


Emergency Management of Tomorrow Research: Emergency Operations Center of the Future Technology Exercises

September 2025

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-38245

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U.S. DEPARTMENT of ENERGY

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Richland, Washington 99354

About the Emergency Management of Tomorrow Research

The Department of Homeland Security (DHS) Science and Technology Directorate (S&T) partnered with Pacific Northwest National Laboratory (PNNL) to execute the Emergency Management (EM) of Tomorrow Research (EMOTR) program to

- Assess the EM research landscape;
- Assess the artificial intelligence (AI) research landscape;
- Elicit capability needs from EM stakeholders;
- Conduct validation exercises; and
- Identify where technology, such as AI, may benefit the future of Emergency Operation Centers (EOCs).

To learn more about this task or others within the EMOTR scope, contact emotr@pnnl.gov.

Summary

Our nation's threat landscape is rapidly evolving, demanding innovative and adaptable approaches to EM/PS. To address this dynamic environment, leveraging advanced technologies such as AI is crucial to provide emergency managers and first responders with solutions that directly align with their operational needs. This report outlines the methodology, activities, and outcomes of the 2025 EMOTR exercises—a collaboration between DHS S&T and PNNL.

Interactive exercises in 2025 sought to evaluate emerging technologies through practical applications and tailored experiments with EOCs. These exercises focused on the mitigation phase of EM, which traditionally receives limited attention but holds substantial potential for advancing long-term resilience and preparedness. Participants engaged in structured brainstorming to address high-priority challenges within EOC operations, generating detailed technology profiles and actionable requirements for next-generation solutions.

The exercises yielded a set of 13 actionable, high-impact, and advanced profiles of technologies likely to benefit the EOC of the Future:

- Automated EM/PS Training Customization
- Automated After-Action Reporting Data Pipeline Insights
- Immersive-Reality, Data-Aggregating AI
- Custom Predictive Data Validation Dashboard
- AI-Driven Data Fusion Insights
- Predictive Risk Assessment Knowledge Base
- Cross-Jurisdictional, Cascading Impact Digital Twin
- Funding Acquisition AI Agent
- Optimized Data-Driven Decision-Making
- Real-Time Shared Situational Awareness
- Real-Time Alert and Warning Generation
- AI Agent for Emergency Public Information
- Interactive, Community-Driven Decision Simulation

Results from these exercises provide an enhanced vision for the EOC of the Future. The generated technology profiles may act as recommendations for future research activities as well as a starting point for collaboration with private industry for commercial technology solutions.

Acknowledgments

Thank you to exercise participants who provided exceptional insights in identifying present-day, high-impact challenges faced by EM/PS personnel. Your inputs generated requirements for next-generation technology concepts to mitigate key challenges.

In particular, the PNNL team would like to acknowledge the host cities, organizations, and personnel who helped make these events a success, including Emily Martuscello from the City of Nashua and Rivier University; Mike Chard from Boulder County and the Boulder County Sheriff's Office; and Curry Mayer from the Seattle Office of Emergency Management and the Seattle Emergency Operations Center.

Acronyms and Abbreviations

AAR	After-Action Reporting
AI	Artificial Intelligence
DHS S&T	Department of Homeland Security Science and Technology Directorate
DRIVE	Do, Restrictions, Investments, Values, and Essential Outcomes
EM	Emergency Management
EMOTR	Emergency Management of Tomorrow Research Program
EOC	Emergency Operations Center
PNNL	Pacific Northwest National Laboratory
PS	Public Safety
R&D	Research and Development
TTX	Tabletop Exercise

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1.0 Introduction

The Department of Homeland Security (DHS) Science and Technology Directorate (S&T) partnered with Pacific Northwest National Laboratory (PNNL) to execute the Emergency Management (EM) of Tomorrow Research (EMOTR) program to

- Assess the EM research landscape;
- Assess the artificial intelligence (AI) research landscape;
- Elicit capability needs from EM stakeholders;
- Conduct validation exercises; and
- Identify where technology, such as AI, may benefit the future of Emergency Operation Centers (EOCs).

This report highlights the methodology, activities, and outcomes from a series of exercises that PNNL conducted with emergency managers and EOCs to yield actionable, high-impact, advanced technology profiles.

1.1 Purpose

As part of EMOTR, PNNL conducted three exercises in Spring 2025 to evaluate use cases representing thematic groupings of EOC of the Future concepts and recommendations identified in previous EMOTR tasks and documented in the EOC of the Future Recommendations Report.[1] Table 1 lists the selected exercise locations and use cases.

Table 1. EOC of the Future Exercises

Location	Use Case
Nashua, New Hampshire	Artificial Intelligence
Boulder, Colorado	Information Sharing
Seattle, Washington	Synergy and Integration

The exercises sought to assess the impact and feasibility of applying new and novel technologies to support EM/PS functions and operations and inform future decision-making for research and development (R&D). These exercises yielded a set of 13 actionable, high-impact, and advanced profiles of technologies likely to benefit the EOC of the Future listed below and detailed in Section 4.0:

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

- Automated EM/PS Training Customization
- Automated After-Action Reporting (AAR) Data Pipeline Insights
- Immersive-Reality, Data-Aggregating AI
- Custom Predictive Data Validation Dashboard
- AI-Driven Data Fusion Insights
- Predictive Risk Assessment Knowledge Base
- Cross-Jurisdictional, Cascading Impact Digital Twin
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Results from these exercises provide an enhanced vision for the EOC of the Future. The generated technology profiles may act as recommendations for future research activities as well as function as a starting point for collaboration with private industry for commercial technology solutions.

This report summarizes the exercise methodology and results intended to inform future planning and investments to benefit the EOC of the Future. An overview of the exercise methodology is summarized in Section 2.0, and a detailed description of the exercise protocol is available in Appendix A. A summary of high-impact challenges brainstormed at these events is available in Section 3.0. Next, Section 4.0 elaborates on the requirements generated for potential technology solutions to address specific high-impact challenges. Finally, Section 5.0 provides a crosscutting analysis of identified trends as well as recommended next steps.

2.0 Methodology

The EMOTR exercises expanded on previous EMOTR findings through in-person activities conducted with three EM/PS audiences across the nation. Exercises sought to:

- Explore how AI, information sharing, and synergy and integration can enhance EM/PS operations.
- Generate requirements for next-generation technology solutions that address some of the highest priority challenges encountered in EOCs.
- Assess the impact and feasibility of emerging technology solutions in an EOC.
- Generate technology profiles, incorporating identified requirements, to inform mission needs for the future of AI, information sharing, and synergy and integration in EM/PS.

The exercises were designed to connect end users to technology developers and avoid developing technology in a vacuum, which often results in negative unintended consequences and technologies that quickly get shelved.

The following summarizes how the exercises were designed and conducted. A detailed exercise protocol is available in Appendix A.

2.1 EOC of the Future Concepts and Recommendations from Year 1

As part of year one of the EMOTR program, PNNL developed concepts for the EOC of the Future and provided recommendations to assist stakeholders in future decision-making. The foundational concepts for the EOC of the Future are outlined in Table 2Table 2.

Table 2. EOC of the Future Foundational Concepts

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

After exploring the EOC of the Future concepts and emerging technologies through landscape assessments, stakeholder input, and tabletop exercises (TTX) in year one, PNNL recommended several opportunities to deliver near-term impact to EM/PS, outlined in Table 3Table 3.

Table 3. 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/PS 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/PS-focused innovation testbed. • Develop an AI-Ready Workforce curriculum. • Create and engage with spaces for students and early-career professionals. •

2.2 EOC of the Future Technology Use Cases for Year 2

The resulting concepts and recommendations from year one were thematically categorized into three use cases for the year two exercises: AI, information sharing, and synergy and integration. Where previous EMOTR efforts focused on the concepts, recommendations, and exploring emerging technologies at a high level, the exercise structure enabled a deeper dive into specific emergency operations processes and tasks, with activities intentionally designed to brainstorm requirements for emerging technology solutions tailored to high-impact challenges. Table 4 provides additional context for each use case.

Table 4. Use Cases

Use Case	Background Context
AI	AI includes technology and machines exhibiting human-like intelligence (e.g., visual perception, speech recognition, decision-making abilities). AI can act as an accelerator in EOCs and empower personnel to perform more meaningful tasks. Given the rapid pace of its development in industry but hesitancy toward adoption, operationalizing AI in EOCs and in EM/PS will be a significant challenge.
Information Sharing	Effective information sharing will require data sharing agreements, varying dissemination formats and platforms, and information security plans. Sharing happens “horizontally” (across EOC functions, between private industry and non-governmental organizations, and to the general public) as well as “vertically” (from a local jurisdictional level, up to a regional level, and finally to a national level).
Synergy and Integration	When properly executed, synergy and integration enable a wide range of players from the private and nonprofit sectors to participate in incident management activities, fostering better coordination and working relationships. As emerging technology is increasingly integrated into EM/PS, existing jobs and skillsets will become redundant or irrelevant, but demand for new jobs and skillsets will emerge.

2.3 Participants

Participants were selected based on their interest expressed during previous EMOTR activities and via elicitation to PNNL's network with EM/PS practitioners, built through EMOTR and other DHS S&T EM/PS outreach activities. Participants included emergency managers as well as representatives from fire service, law enforcement, U.S. Coast Guard, utilities, universities, healthcare facilities, and other public safety personnel. Nashua, NH, Boulder, CO, and Seattle, WA, were chosen to host the exercises because these sites represent thought leadership in their respective assigned use case, familiarity with the EMOTR program's mission, and access to a wide-ranging pool of EM/PS expertise.

2.4 Activities

Compared to the previous year's EMOTR TTXs, the year two exercise activities were designed to generate detailed technology profiles and specific feedback on those ideas through targeted ideation and guided interaction. The general exercise agenda is available in Appendix B. Details on the exercise activities are available in Appendix A.

Participants were split into small breakout groups, and, within the context of the location's assigned use case, each breakout group explored a different process step in the mitigation phase of EM. Of the four phases of EM (Mitigation, Preparedness, Response, and Recovery), mitigation was selected as the exercise focus for three key reasons: the lack of attention this phase receives relative to the other phases of EM, the ability for emerging technology to support advancement in this phase, and a high potential return on investment. EM/PS agencies and their partners understand the value of mitigation but must prioritize their limited time and resources first to response operations that save lives and property in immediate danger. This means mitigation projects, which can take years to complete, might not receive the support they deserve. Technology can provide a means to support more mitigation activities without impacting response efforts. Down selecting to a single phase further helped bound the exercise activities and focus participants.

