writing. This would allow EM to quickly generate after-action reports, automate queries and status during an unfolding emergency, conduct retrospective analysis for after-action and performance reviews, and quickly generate press reports.

- Developing risk models for optimal asset deployment, modern risk modeling methods paired with optimization to guide the deployment of assets in a risk-optimal way.
- Embedding AI for alternative data streams, moving beyond the current paradigm where each new data type requires bespoke analysis solutions (e.g., peak fitting for spectra). With modern contrastive learning and neural architectures, it will be possible for EM to have a unified approach for all data types.

5.0 Conclusion

The Future of AI and EM

EMOTR outreach and analysis highlighted priority areas of opportunity for future EM R&D and technology investments, including:

- AI embedding for alternative data streams
- AI-enabled productivity applications for administrative tasks
- Open architecture standards for data and information sharing
- Operationally secure requirements and environments for deploying new technology
- Risk models for optimal asset deployment
- Stakeholder engagement for continuous improvement
- Training and workforce development

This report highlighted high-level areas of need and opportunity to inform DHS S&T and other EM stakeholders in decision-making and investments for the future of EM and EOCs. Each recommendation, gap, or opportunity will benefit from further exploration to roadmap the feasibility, timing, barriers, and needs for implementation. Furthermore, testbeds, operational field assessments, and pilot programs connecting government, academic, and industry partners with the EM community can test emerging technologies and capabilities in real time and with real-world scenarios to deliver solutions that fit end-user needs. Additionally, visioning exercises through university sandpits and other venues tailored to young and early-career professionals can engage the next generation in out-of-the-box thinking to envision how emerging technologies can benefit EM.

EMOTR recommendations reflect potential opportunities to respond to high-level areas of EM R&D need and opportunity to benefit the future of EM and EOCs. Opportunities vary greatly by time and level of effort required for implementation—some are longer-term (e.g., 5-7 year) or shorter-term (e.g., 1-3 year) recommendations that can be achieved, some will require significant R&D investment to achieve in the longer term, and some can be enabled by federal government development and ownership (i.e., public safety network). Each recommendation will benefit from further exploration to define next steps for implementation and from continued engagement (TTXs, operational field assessments, visioning exercises, pilots, etc.) with the EM community to test emerging technologies and capabilities with real-world scenarios to deliver solutions that fit end-user needs.

Lastly, this report is only timely at the time of publication and the threat landscape—and the technology to address it—is changing fast. The relevance of this information is tied to the time of its publication, as information fluctuates based on the dynamic landscape of evolving knowledge, changing threats, and the pace at which technology is researched and developed. Its significance is deeply rooted in the contemporary context, and its impact may vary as new developments unfold. To maintain similar and ongoing R&D and technology prioritization into the future, continued outreach is needed to understand and vet current and emerging priorities and opportunities in EM. These discussions should emphasize collaboration, transparency, and reduced duplication of effort. Involving diverse stakeholders, documenting findings, and establishing follow-up mechanisms can enable continuous improvement and visibility in EM R&D efforts and ultimately inform future DHS S&T considerations to address capability gaps, enhance response capabilities, and enable adaptability in the face of increasing disaster frequency and intensity.

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