PNNL tailored the following facilitated activities for each exercise:

- Facilitators led a version of **D**o, **R**estrictions, **I**nvestments, **V**alues, and **E**ssential Outcomes (DRIVE, adapted from Tim Hurson's 2007 Think Better) designed to develop evaluative criteria for technology solution brainstorming. Participants identified the nonnegotiable elements of success (e.g., reduced time to decision during incident response), changes or impacts to be avoided (e.g., inaccuracy, lack of integrity, cognitive overload), and values to which technology solutions should adhere in solving problems (e.g., secure, relevant, timely).
- Participants worked in pairs on a structured brainstorming activity designed to identify specific present-day challenges within the breakout group's assigned process step. Facilitators guide the exercise, prompting deeper exploration through follow-up "why" questions to uncover root causes beneath surface-level pain points, ultimately working toward identifying which challenges, if addressed, would have the greatest operational impact.
- Facilitators presented an overview of the emerging technologies that participants would be utilizing during post-lunch activities as a series of demonstrations during a working lunch. These presentations highlighted certain technologies relevant to EM/PS as well as the exercise location's specific use case and process steps.

- Participants built technology solutions to solve identified high-value challenges by selecting technology cards (Appendix C) from three categories: capabilities (what can the technology do?), interfaces (what does the technology look like?), and interactions (how is the technology controlled?). Each time participants chose a card, they made a brief pitch to their breakout group about why their chosen card could help ameliorate the challenge.
- Facilitators used a technology profile (Appendix D) to guide participants through a thought exercise on how EOC and EM/PS operations might be different given access to a fully functional version of their ideated technology. To prevent overly optimistic thinking, this profile also prompts discussion of how the technology's introduction may lead to unintended consequences, abuse, and/or misuse.

3.0 High-Impact Challenges

Each process step was assessed individually during breakout group activities to generate a set of present-day, high-impact challenges associated with the breakout group's assigned process step. These challenges represent those that, if mitigated and/or solved, participants prioritized as having the most significant, positive impact on their EM/PS operations. Several themes emerged as common barriers to effective mitigation and technology adoption in EM/PS. The themes among challenges or barriers included:

- Cross-jurisdictional collaboration
- Data management
- Information transparency and reliability
- Technology literacy
- Collective buy-in
- Cybersecurity

3.1 Cross-Jurisdictional Collaboration

Hazards and threats do not obey authoritative boundaries; incidents often span multiple jurisdictions. However, the siloed nature of current approaches makes it challenging to understand these cascading impacts and how decisions in one jurisdiction impact conditions in another. The existing disconnects hamper effective information sharing, undermine holistic risk assessment, prevent efficient resource allocation, and ultimately weaken EM/PS capabilities. Aggregating, tracking, deconflicting, and updating data across various authorities is difficult and time-consuming, but participants expect that if done effectively, it would lead to more informed and impactful decision-making. Shared institutional knowledge and best practices across jurisdictions would enable different areas and roles to learn from each other to implement cohesive, informed strategies.

3.2 Data Management

Some physical areas remain inadequately monitored and would require additional sensor deployment or capabilities to gather more current data. Data processing is a resource-intensive process, taxing already constrained personnel hours. Large volumes of data exist that contribute to solving problems and making decisions in EM/PS; sifting through these large volumes to identify and prioritize data is time consuming and creates cognitive overload. Valuable data can be found at multiple levels (from local to federal) and from varying sources (from research and academia to the private sector) but extracting actionable information from these data is (again) resource intensive and at times beyond the technical capabilities of EM/PS personnel. Finally, ensuring data gathering, processing, and storage align with regulations across various organizations and governments is a complex process. It involves extensive cross-checking with numerous stakeholders. The quantity of regulations and the absence of a notification system for changes add to this difficulty.

3.3 Information Transparency and Reliability

Unintentional inaccuracies in data, information, and intelligence—often resulting from errors or miscommunications—can add additional challenges. Ensuring the accuracy and integrity of data requires meticulous efforts in validating both inputs and outputs. Bias is a compounding concern to accuracy. EM/PS personnel struggle to find a balance between historical and prediction-based data when making decisions. Essentially, they worry that recency bias due to a variety of factors may disproportionately take precedence over the experience of decision-makers rather than allowing objective data to guide the focus of discussions. EM/PS personnel desire to drive toward the essential outcomes of mitigation and to enhance prediction abilities to forecast possible future states of their jurisdictions and communities. Most EM/PS professionals strive to be proactive, but attention is not given to some scenarios because of the mentality that, while the impacts might be significant or even catastrophic, the frequency of occurrence will be low. Correlation between mitigation and avoided harm is sometimes difficult to quantify and makes justifying mitigation challenging.

3.4 Technology Literacy

A lack of technology literacy was the most common deal-breaker for technology adoption among exercise participants. It involves an understanding of how to use a specific technology through its unique interface, not just a general understanding of a technology's category or capability. Participants note that personnel need adequate training on the technologies and that the technologies they find easiest to use are those incorporated into everyday EM/PS operations. Only using a technology during incident activations is likely to generate adoption hesitancy among personnel. New tools require customized trainings to help personnel understand how to deploy them effectively. For maximum effectiveness, these trainings should occur at regular intervals as well as when major updates are made to the technology.

3.5 Collective Buy-In

EM/PS personnel are apprehensive about developing an overreliance on technology, fearing it could eliminate critical human judgement and make mistakes. This potential overreliance on technology is particularly concerning in the EM/PS environment due to the nature of the work. External conditions can change drastically, rendering certain technologies inoperable or resource constrained. EM/PS operations must persist through these situations. Mistakes could, in turn, generate long-term public mistrust about why important decisions were left solely to a machine. EM/PS personnel want reassurance that AI outputs are reliable and accurate along with the ability to use technology to assist, rather than replace, human decision-making. Some worries exist that technology will make EM/PS personnel mere technicians rather than enable them to be better practitioners. They are also concerned that relying too much on technology, particularly AI, creates a lack of humanity in an environment where protecting and supporting communities is the goal.

3.6 Cybersecurity

New technologies expand the attack surface for cyber threats by introducing new vulnerabilities. Data that provide cross-jurisdictional insights to critical infrastructure can be an attractive target for insider threats and can be used to plan attacks if accessed inappropriately. Also, many technologies are only as good as their input data. People may be unwilling to share sensitive information due to privacy concerns, and organizations may be hesitant to share data due to liability concerns, limiting the performance of some technologies.

4.0 Technology Profiles

Following the identification of high-value challenges, the breakout groups focused their brainstorming toward developing requirements for potential technology solutions to address the challenges. A total of 13 technology profiles were generated, each captured in a standard template (available in Appendix D). These technology profiles can function as a starting point for DHS S&T to collaborate with the private sector toward developing more concrete and marketable tools that can positively impact the EOC of the Future.

Due to time constraints, exercise participants were unable to fully capture feasibility and impact information in two out of 13 technology profiles. However, capability, interface, and interaction selection information were captured along with a general technology description and details on the high-impact challenge being addressed. Additionally, the consistency and volume of data captured by PNNL researchers likely enables high-fidelity future feasibility and impact assessments for these partial profiles. This section provides detailed technology profiles for the following technologies:

- Automated EM/PS Training Customization
- Automated AAR Data Pipeline Insights
- Immersive-Reality, Data-Aggregating AI
- Custom Predictive Data Validation Dashboard
- AI-Driven Data Fusion Insights
- Predictive Risk Assessment Knowledge Base
- Cross-Jurisdictional, Cascading Impact Digital Twin
- Funding Acquisition AI Agent
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4.1 Automated EM/PS Training Customization

Use Case: AI
Process Step: Workforce Training
Location: Nashua, NH

General Description: This technology aims to customize training for EOC personnel as well as the trainers themselves based on individual learning styles, roles, and local contexts. It empowers students to personally feel the content and internalize takeaways using AAR and AI to fuel the training knowledge base. Augmented/virtual/mixed reality and gaming consoles are deployed to further enhance engagement and realism, providing custom simulations to help students translate book knowledge to practical experience. The technology researches, selects, and tailors content for these interfaces, among others, while identifying needs for updates to that content automatically. The system automates initial content generation, accelerating the transformation of raw data into training materials, ensuring timeliness and relevancy while mitigating issues like outdated content and instructor freelancing. Automated feedback loops create a culture of continuous improvement that ensures lessons learned from incidents are properly incorporated and students are provided materials that meet them where they are at rather than an all-encompassing baseline or standard. Rather than replacing human trainers, this tool augments their capabilities, enabling them to deliver more relevant, engaging training while saving time and resources to be reinvested in other EM/PS activities.

Corresponding Challenge: Workforce training within EM/PS faces significant challenges in adapting course content to different learning styles, varying levels of knowledge/experience, community characteristics, and constrained time availabilities. Customizing content to meet individual needs and providing tailored, immediate feedback based on each participant's knowledge level is particularly difficult and not currently practiced. Creating relevant, resonant examples for diverse materials further complicates the process. The varying needs of students—some requiring repetitive practice, others needing to develop critical thinking skills—make it hard to engage all participants equally. As a result, some students may fall behind while others become bored.

Anticipated Impact: This technology would significantly speed up the process of transforming raw data into training content. In addition to relieving personnel time, this expediency would prevent trainings from becoming obsolete. Increased relevancy means increased buy-in, which in turn leads to increased effectiveness given more support for trainings. Circular, timely feedback from AAR would help integrate lessons learned in future decision-making while creating a culture of continuous improvement and problem solving. This technology would also eliminate instructor freelancing, which tends to happen when training content is obsolete. Instructor freelancing leads to inaccuracies, inapplicability to the audience, inconsistencies, and perpetuation of biases. Instructors could further benefit from this tool if it is used to train the trainer, tailor trainings to the trainer's strengths, and help the instructors build confidence. Finally, the personalized aspect of training content would help students understand the "why" behind lessons learned from AAR and tailor the trainings to their level instead of a one-size-fits-all approach.

Operational Feasibility: Customization of trainings may appear too targeted, which can be eerie. However, the expectation is that the benefits of more engaging trainings would outweigh the hesitancy regarding personalization. If implemented similarly to targeted advertising, students may not even know that customization is occurring, but they would still appreciate its benefits. An opt-in should be built into this tool to mitigate these privacy concerns. Security concerns may be ameliorated by information segmentation and security by design. However, if the technology is misused/abused to perpetuate biases, mislead, or gatekeep, it is expected to become infeasible.

4.2 Automated AAR Data Pipeline Insights

Use Case: AI
Process Step: Workforce Training
Location: Nashua, NH

General Description: A tool that begins data collection and pipelining for AAR at the start of an incident, perhaps even before EOC activation. This process will be automated and comprehensive, deploying knowledge graphs and data fusion techniques to create a comprehensive knowledge base that feeds into training tools (see Section 4.1). It will conduct pre-mortems as well, including human and operational performance evaluation, identification of systemic problems, root-cause analysis, data storage, and data sharing. It has the potential to anonymize AAR and share findings vertically; therefore, the tool would be customized according to user authorities and security clearances while addressing agency-specific information security requirements. This knowledge base may revolutionize response efforts as it could provide quick insights for problem identification during incidents, thereby enabling corrective actions to be taken to avoid or limit negative outcomes.

Corresponding Challenge: Capturing, creating, documenting, and summarizing knowledge about a complex incident, particularly from AAR, is difficult, resulting in significant gaps in data and information needed to identify lessons learned, create corrective action plans, and generate trainings. AAR is slow and often fails to capture all relevant information associated with an incident response. Information pipelining needs an overhaul since data are disparate, spread through internal systems, and not always logged/captured. Multi-modal media is not often incorporated. Sentiment differences between news media, the general public, and EOC personnel are not captured. AAR is not conducted within the context of the system, which means decisions and outcomes are not connected. Often, it occurs based on what can be found or remembered and what leadership wants included, and it is usually missing information from the first 24 hours of the incident.

Anticipated Impact: This technology provides neutrality by relying on pre-incident information sharing agreements to provide automated, unbiased, and comprehensive collection and analysis of incident data. Resulting information would be persistent and traceable from all participants. This approach builds transparency and trust among all stakeholders and will accelerate the identification of lessons learned. This technology would also level the playing field across programs and regions regardless of their maturity and resources. Lessons learned from AAR are not always learned presently due to their ad hoc, informal nature, so this would facilitate that learning and continuous improvement process. Ideally, this tool increases information visibility and connectivity.

Operational Feasibility: Privacy is a significant concern regarding this technology, along with fear of liability, particularly in the private sector. The proposed system will require a significant increase in data collection from sources currently not available or accessed, such as sensors, devices, telephone calls, meetings, email, and incident management software. If the information from AAR is leaked, then it may cause a rush to assign blame for bad outcomes and public criticism. If the technology records audio from decision-makers during incidents, they may be more hesitant to be open and honest, hindering response efforts. There is some concern that this type of tool could be used to target individuals, feed fake reports, and create public perception issues.

4.3 Immersive-Reality, Data-Aggregating AI

Use Case: AI
Process Step: Monitoring and Evaluation
Location: Nashua, NH

General Description: An advanced immersive reality data management tool designed to revolutionize data aggregation, which is a significant challenge due to large volumes of data and constrained resources. Utilizing augmented reality/virtual reality and gesture controls, along with a voice-command-controlled AI digital assistant, this solution enables efficient data aggregation and tailored information generation to create customized datasets. It incorporates sophisticated classification, clustering, and data fusion capabilities for real-time data monitoring and open-source analysis. Humanoid robots and drones serve as deployable sensors to collect additional data and address information gaps. The system's intelligent conversational interface allows it to swiftly identify and fulfill user-specific data requirements, enhancing operational efficiency.

Corresponding Challenge: The process of collecting and combining data from multiple sources into a single, unified dataset for analysis, reporting, and/or storage (i.e., data aggregation) is a central challenge in monitoring and evaluation. The process is taxing on personnel hours, which are a constrained resource, making it challenging to manage efficiently. Handling large volumes of data adds to the complexity, presenting a major challenge in collating all necessary information. These issues underscore the difficulties in effectively aggregating data while balancing already limited resources within EOCs.

Anticipated Impact: This technology would replace some manual operations associated with monitoring and evaluation. It would increase personnel speed and efficiency while streamlining planning and damage assessments. Data visualization and management would help information comprehension. It improves, enhances, and hardens the system.

Operational Feasibility: A lack of technology literacy is the main reason participants imagine this tool would not be adopted.

4.4 Custom Predictive Data Validation Dashboard

Use Case: AI
Process Step: Monitoring and Evaluation
Location: Nashua, NH

General Description: An intuitive next-generation data management dashboard designed to ensure data accuracy and integrity, addressing the fundamental challenges posed by a lack of information transparency. Equipped with advanced accuracy analysis and reporting, this solution utilizes predictive modeling to anticipate data needs and potential cascading situations, while classifying and clustering outputs for enhanced validation. Integrating sophisticated geospatial tools, it adds essential context to outputs, such as geolocation, while triaging alerts and recognizing anomalies to verify data validity. The system's user-centric design empowers end users to swiftly identify data gaps and maintain high standards of information accuracy, enhancing operational efficiency.

Corresponding Challenge: Data validation is tricky. Ensuring the accuracy and integrity of data requires meticulous efforts in validating both inputs and outputs. The proliferation of open-source information and information generated from a black box further complicates this process. Unintentional inaccuracies, often resulting from errors or miscommunications, add additional challenges. These issues underscore the complexities of maintaining data integrity for monitoring and evaluation purposes.

Anticipated Impact: This technology would provide contextualized validation for data collected from publicly available sources. It would add predictive capabilities and analysis that is currently difficult to do based on only historical data and AAR. Trusted outputs would lead to more efficiency (i.e., better actions) along with quantification of benefits.

Operational Feasibility: A lack of technology literacy and training is a main hesitancy for using this technology. Being able to trust the technology is another barrier. On the physical resources side, there are some worries that data storage would be inadequate to support the desired functionalities of this technology. Further, users providing results from this technology without truly understanding the validation methodology employed and possible variation in AI-generated results would be an unwanted behavior. Similarly, manipulating validation scores could be an issue. All of these may negatively impact public perception and trust.

4.5 AI-Driven Data Fusion Insights

Use Case: AI
Process Step: Planning
Location: Nashua, NH

General Description: Acting as an investigative resource for data gathering and validation, this tool will streamline the generation of data-driven, actionable planning insights without creating cognitive overload. It will be driven by best practices in data fusion, open-source data analysis, and next-generation data management to utilize a wide variety of sources. Advancements in AI algorithms (e.g., in natural language processing, classification, and clustering) will prevent the tool from triggering analysis paralysis in users. Users will have the option to interface with this technology using several different tools based on their own learning style and operational role. The technology will prioritize natural interactions and information retrieval speed.

Corresponding Challenge: Data gathering and validation present challenges to planning due to insufficient data sources or an overabundance from certain sources, leading to imbalances. Privacy restrictions, which vary by jurisdiction, and other regulatory authorities complicate data collection efforts. Additionally, a lack of sensors hampers data gathering, and there is no straightforward way to validate data accuracy, making it hard to avoid biases.

Anticipated Impact: This technology would act as a time saver and force multiplier by managing data used by planning processes. It would provide a wide variety of stakeholders with real-time information highlighted by importance, facilitating information sharing. Users could explore the provided information in greater detail if desired. It would improve damage assessment and possibly help incorporate community input more effectively. Ideally, it would have more security than today's computer systems. It would help track training and follow-up needs from planning exercises in addition to recommending resources for missions based on availability and objectives. All phases of planning would benefit from its information triage capabilities (i.e., its ability to highlight relevant regulations, laws, best practices, court decisions, criminal activity, trends).

Operational Feasibility: Fear of making a mistake and causing harm to communities would generate hesitancy to use this tool among EM/PS practitioners. An ability to maintain proficiency working with the technology is necessary to ensure personnel feel comfortable using it. Without enough time devoted day-to-day to stay familiar with the technology, it will not maintain its utility. There are further concerns that it may increase the attack surface for cyber threats or lead to exploitation of human error. Data, information, and intelligence outputs could all be manipulated to do harm.

4.6 Predictive Risk Assessment Knowledge Base

Use Case: Information Sharing
Process Step: Risk Assessment
Location: Boulder, CO

General Description: A comprehensive knowledge base for risk assessments used for both mitigation/planning purposes and during EOC activations. This knowledge base would generate initial insights, triage findings, and enable humans-in-the-loop to do final down selection and decision-making without cognitive overload. It fuses open-source, proprietary, and real-time data sources while using predictive modeling to generate actionable information from the data. All data is geotagged for storytelling purposes. While the knowledge base breaks down information silos, the platform itself enables more frequent information updates and features a user-friendly “community library” model where users can pull the specific information they need rather than being overwhelmed by pushed notifications. It also promotes a collaborative approach to hazard identification and risk analysis among regional partners. The knowledge base would support jurisdiction-level assessments while combining them into a comprehensive, integrated regional and state-level view.

Corresponding Challenge: A significant challenge to risk assessment within EOCs is the difficulty and time-consuming process of deconflicting, aggregating, and updating data across various jurisdictions. In addition, jurisdictions are not static; dynamic factors such as population, environment, demographics, or commercial/industrial development constantly influence risk assessments. Furthermore, new hazards may be discovered or more information about known hazards may be developed. Despite these challenges, this process is essential for creating impactful and accurate risk assessments, which are the foundation for all phases of emergency management. Streamlining data management and collaboration across jurisdictions is crucial to improving the quality and effectiveness of risk assessments.

Anticipated Impact: This technology would help EM/PS personnel, supporting agencies, and the community better understand their risks and potential cascading impacts of upcoming or active hazards. It would bridge gaps resulting from a lack of institutional knowledge, leading them to consider more scenarios in risk analysis. A common understanding of risk analysis inputs, outputs, and methodology would be possible regardless of where someone is located. Communication and accuracy of complex modeling results would also be improved. Proactive, better-informed approaches to mitigation planning, including cost-benefit analyses, would become achievable. It would break down information silos and provide more frequent, up-to-date information for assessing risk. Risk assessments could be cross-jurisdictional with larger viewership of generated insights.

Operational Feasibility: Like current risk assessments, a human would still need to verify the information and make final decisions. Information in previous tools and lessons learned would need to be transferred to this knowledge base so it contains comprehensive insights into existing knowledge, not just newly generated knowledge. User friendliness of the tool would be make-or-break for its adoption. Unfamiliarity with the tool may occur if used infrequently, so it should be integrated with day-to-day operations. Incorrect use could harm its benefit potential. It also needs to be interoperable with other tools and data formats. Data standards, and corresponding enforcement, should be in place. Cognitive overload may occur, so it is important that the user interface is intuitive and supports a pull, not push, mode. If verifying insights generated by the tool becomes unwieldy in terms of time consumed, the technology’s effectiveness may also decrease. Overreliance on the tool is another concern, and users should be cautioned against thinking the tool replaces their decision-making skills. Data manipulation to achieve desired, rather than factual, results is another concern.

4.7 Cross-Jurisdictional, Cascading Impact Digital Twin

Use Case: Information Sharing
Process Step: Risk Assessment
Location: Boulder, CO

General Description: A simulator for cascading, multi-jurisdictional failures across multiple what-if scenarios without harming real-life systems, thereby enhancing the utility of risk assessments within EOCs. By leveraging predictive modeling, knowledge graphs, and digital twin simulations, this technology offers a proactive approach to identify and mitigate potential hazards. The integration of automated content generation and customized UIs ensures efficient and accurate data management, facilitating informed decision-making and comprehensive planning across a variety of regions, agencies, and organizations.

Corresponding Challenge: Risk assessment within EOCs is often hindered by a siloed approach, making it challenging to understand cascading impacts and the consequences of hazards that span multiple jurisdictions and critical infrastructure. The absence of predictive modeling and comprehensive data leads to a primarily reactionary risk posture rather than a proactive one. Additionally, the data used for these assessments can become outdated quickly. Addressing these issues requires enhanced collaboration, integration of predictive modeling, and more dynamic data management to improve the effectiveness and timeliness of risk assessments.

Anticipated Impact: This tool's main benefit would be breaking down informational silos and enabling cross-jurisdictional collaboration. By bringing together disparate systems, it would lead to expedited information and insight generation that are not currently possible with today's siloed approach. It would create clear paths forward for collaboration due to its common system. The tool would facilitate more informed planning. Predictive modeling and proactivity would become realistic instead of theoretical. Efficiency and less bias would ideally be outcomes of this tool's deployment as well.

Operational Feasibility: A lack of understanding as to how the tool functions due to inadequate training may make its deployment infeasible. Not understanding the backend data may also cause harm. If outputs for simulation scenarios run with "doom and gloom" parameters are leaked to the general public, they may instill fear and/or distrust of government. It could also become a weapon on the offensive side of cyberattacks against critical infrastructure if threat actors gain access. While it would not introduce vulnerabilities to the critical infrastructure, it would make these vulnerabilities known upon unauthorized access.

4.8 Funding Acquisition AI Agent

Use Case: Information Sharing
Process Step: Funding and Resource Allocation
Location: Boulder, CO

General Description: A web-based AI assistant where users supply input parameters to search funding opportunities and the AI assistant collects and tailors the summarization of the results to the user, setting the user up for immediate next steps toward successful funding acquisition. Search parameters include objectives, such as optimizing for stable funding throughout the year over going after the biggest sources of funding. Users may also subscribe to receive updates and notifications regarding their queries. The AI assistant will provide helpful context to the search results, including metrics such as success rate/likelihood or administrative burden of going after a particular funding source, and it will know the other parties that need to be involved for certain joint opportunities.

Corresponding Challenge: The complexity and unpredictability of funding processes is a major pain point for EOCs and EM/PS personnel. Funding is often erratic, and awareness of available funding sources and grant application opportunities is limited. Additionally, the extensive paperwork involved further complicates the funding process. Streamlining funding efforts and improving awareness of funding options are essential to addressing these challenges and ensuring efficient resource allocation.

Anticipated Impact: This tool is expected to streamline searches for/securing funding, reducing the unpredictability and complexity associated with traditional processes. By tailoring funding opportunities to specific organizational needs, the tool allows users to focus on strategic resource allocation rather than navigating tedious administrative hurdles. Proactive notifications and clear metrics like success likelihood and workload impact will help decision-makers prioritize the best opportunities. Additionally, the AI assistant's ability to identify collaborative funding options enables stronger partnerships between agencies and across jurisdictions. Overall, this technology empowers access to funding more efficiently, ensuring critical operations remain supported and well-resourced.

Operational Feasibility: A lack of technology literacy is a main barrier to adoption for this technology. Entrenched practices related to funding procedures may also prevent it from being widely adopted. Additionally, participants want humans to verify the AI's decisions so the objectives associated with this technology cannot be fully automated. If everyone uses this tool and gets the same results and decisions, then its utility is nullified, and no positive impacts can be realized from the tool's deployment.

4.9 Optimized Data-Driven Decision-Making

Use Case: Information Sharing
Process Step: Funding and Resource Allocation
Location: Boulder, CO

General Description: A sophisticated dashboard tool designed to shift the current decision-making paradigm to be more data-driven. Equipped with next-generation data management capabilities, this solution leverages data fusion, open-source analysis, and accuracy reporting for comprehensive risk assessments and cost-benefit analyses. Real-time data monitoring and advanced knowledge graphing provide insightful optimization and assisted resource allocation, ensuring balanced consideration of historical data with future forecasts. The platform enables mutually vetted justification of resource allocation by incorporating geospatial and statistical analyses, identifying the right metrics to support proactive measures and enhance operational efficiency.

Corresponding Challenge: The subjective nature of decisions, rather than data-driven approaches, complicates funding efforts. The current system often funds operations only after failures occur, necessitating constant justification for funding. This creates a cycle where reactive rather than proactive measures are taken. Furthermore, balancing historical data with future forecasting is challenging to determine the correct metrics for justifying funding. Identifying the right metrics remains a key barrier to efficient and effective resource allocation.

Anticipated Impact: This technology would build support for existing funding programs while helping EM/PS personnel advocate for the creation of new funding programs that address emerging needs. It would provide crucial justification for funding. Essentially, it centralizes and automates processes currently associated with obtaining funding.

Operational Feasibility: If users do not trust the input data, then they will not trust the result. It may come with a learning curve. Proliferation of this tool may depend on who else is using it and accepting it. To be effective, the tool must be able to perform data analysis because EOCs are unable to hire dedicated data analysts. It could be abused by making statistics align with the user's desired outcome. If the information gets into the wrong hands, abuse of the tool could occur. Finally, garbage in equals garbage out, so inadequate input data would cause the performance and utility of this technology to suffer.

4.10 Real-Time Shared Situational Awareness

Use Case: Information Sharing
Process Step: Capacity and Capability Building
Location: Boulder, CO

General Description: An integrated geospatial platform that turns real-time data into actionable information using multiple cross-platform applications and maximizing the end user's preferences. This tool will create a more integrated common operating picture that enables a consistent, shared understanding of the situation and support coordination. This tool would improve individuals' and teams' abilities to comprehend what is happening, anticipate possible future states, and make informed decisions.

Corresponding Challenge: Coordinating multiple agencies and jurisdictions during the same emergency response is difficult. One major reason for this challenge is the incompatibility of different systems for information sharing, which hinders effective communication and collaboration. Building interoperable systems and improving coordination mechanisms are essential for enhancing the overall efficiency of emergency response efforts.

Anticipated Impact: Acting as a copilot, this technology would outsource some of the information processing to machines to better inform human decision-making. It would be a force multiplier, especially during initial activation when EM/PS personnel are typically playing catch-up. It decreases the number of people needed to collect, analyze, and share information, allowing decision-makers to focus on strategy instead of devoting time to finding needed data. Less time devoted to analysis allows EOC personnel to focus more on creating solutions. It would improve interoperability across jurisdictions by enabling data analysis through multiple device types. Data used in decision-making would be up-to-date and more comprehensive. A higher level of confidence in the accuracy of information would additionally provide decision-makers with greater confidence.

Operational Feasibility: An understanding of and trust in how this technology works are needed in order to use it. Knowing what data is going into the tool and how that data influences the information outputs would help the user significantly. Trusted data sources do not necessarily mean complete data. Given the inherent complexity and time-sensitive nature of emergencies, this technology will have to support user decision-making where incident data is conflicting, incomplete, inaccurate, false, and/or unavailable. While this technology is new and untested, it could create liability issues if it is determined later that problems occurred, such as incompleteness or inaccuracies. Privacy is a concern as well due to the sensitive nature of information generated during incidents, including 911 calls and health data.

4.11 Real-Time Alert and Warning Generation

Use Case: Synergy and Integration
Process Step: Community Involvement and Participation
Location: Seattle, WA

General Description: An advanced emergency alerting system that proactively provides decision support and automated alerting capabilities. This technology would pre-populate emergency alerts and warnings with real-time data from monitoring systems, saving valuable time associated with manual drafting in an emergency while also offering enhanced communication features like multi-language support, custom-generated visual content, and geofenced notifications. This technology would integrate with other government and privately operated systems to trigger automated harm mitigation actions (e.g., closing a valve at a chemical plant), based on the type of incident. It aims to transform emergency response from an information pull model to a push model where managers receive timely suggested alert and warning actions based on real-time incident data. The system would operate collaboratively with humans, who provide context and make final decisions, while the technology handles data integration and alert prioritization to save time, reduce administrative burden, and improve public engagement.

Corresponding Challenge: Close coordination is needed between incident command and entities generating alerts to ensure the alerts are timely, directed at the correct audience, and appropriately support active operations. Emergency managers face significant challenges with current alert and warning systems for many reasons: their distributed nature, the time-sensitive nature of incidents, not enough available information to determine who to alert and what to tell them, and overlapping alert and warning systems spread across several jurisdictions. These factors result in delays in alerts and warnings reaching the public, an increase in administrative burden and geographical barriers, and a reduction in public trust and cross-jurisdictional collaboration. Public understanding of the fragmented communication is lacking across government entities. This fragmentation leads to an increase in false or outdated alerts. These systems are often developed by technologists who lack expertise in EM/PS, failing to address the specific complexities and constraints involved in disaster response. This mismatch results in cumbersome processes for emergency managers, who are not only tasked with disseminating information but also guiding actions recommended by alerts and warnings. EM/PS personnel currently have no way to immediately assess the effectiveness of the alerts and warnings they send out. Additionally, alerting technology struggles to keep pace with modern advancements in how people receive information. Finally, engaging people during the mitigation phase without overloading them with information remains a challenge, and critical response alerts might be ignored as noise.

Anticipated Impact: This technology would proactively provide a menu of timely alert and warning actions and prompt users to take action(s) rather than doing the human's job or decision-making itself. It would therefore automate decision prompting and support. The tool would augment current systems by adding new capabilities and dimensions. Alerting could also have a collaborative, cross-jurisdictional aspect using this tool. It would save time by pre-populating information, multi-lingual translations, and visual cues instead of starting from scratch each time, greatly reducing administrative burden. It could incorporate detours and real-time changes into evacuation locations and directions. This technology would flip the alerting process from a pull to a push model, including pushing information and suggestions to EM/PS users that are typically not considered based on time or experience constraints. It could streamline translation of "boots on the ground" observations into usable alerting information for public dissemination.

Operational Feasibility: Arbitrary or inaccurate cutoffs for geofenced alerts and warnings may lead to public mistrust. Trust in technology would need to be built over time rather than relying on expectations that this trust would immediately be granted by the public. If built into critical infrastructure monitoring systems, it could introduce new cyber vulnerabilities. If working across organizations, the most stringent data management rules among the participating organizations may be proliferated, reducing capabilities for the rest. Differences between the geographical extent of authority and the geographical extent of an incident may be difficult to work out. A lack of standardization would make this tool difficult to use, and this variability is expected unless a central authority such as the federal government provides a minimum viable product. If personnel over-rely on the technology and do not vet alerts prior to sending, inaccuracies or false alerts could harm public trust. Cyber criminals could use this system to send false alerts, generating panic or overloading the system. Bad sources may lead to detrimental content in the auto-populated alerts, intentionally or unintentionally. False interpretations of voice and gesture control components might lead to a need for constant user correction, making the tool disappointing and time consuming to use.

4.12 AI Agent for Emergency Public Information

Use Case: Synergy and Integration
Process Step: Community Involvement and Participation
Location: Seattle, WA

General Description: An administrative tool for EM/PS personnel and local government agencies that coordinates information about individual citizens and local operational conditions. This AI-enabled system would improve public-facing information resources by automatically rearranging website interfaces to highlight critical information, such as boil water advisories, during emergencies. The technology would identify regular callers and active community members as potential trusted partners, use call hold time for educational purposes, and gather citizen feedback through quick surveys tacked onto existing interactions to improve government services. It aims to expedite emergency communications, reduce delays caused by traditional approval processes, and provide relevant information to the public even when they "don't know what they need to know."

Corresponding Challenge: A widening gulf exists between government and private industries in terms of both internal functionality and capabilities. However, communities do not adequately understand these differences or their own civic duties. EM/PS personnel perceive that most people do not seem to know or understand how government works and why it functions differently than a business. Civic education and responsibility are important components of a prepared community. In mitigation as well as response efforts, government and the community it serves must work together. Even if government could technologically match private industry operations, the public would likely not be happy with the implications/results due to concerns and constraints like privacy and mistrust in government.

Anticipated Impact: This technology would increase effectiveness and task completion speed. Sometimes, some of the last people to engage in incident management are information technology specialists, so these updates typically happen last. This tool would overcome the delay between incident start and relevant information becoming available to the public. The public usually does not know to search for specific content unless they have a relevant question, so this tool would also overcome issues from this lack of public awareness. It would help the public learn nuances of terms and topics while improving access to relevant downstream, long-term information that helps the public handle the aftermath of incidents. It would help overcome communication gaps where EM/PS thinks something is common knowledge, but the public does not.

Operational Feasibility: This technology needs to work automatically, making the EM/PS website changes regardless of time and staffing availability. Some delays could be due to errors in the technology itself; if these issues happen often enough, the technology becomes unattractive at best or unusable at worst.

4.13 Interactive, Community-Driven Decision Simulation

Use Case: Synergy and Integration
Process Step: Doctrine and Strategy Development
Location: Seattle, WA

General Description: A whole community web portal and/or mobile app, accessible from any device with an internet connection, plus options for working offline, to enable community members and organizations to safely and effectively coordinate their contributions to EM/PS efforts with the government. UIs are customized by role-based access. Decision-makers are able to provide data sources, visualizing comprehensive, yet simplified, data dashboards to help them do their job. Data and algorithms are designed to provide predictive and accurate information that is representative of all members of the community—even those who are traditionally underrepresented. Community members are able to provide crowd-sourced, real-time information to contribute to the decision-making process. Both the decision-makers and the community members have access to a game/simulation interface that enables end users to see downstream effects of decisions, with additional context for why these decisions were made.

Corresponding Challenge: Emergency managers currently face the challenge of establishing trust and securing buy-in from the community, which is essential for effective doctrine and strategy development. Identifying community leaders and forming partnerships with them are priorities. There is a critical need to create plans with, and not for, the community that ensure underrepresented groups have a voice, foster stronger relationships, and achieve genuine community buy-in.

Anticipated Impact: This technology would be interactive and engaging while providing a feedback loop mechanism for continual improvement. The community would get to be part of what decision-makers do by contributing data through the gamified interface. Where possible, this tool would support closer coordination between government and community members. Officials could request community resources to help solve problems and reduce the strain on overwhelmed government resources. This technology could increase the magnitude of community involvement. AI would enhance understanding of complex ideas while augmenting the human part of human-machine teaming. It would bring order to what currently feels like chaos and simplify the process of doctrine and strategy development. This tool would free up decision-makers to focus on more personal interaction with the community, which helps build trust and buy-in.

Operational Feasibility: This tool may inadvertently contribute to a public perception of a "lack of humanity" due to its reliance on AI. Leaving the human-in-the-loop is critical to fostering the necessary public trust and community buy-in.

5.0 Summary and Conclusions

The exercises resulted in a series of high-impact challenges facing EM/PS and 13 profiles of technologies that can address these identified challenges. Analysis of those challenges and technologies highlighted three overarching priorities for how technology can benefit EM/PS and the EOC of the Future:

- Technology as a force multiplier
- Effective utilization and communication of data
- Humanoid technologies for familiar and easy interaction

These 13 technology profiles can serve as starting points for collaboration with private industry and government to inform next steps for future operationalization in the EM/PS mission space.

5.1 Technology as a Force Multiplier

Participants identified time savings and efficiency as a primary, direct benefit of almost all technology solutions. Doing more with less is a common desire as well as getting to mitigation activities that are not currently addressed due to constraints on time, personnel, funding, and other resources. In all cases, the expectation is that a technology solution streamlines the associated mitigation process step. Sometimes, this change allows EM/PS personnel to successfully accomplish the mitigation process step and move onto other, more time-sensitive tasks. Alternatively, this change can also make the mitigation process step more approachable, which in turn moves it from the “would be nice to do” list to the “actively able to do” list.

At the same time, technology may be used to help EM/PS personnel overcome skillset gaps. Some EOCs are staffed by generalists and still others barely have any staff. In addition to adding efficiencies to staff’s work, tech-savvy staff can deploy future technologies to help reduce knowledge and skill gaps. For example, while in-depth, comprehensive risk analysis requires technical knowledge beyond that of typical EM/PS practitioners, well-designed technology may provide this knowledge in the place of hiring additional staff. However, effective training on how to use these new technologies must be available to EM/PS personnel to ensure the technologies are actively and accurately used.

Technology, including AI, should act as a force multiplier rather than a force replacement. Participants emphasize that humans must remain in the loop while being supported by technology rather than relying on technology to do their jobs. An analogy that particularly resonated with this audience is that AI takes the role of a highly capable intern. It does not, however, act as an assistant. Unlike assistants, interns do not act unsupervised on their own but rather receive directions from their supervisors on what to do and how to do it. Moreover, their outputs are reviewed by the supervisors prior to taking effect in the real world.

Notably, EM/PS personnel do not make the force multiplier instead of force replacement distinction out of fear for their own jobs. Rather, they feel the decisions made in EM/PS, including those in the mitigation phase, require contextualization beyond current machine capabilities. EM/PS decisions often influence significant real-world outcomes, including illness, death, and property loss. Further, EM/PS is for the community, by the community. Leaving decisions of this magnitude and reach entirely up to a machine risks turning EM/PS into an impersonal, ineffective, and untrustworthy effort.

Additionally, participants underscored that existing challenges are typically caused by human behavior and system process challenges rather than by technology itself. Technology can exacerbate existing issues if developed and deployed without end users in mind while trying to create technicians rather than practitioners. As technology requirements are developed, it is critical to focus on how the technology augments or revolutionizes the current qualifications and aptitudes needed in EM/PS and public safety personnel so that they can continue to be practitioners, just equipped with better tools.

5.2 Effective Utilization and Communication of Data

These exercises underscore that EM/PS personnel across many, if not all, roles want more data usable to them as they do their jobs. Improving access and utilization of data plays a central role in all technology profiles, substantiated by the prevalence of capabilities such as data fusion, next-generation data management, open-source data analysis, and real-time data monitoring. These data are expected to provide up-to-date, cutting-edge information spanning jurisdictional boundaries for holistic, informed decision-making efforts. Access to data is expected to be a key enabler of shifting EM/PS mitigation and planning efforts from reactive to proactive.

To generate positive impact and avoid negative unintended consequences, technologies should excel at turning data into knowledge. This outcome can be accomplished by capabilities such as classification and clustering, knowledge graphing, and predictive modeling. None of these algorithms are new, yet their frequent appearance in the technology profiles suggests that they are not being widely and/or effectively deployed in EM/PS settings. An essential piece of impact when increasing data availability is tailoring content (i.e., generated and presented information/data) to the task at hand. Just providing data for data's sake is not nearly enough—technology should slice, dice, and transform that data to different tasks. Some tasks require dashboarding with geotagging while others require predictive modeling. Having a one-stop shop for information is likely ineffective. The same technology may be able to assist EM/PS personnel with multiple tasks, but it will need to have different functionalities crafted for the varying use cases and tasks. Even better, these functionalities will be customizable by user, role, or organization to accelerate impact.

As an example, multiple breakout groups selected predictive modeling as a capability in their technology profile. However, predictive modeling was not used in the exact same way every time. Multi-faceted questions must be asked and answered before deploying predictive modeling algorithms within technology for EM/PS. Answers will almost certainly vary by role and task. For instance, predicting the characteristics of a community in five years (see Section 4.13) changes the answers to the following questions compared with predicting the cascading impacts of infrastructure mitigation projects (see Section 4.7).

- What is being predicted?
- In what area should the prediction be valid?
- How reliable is the prediction?
- How does this prediction work with other information?
- How does the user know they can trust this prediction?
- How does the user know what information and data was used to generate this prediction?
- How does this prediction influence the user's decision-making process?

- How often does this prediction need to be updated?

Finally, this increase in data availability needs to happen in a way that avoids cognitive overload. Technologies should also follow a “push” rather than “pull” model. Essentially, technologies should intelligently understand what EM/PS personnel need and when they need it, so the technology itself can down-select available information and present just the most pertinent information to the user. The technology should be designed to share the information in an accurate and trustworthy manner (accuracy analysis and reporting was a frequently selected capability), so at the same time, users should be able to access additional data and information upon request in technology interfaces. Metadata about the data itself and possibly even chain-of-custody tracking about where the data came from and who manipulated it should be provided to further enhance technology transparency and trust. This model of UI design enables a user to dig as deeply as they would like, given their availability, while prioritizing communication of pertinent information upfront.

5.3 Humanoid Technologies for Familiar and Easy Interaction

A more futuristic theme among solutions is the desire to interact with technology as one might with a fellow human, using natural language, voicing of instructions, and gesturing. Digital assistant was the most frequently selected interaction modality. Some solutions include specific requests for gesture control and/or voice control or interfaces that require these interaction methods, like augmented, mixed, and virtual reality. Similarly, J.A.R.V.I.S., an advanced AI assistant from the Marvel Cinematic Universe film series and known for its human-like communication and task completion skills, was mentioned multiple times as an example of how they want to interact with technology in the future, particularly during incidents when time is of the essence.

EM/PS professionals state that technology communicating with them similarly to how a human might is useful for a variety of reasons. Participants perceive digital assistants to be more personalized than other interaction methods and enable them to easily connect with both formal and informal content from many sources, including other people. Dealing with additional physical items and touch interaction requirements in the future was identified as burdensome to some. For training-related tools in particular, having a human-like aspect was identified as important to success even while keeping a human trainer in the loop.

The frequent selection of user experience customization also illuminates this trend for desiring humanoid technologies. When humans interact with each other, they tend to customize their speech content and phrasing to the person or people to whom they are speaking. Similarly, exercise participants show a strong desire for technology that can perform this type of customization.

Appendix A – Detailed Exercise Protocol

How can technology enhance emergency operations in the future? To answer this question, EM/PS personnel from across the country participated in three research and development experiments facilitated by the PNNL EMOTR team. Participants ideated next-generation technology solutions to address high-priority challenges encountered in EOCs today. Technologies investigated include the new and emerging capabilities identified in the EMOTR Phase I AI Landscape Assessment.[2] EM/PS participants advanced these technology solutions from general ideas to realistic, comprehensive concepts by assessing impact and feasibility. Results from these exercises provide an enhanced vision for the EOC of the Future. The generated technology concepts may act as recommendations for future DHS S&T research activities.

This phase's exercises utilized the previous year's findings to inform research direction and themes. Compared to the TTXs conducted in year one, this phase's sessions were designed to generate more concrete technology solutions and specific feedback on those ideas. While the previous phase's TTXs tended toward open discussion format, the data collection during this phase was more structured to elicit concrete information about the impact and feasibility of future technologies on EOC operations.

A.1 Impact

Historically, technology is a significant driver of change. Understanding this change is vital to ensure new technology deployments bring widespread benefits while limiting unintended consequences. Impacts, for the purposes of this report, are the set of changes expected if the technology is introduced to the EOC environment and EM/PS operations. These changes can be positive or negative, but usually they are a combination of both. Positive means the technology is helpful to its users, does not cause harm, and provides benefits to its surrounding ecosystem. For a technology idea to be an attractive investment, the anticipated impacts should be both majority positive and large in magnitude. While smaller changes are not necessarily bad, incremental benefits do not usually outweigh the resource investment required to develop technology. To assess impact, facilitators use a technology profile (Appendix D) to guide participants through a thought exercise on how EOC and EM/PS operations might be different given access to a fully functional version of their ideated technology. To prevent overly optimistic thinking, this profile also prompts discussion of how the technology's introduction may lead to unintended consequences, abuse, and/or misuse.

A.2 Feasibility

Feasibility can be split into five dimensions and evaluating each separately is important to a truly effective assessment of technology viability.[3] The exercises evaluate two dimensions:

- **Operational Feasibility**: Will this technology be accepted by users, and what changes to the operational environment will be necessary to adopt it?

[2] Barr, J., Hagen, A., Tietje, G., Betzsold, N., Greer, A., & Best, E. (2024). *Emergency Management of Tomorrow Research: Artificial Intelligence Landscape Assessment*. PNNL-36083. Richland, WA: Pacific Northwest National Laboratory.

[3] https://www.indeed.com/careeradvice/careerdevelopment/feasibilitystudies

- **Technological Feasibility**: Are technical resources and knowledge available to build the technology to an extent that it can be used effectively within the target environment?

Each technology solution generated during the exercises has an associated technology profile designed to dive deeply into operational feasibility, while a first pass at technological feasibility was conducted by subject matter experts at PNNL. The cards available to participants during the technology building exercise, described later, were down-selected based on PNNL's internal assessment of technological feasibility with a 5–10-year time horizon. The technology profiles contain enough detail for technology and EM/PS experts to collaboratively further assess technological feasibility within the constraints of EOCs and other EM/PS environments.

Three dimensions of feasibility were not assessed as part of these exercises:

- **Economic Feasibility**: Does sufficient funding exist to create, deploy, and operate this technology in a way that will lead to not just its existence but also its success?
- **Legal Feasibility**: Does the technology adhere to rules, from local ordinances to federal laws, relevant to the geographic region in which the technology will be deployed?
- **Political Feasibility**: Will the political climate and its players be in favor of this technology, open to the changes it will bring, and supportive of its development and use?

While funding, legal, and policy considerations are at the forefront of many minds in EM/PS, these dimensions were outside the scope of this effort. The EMOTR team would like to acknowledge that, as with revolutionary technology introduction in many sectors, policy likely needs to adapt alongside technology to maximize the benefits of the proposed solutions introduced in this report. The authors of this report recommend further study devoted to financial, legal, and political feasibility prior to finalizing technology investment decisions.

A.3 Exercise Structure

Three use cases emerged from discussions during the Phase I TTXs: AI, information sharing, and synergy and integration. Each use case represents a set of concepts and recommendations that participants in last year's TTXs deemed crucial to the future effectiveness of EOCs. To enable methodical investigation of the themes, one theme was assigned to each exercise. Participants were separated into small breakout groups, and each breakout group explored a different process step within the mitigation phase of EM. The individual exercise's theme guided selection of specific process steps for the breakout groups.

According to the National Mitigation Framework, "threats and hazards present long-term risks to people and their property. Mitigation is risk management actions taken to avoid, reduce, or transfer those risks. By reducing the impact of disasters, mitigation supports protection and prevention activities, eases response, and speeds recovery to create better prepared and more resilient communities."[4] In short, mitigation aims to "reduce the loss of life and property by lessening the impact of future disasters."[5] Incidents are increasing in frequency, complexity, and cost throughout the U.S. According to a 2022 Congressional Budget Office report, over the past

[4] Federal Emergency Management Agency. (2016). National mitigation framework (tech. rep.). U.S. Department of Homeland Security.

[5] https://www.fema.gov/emergency-managers/risk-management/hazard-mitigation-planning

three decades, the Federal Emergency Management Agency has spent $347 billion (in 2022 dollars) on disaster response, recovery, and some post-disaster mitigation.[6]

The case for mitigation is simple: it saves money. For example, the National Institute of Building Sciences in its 2019 report, Natural Hazard Mitigation Saves,[7] estimates that:

- Adopting model codes saves $11 per $1 spent.
- Federal mitigation grants save $6 per $1 spent.
- Private sector building retrofits save $4 per $1 spent.
- Exceeding codes saves $4 per $1 spent.
- Mitigating infrastructure saves $4 per $1 spent.

EM/PS agencies and their partners understand the value of mitigation but must prioritize their limited time and resources first to response operations that save lives and property in immediate danger. This means mitigation projects, which can take years to complete, might not receive the support they deserve. Technology, as demonstrated by the proposed solutions from the EMOTR exercises, can provide a means to support more mitigation activities without impacting response efforts.

A.4 Themes and Mitigation

The following subsections describe the three use cases and their corresponding mitigation process steps.

A.4.1 Artificial Intelligence

AI has the potential to act as an accelerator in EOCs, empowering personnel to perform more meaningful tasks while AI handles repetitive and/or tedious tasking. Given the rapid pace of its development in industry, operationalizing AI in EOCs and in EM/PS more broadly will be a significant challenge, particularly if EM/PS is not the primary application, e.g., ChatGPT. EMOTR's previous TTX participants demonstrated both an interest in and hesitancy to use AI technologies. They further emphasized that just because AI can automate a process does not mean it should automate said process.[8] These findings led the EMOTR team to further explore the feasibility of integrating AI into EOC and EM/PS operations during this year's exercises.

The Nashua, NH, AI-themed exercise on March 18, 2025 focused on three mitigation process steps:

- **Monitoring and Evaluation**: Mitigation strategies and projects require close attention as conditions may change, including threats, hazards, risk assessments, priorities, and community support. Success depends on establishing baseline conditions, implementing

[6] Congressional Budget Office. (2022). FEMA's disaster relief fund: Budgetary history and Projections (tech. rep.). Congressional Budget Office.
[7] Multi-Hazard Mitigation Council. (2019). Natural hazard mitigation saves: 2019 report (tech. rep.). National Institute of Building Sciences.
[8] Betzsold N.J., J.L. Barr, S.R. Ortega, C.M. Sleiman, M. Disney and G. Tietje, et al. 2024. *Emergency Management of Tomorrow Research – Emergency Operations Center of the Future Nashua, NH Tabletop Exercise Report*. PNNL-36059. Richland, WA: Pacific Northwest National Laboratory.

sound project management principles, defining clear parameters for evaluation, and creating formal feedback loops that connect response and recovery experiences to mitigation planning. Plans may need revision depending on monitoring and evaluation outcomes.

- **Planning**: Conduct a systematic process engaging the whole community as appropriate in the development of executable strategic, operational, and/or tactical level approaches to meet defined EM/PS objectives. Identify and prioritize down-selection criteria to inform the choice of mitigation projects pursued. Ensure plans comply with local, state, and federal regulations.
- **Workforce Training**: Instruction in the knowledge and skills necessary to conduct expected missions, assignments, and tasks as described in plans, job descriptions, task books, and similar documents. Training curriculum can be derived from scientific and academic research, industry standards, best practices, lessons learned, policies, regulations, laws, and experiential knowledge. Instruction can include lectures, demonstrations, hands-on learning, simulations, job shadowing, and supervised work.

A.4.2 Information Sharing

Information sharing requires data sharing agreements, varying dissemination formats and platforms, and information security plans. Sharing can happen "horizontally" across EOC functions, between private industry and nongovernmental organizations, and to the general public as well as "vertically" from a local jurisdictional level, up to a regional level, and finally to a national level. Information sharing is a vital activity that helps EM/PS personnel and EOCs have comprehensive, holistic information to feed accurate situational, community, and risk awareness while maintaining an understanding of available resources and relevant stakeholders. Last year's TTXs illuminated a multitude of current challenges associated with information sharing, from accessing, summarizing, and deconflicting a wide variety of sources to adequately understanding what data might be available from various stakeholders and sources.[9]

The Boulder, CO, information-sharing-themed exercise on April 8, 2025, focused on three mitigation process steps:

- **Capability and Capacity Building**: Evaluate current capabilities against potential hazards and threats to identify resource gaps. Develop strategies to overcome gaps and test assumptions through regular exercises. Align capacity and capability needs to current mission strategy and tactics while understanding capabilities of mutual aid and other partners.
- **Funding and Resource Allocation**: Begins with an understanding of threats, hazards, and risk assessments. Using a process that involves community and government stakeholders, risk mitigation priorities are established, and projects to reduce risk are identified for funding. Requires an understanding of available funding sources and their complexities.
- **Risk Assessment**: Involves identifying potential hazards, threats, and vulnerabilities through review of previous assessments, infrastructure surveys, and historical incident analysis. Evaluates critical infrastructure, emergency response resources, and human systems to determine possible consequences of hazards/threats if realized. Generates

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

reporting materials for broad dissemination to stakeholders that guide preparedness and response efforts.

A.4.3 Synergy and Integration

Synergy and integration enables a wide range of players from the private and nonprofit sectors to participate in incident management activities, fostering better coordination and working relationships. As emerging technology is increasingly integrated into EM/PS, existing jobs and skillsets will become redundant or irrelevant, but demand for new jobs and skillsets will emerge. Trends observed at last year's TTXs, particularly in Seattle, highlight a desire to learn from the private sector; engage community partners, particularly younger generations (university age or below); and leverage volunteer skillsets that exist beyond EM/PS personnel.[10]

The Seattle, WA, synergy and integration-themed exercise on April 30, 2025, focused on two mitigation process steps:

- **Community Involvement and Participation**: Successful EM/PS outcomes depend on meaningful community participation rather than government-imposed solutions. Understanding local demographics and needs is critical, as is incorporating community members in decision-making efforts like establishing and modifying priorities and strategies, project selection and oversight, design review and approval, review and modification of plans, and funding and budget approval.
- **Policy and Regulation Development**: Develops robust policies and regulations that serve as directive frameworks for promoting community resilience. Identifies data and lessons learned to generate evidence-based policies and best practices. Requires understanding of intended and unintended consequences of policies and regulations.

A summary of all mitigation process steps can be found in Table A.1.

[10] Betzsold, N., Barr, J., Lesperance, A., Sleiman, C., Disney, M., & Tietje, G. (2024). *Emergency Management of Tomorrow Research – Emergency Operations Center of the Future Seattle, WA Tabletop Exercise Report*. PNNL-36060. Pacific Northwest National Laboratory.

Table A.1. Mitigation Process Steps

Process Step	Use Case	Description
Workforce Training	AI	Instruction in the knowledge and skills necessary to conduct expected missions, assignments, and tasks as described in plans, job descriptions, task books, and similar documents. Training curriculum can be derived from scientific and academic research, industry standards, best practices, lessons learned, policies, regulations, laws, and experiential knowledge. Instruction can include lectures, demonstrations, hands-on learning, simulations, job shadowing, and supervised work.
Monitoring and Evaluation	AI	Mitigation strategies and projects require close attention as conditions may change, including threats, hazards, risk assessments, priorities, and community support. Success depends on establishing baseline conditions, implementing sound project management principles, defining clear parameters for evaluation, and creating formal feedback loops that connect response and recovery experiences to mitigation planning. Plans may need revision depending on monitoring and evaluation outcomes.
Planning	AI	Conduct a systematic process engaging the whole community as appropriate in the development of executable strategic, operational, and/or tactical level approaches to meet defined EM/PS objectives. Identify and prioritize down-selection criteria to inform the choice of mitigation projects pursued. Ensure plans comply with local, state, and federal regulations.
Risk Assessment	Information Sharing	Involves identifying potential hazards, threats, and vulnerabilities through review of previous assessments, infrastructure surveys, and historical incident analysis. Evaluates critical infrastructure, emergency response resources, and human systems to determine possible consequences of hazards/threats if realized. Generates reporting materials for broad dissemination to stakeholders that guide preparedness and response efforts.
Funding and Resource Allocation	Information Sharing	Begins with an understanding of threats, hazards, and risk assessments. Using a process that involves community and government stakeholders, risk mitigation priorities are established, and projects to reduce risk are identified for funding. Requires an understanding of available funding sources and their complexities.
Capability and Capacity Building	Information Sharing	Evaluate current capabilities against potential hazards and threats to identify resource gaps. Develop strategies to overcome gaps and test assumptions through regular exercises. Align capacity and capability needs to current mission strategy and tactics while understanding capabilities of mutual aid and other partners.
Doctrine and Strategy Development	Synergy and Integration	Develops robust doctrine and strategies that serve as directive requirements for promoting community resilience. Identifies data and lessons learned to generate evidence-based best practices. Requires understanding of intended and unintended consequences.
Community Involvement and Participation	Synergy and Integration	Successful EM/PS outcomes depend on meaningful community participation rather than government-imposed solutions. Understanding local demographics and needs is critical, as is incorporating community members in decision-making efforts like establishing and modifying priorities and strategies, project selection and oversight, design review and approval, review and modification of plans, and funding and budget approval.

A.5 Exercise Activities

PNNL tailored facilitated activities for each exercise. Small variations in timing and activity ordering occurred between exercises; however, each iteration included all activities described below. To ensure findings reflect a broad swath of emergency managers and related roles throughout the U.S., PNNL designed the EMOTR exercise facilitation methodology to foster participation and ensure comprehensive data collection through structured activities. The following techniques were integrated throughout the day's activities to help all participants feel comfortable contributing their ideas:

- Pair-based activities to create a welcoming environment for those who might be hesitant to speak in larger groups.
- Question rotation system to allow everyone to contribute to all questions without requiring public speaking.
- Nonverbal feedback mechanisms, such as stars and question marks, to indicate agreement or questions about others' contributions without verbal confrontation.
- Written and verbal contribution opportunities to appeal to multiple communication styles.
- Structured, time-limited sharing to allow all participants to contribute while preventing more vocal participants from dominating discussions.

In turn, the following characteristics of the facilitation methodology ensured standardized and thorough data collection:

- Verification of mitigation process steps to ensure accuracy of EM/PS content and focus prior to activity proceedings.
- Consistent questions posed to participants across themes and mitigation process steps.
- Facilitation guide thoroughly detailed content level expectations, facilitator instructions, example answers, and question prompts.
- Documentation protocols and use of note takers (where available) captured both written and verbal participant responses.

The following subsections detail the individual activities comprising this methodology. They are presented in the order most commonly followed throughout the exercises, with an example agenda available in Appendix B.

A.5.1 Modified DRIVE Activity

DRIVE stands for Do, Restrictions, Investments, Values, and Essential Outcomes and has been adapted from Tim Hurson's 2007 Think Better. The DRIVE exercise is designed to develop evaluative criteria for brainstorming solutions, narrowing the solution space. In this structured activity, participants work to identify three of the five key components in the following order:

- **Essential Outcomes:** What are the non-negotiable elements of success? What must happen for the solution to be considered a success?
- **Restrictions:** What changes or impacts must be avoided? What must the solution NOT do? What must be prevented from happening?

- **Values:** What values must be followed in achieving the solution? What values cannot be compromised?

Each breakout group answers these questions using sticky notes on poster boards, and these answers apply to all technology solutions related to their breakout group's mitigation process step. While quantity is alright for this activity, facilitators also emphasize clarity and specificity in defining criteria. Participants are instructed to avoid vague statements like "students have more knowledge" (Workforce Training) in favor of precisely articulated outcomes, for instance elaborating on which topics students are supposed to better understand and how they are supposed to apply this new knowledge. This precision helps ensure that when solutions are later proposed, they can be evaluated against well-defined, meaningful criteria. The exercise creates a foundation for afternoon solution development by establishing a shared understanding of what constitutes an effective response to identified challenges.

A.5.2 Pain Points Elicitation

This exercise is a structured brainstorming activity designed to identify specific present-day challenges within EOC mitigation processes. Participants work in pairs to answer a targeted question about the breakout group's process step. The question is written on a poster board, and the pairs write their answers on sticky notes, attaching these to the poster board. Each pair has five minutes to brainstorm responses before rotating to the next question, ensuring all participants contribute to all questions. When pairs receive a new question, they are instructed to review all previous responses, optionally marking them with stars for strong agreement or question marks to indicate confusion. These marks serve as visual indicators for the facilitator to quickly identify trends and points of confusion. After all pairs have answered each question, they then analyze their current poster board to synthesize trends and points of strong consensus prior to presenting these insights to their larger breakout group.

A facilitator guides the exercise, prompting deeper exploration through follow-up "why" questions to uncover root causes beneath surface-level pain points, ultimately working toward identifying which challenges, if addressed, would have the greatest operational impact. This exercise emphasizes quality over quantity, encouraging participants to provide concrete examples and explanations rather than general statements. During lunch, the facilitators further synthesize data generated by this exercise to develop 3–5 comprehensive pain points from the identified written and discussed trends. Results from this activity help focus technology development on high-frequency, large-magnitude challenges rather than nice-to-haves or potential low-impact solutions.

The following four questions were used during this exercise for the EMOTR exercises:

1. What are the trickiest, most challenging parts of *[process step name]*?
2. What are the most tedious parts of *[process step name]*?
3. Not considering current constraints, where would you like to see change or improvement in *[process step name]*?
4. What type of help might you look for and accept with *[process step name]*?

A.5.3 Technology Demonstrations

To begin familiarizing participants with the emerging technologies they would be utilizing in the technology card exercise, a series of overviews and demonstrations are presented during the working lunch. This activity is meant to highlight certain technologies relevant to EM/PS and the location's specific use case and process steps. A facilitator presents these overviews and demonstrations, focusing on the technology capabilities, interfaces, and interactions. The following are technologies demonstrated in the three exercises:

- **PNNL's AI Incubator**.[11] The AI Incubator is PNNL's secure, user-friendly platform for integrating generative AI into existing workflows. It serves as a generative AI hub, capable of supporting operational enhancements with both off-the-shelf as well as custom-developed capabilities, including custom agents—models tailored for use in specific tasks. *Related technology cards: Automated Content Generation, Natural Language Summarization, Open-Source Data Analysis*
- **Figure's Helix**.[12,13] Helix is a generalist Vision-Language-Action model that unifies perception, language understanding, and learned control to overcome multiple longstanding challenges in robotics. Unlike earlier robot systems, Helix can generate long-horizon, collaborative, dexterous manipulation on the fly without any task-specific demonstrations or extensive manual programming. *Related technology cards: Humanoid Robot, Robotic Automation, Voice Control*
- **NVIDIA's Cosmos**.[14,15] Cosmos is a platform of state-of-the-art generative world foundation models, advanced tokenizers, guardrails, and an accelerated data processing and curation pipeline. It is built to power world model training and accelerate physical AI development for autonomous vehicles and robots. *Related technology cards: Data Fusion, Digital Twin, Predictive Modeling, Automated Content Generation, Robotic Automation*
- **Halliday Smart Glasses**.[16,17] Halliday's mission and vision are to enhance life with wearable tech, empowering human potential through intelligence and technology. *Related technology cards: Automated Content Generation, Natural Language Summarization, Predictive Modeling, Wearables*
- **Airport Risk Assessment Model (ARAM)**.[18,19] Developed by PNNL on behalf of DHS S&T, ARAM is an advanced risk modeling and assessment tool that helps airport security stakeholders prioritize the use of their resources based on evolving threats. With a user-friendly interface accessible via a mobile device, ARAM quickly calculates the needs and best assignment of security assets—personnel, canines, and other countermeasures—that work together in innumerable combinations to keep passengers and the airport safe and secure. *Related technology cards: Assisted Resource Allocation, Optimization*

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[11] https://ai-incubator.pnnl.gov/
[12] https://www.figure.ai/news/helix
[13] https://www.youtube.com/watch?v=Z3yQHYNXPws
[14] https://www.nvidia.com/en-us/ai/cosmos/
[15] https://www.youtube.com/watch?v=9Uch931cDx8
[16] https://hallidayglobal.com/pages/halliday-glasses
[17] https://www.youtube.com/watch?v=6tA2u_V6pw0
[18] https://www.pnnl.gov/available-technologies/airport-risk-assessment-model-data-driven-risk-based-decision-analytics
[19] https://www.youtube.com/watch?v=OABmN0IUc6U

- **Zipline**.[20,21] Zipline drone delivery is transforming access to healthcare, consumer products, and food. Originally delivering blood and medical products in Rwanda in 2016, Zipline has expanded to food, retail, agricultural products, and animal health products through long-range and precise home delivery platforms. *Related technology cards: Autonomous Mobile Robots, Robotic Automation*
- **Zencity**.[22,23,24] With Zencity platforms for local government, public safety, and state agencies, government and law enforcement leaders make informed, transparent, and effective decisions that earn the trust of the communities they serve. *Related technology cards: Automated Content Generation, Data Fusion, Open-Source Data Analysis, Real-Time Data Monitoring*

A.5.4 Future Technology Card Exercise

The technology card exercise is a structured, fast-paced activity designed to develop multifaceted technology solutions that address individual operational pain points. Three types of cards are used in this activity to characterize specific pieces of the technology solutions. The full list of cards is available with definitions in Appendix C.

- Capability: What can the technology do?
- Interface: What does the technology look like?
- Interaction: How is the technology controlled?

Participants focus on one overarching pain point (identified trend) at a time. Through a series of guided selection and down-selection rounds (see

Figure A.1), participants identify the most promising capabilities, interfaces, and interaction methods. These card playing rounds are conducted with participants in pairs, and every time a pair plays a card, they must make a brief "pitch" explaining why they selected that particular card. Essentially, they must argue why their card has potential to address the identified pain point. This activity deliberately maintains a "play and learn" mindset, encouraging creative exploration of emerging technologies.

[20] https://www.zipline.com/about
[21] https://www.youtube.com/watch?v=u29OWb12oxo
[22] https://zencity.io/
[23] https://www.youtube.com/watch?v=MCDHmB10Arc
[24] https://www.youtube.com/watch?v=mFhBqJabirg

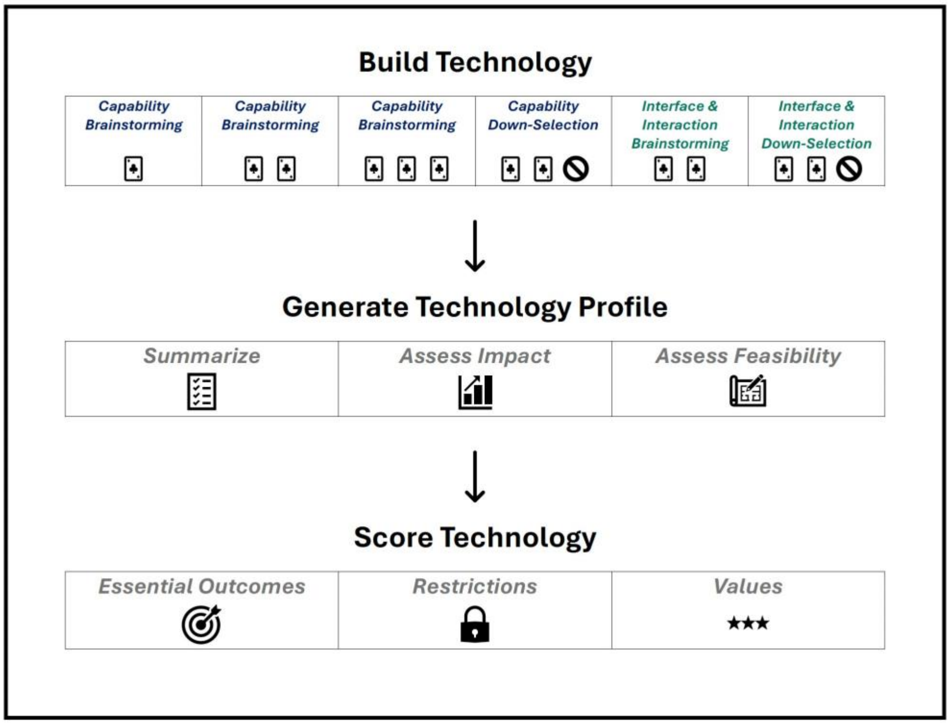

Figure A.1. Activity Tracker for Technology Solution Generation

A.5.5 Technology Profile Generation

After participants complete the card selection process for a single technology solution, facilitators guide their breakout groups to collaboratively fill out a technology profile that captures their choices, reasoning, and a self-evaluation of how effectively their proposed group of cards might solve the targeted pain point. The questions on the technology profile are adapted from the 2017 First Responder Technology Operational Field Assessment[25] published by PNNL for DHS S&T (Lesperance et al., 2017). Participants are encouraged to focus on substance over form—the profile does not need perfect sentences or extensive documentation. Rather, participants must clearly articulate how the proposed technology would function and why it would be effective. This stage transforms the collection of capabilities, interfaces, and interactions into a tangible solution concept, with breakout groups evaluating their technology's potential effectiveness in partially or fully solving the targeted operational challenge. The output is a detailed technology profile that balances innovation with an assessment of feasibility and potential impact. See Appendix D for the technology profile template.

[25] Lesperance, A., Ozanich, R., & Disney, M. (2017). First responder technology operational field assessment (tech. rep.). Pacific Northwest National Laboratory.

Appendix B – Example Exercise Agenda

TIME	TOPIC
8:00 – 8:30 am	Arrival & Check-In
8:30 – 9:00 am	Welcome/Opening Remarks, PNNL/EMOTR Recap, and Introductions
9:00 – 9:15 am	Agenda Review and Instructions
9:15 - 10:00 am	Breakout Groups: Define the Goals, Constraints, and Metrics for Success
10:00 - 11:45 am	Breakout Groups: Present Day Pain Point Elicitation
11:45 am - 12:45 pm	Working Lunch: Technology Demonstrations and Discussion
12:45 – 3:15 pm	Breakout Groups: Solution Concept Ideation
3:15 – 3:45 pm	Team Outbriefs and Discussion
3:45 – 4:00 pm	Closeout & Adjourn

Appendix C – Technology Cards

C.1 Capabilities

3D PRINTING: Ability to create 3D parts from computer-aided design models by adding material (e.g., plastics, resins, nylons, metals) layer by layer.

ACCURACY ANALYSIS AND REPORTING: Evaluating and reporting the correctness of information and data analysis outputs. Can be used to identify factual errors, trace logical reasoning, and/or evaluate the accuracy of other technological/algorithmic outputs.

ADVANCED WIRELESS COMMUNICATION: Leveraging networking equipment (satellites, high-altitude platform stations, drones, 5G/6G) to provide faster, more reliable, available, secure, and adaptable network connectivity.

AI-ENABLED TRAINING/LEARNING: Using AI as an educational approach to tailor learning or training experiences to the needs, skills, interests, and strengths of each student.

ALARM/ALERT TRIAGE: Process of evaluating, prioritizing, routing, and managing a stream of alerts or alarms to help viewers/operators/users find and fix problems, ensuring that the most critical issues are addressed first.

ASSISTED RESOURCE ALLOCATION: Assigns resources to tasks. May predict task completion rates and timelines using environmental data, skillsets, computational needs, physiological data, etc.

AUTOMATED CONTENT GENERATION: Using AI to create audio (sounds, speech, music), video, presentations, designs (logos, flyers), and images (animated, realistic). Generates new content that never existed by synthesizing the meaning of the original content and user inputs.

AUTONOMOUS MOBILE ROBOTS: A type of robot that can understand its environment and move independently using sensors and artificial intelligence to plan paths.

BIOMETRIC IDENTITY VERIFICATION: The process of identifying a person via their unique biological traits, such as fingerprints, hand geometrics, retina patterns, written signatures, and/or voice prints.

CLASSIFICATION AND CLUSTERING: Assigning specific instances in data to predefined categories or to categories based on similar characteristics. May be used for tasks like image recognition, object identification, and anomaly detection.

DATA FUSION: The process of combining data from many sources (sensors, databases) to create a more holistic, insightful, and useful dataset.

DIGITAL TWIN: Recreating entities that exist in the physical world (e.g., infrastructure, assets) in a virtual environment. May be based on real-time and historical data while incorporating predictive algorithms and simulation.

DRONES AS A SENSOR: Drones equipped with GPS, LiDAR, thermal, air pressure, and inertial measurement sensors to perform various tasks including infrastructure inspection, search and rescue operations, land surveying, security surveillance, and disaster management.

HUMANOID ROBOT: Any robot with two arms, two legs, and a human-like head that can receive, process, and respond to information. Can move like a human (climb stairs, ladders, etc.) and operate equipment designed for humans.

KNOWLEDGE GRAPHING: Representing a network of real-world entities (objects, events, situations, concepts) and illustrating relationships between them, including sourcing information.

NATURAL LANGUAGE SUMMARIZATION: Selects the most important phrases and sentences
from the original text and combines them to create a summary. This method is like a highlighter, as it produces a subset of information from the original text.

NEXT-GEN DATA MANAGEMENT: The use of AI to effectively and efficiently manage data to deconflict information, identify changes/gaps, logically organize data, and perform automatic content updates. May involve automatically sharing data using logic-based rules.

NEXT-GEN GEOSPATIAL TOOLS: Monitoring/analyzing entities' physical locations to enhance situational awareness, deployment efficiency, and mission effectiveness. Enables identification of distance, proximity, and regional distance patterns plus shifts over time.

OPEN-SOURCE DATA ANALYSIS: Analysis of publicly generated, accessible data such as media, research publications, and government publications. Outputs may provide situational awareness, multiple perspectives, and cutting-edge knowledge.

OPTIMIZATION: Considers several conflicting, quantifiable objectives simultaneously. Typically, rather than a single optimal solution existing, a set of alternative solutions with varying tradeoffs exists.

PREDICTIVE MODELING: Identifying and analyzing patterns in a meaningful way, generating forecasts and assumptions about what may occur in the future.

REAL-TIME DATA MONITORING: Process of continuously watching and analyzing data in real-time. Includes collecting, processing, and visualizing data from multiple (near) real-time sources. May be large-scale or rule-based (e.g., only when a change occurs).

ROBOTIC AUTOMATION: Uses intelligent automation technologies to perform repetitive tasks typically assigned to human workers.

TAILORED INFORMATION GENERATION: Automatically tailor messages and other generated information not only for understanding (i.e., language translation) but also for consumption and responsive action as well.

C.2 Interfaces

AUGMENTED, VIRTUAL, AND MIXED REALITY: Superimposes digital elements (images, audio, video, etc.) onto the real world via a headset or mobile device and/or provides an immersive virtual experience that isolates users from the real world.

DESIGN YOUR OWN ROBOT:

Looks Like (choose one): human, vehicle, swarm, orbital, aquatic, animal, other: ______
Controlled By (choose one): a human, autonomously

DESKTOP COMPUTER:

GAMING CONSOLE:

HOLOGRAM: A picture of a "whole" object, shown in three dimensions. Can be examined from all angles and virtually dissected.

LAPTOP COMPUTER:

MOBILE DEVICE:

TABLET:

TELEPRESENCE ROBOTS: Mobile robots equipped with cameras, microphones, and screens that enable remote users to interact with the environment. Interactions include moving around and talking to people.

WEARABLES: A device that can transmit and receive a signal or other data. It is wearable by a human. Includes smart watches, smart glasses, etc.

C.3 Interactions

DIGITAL ASSISTANT: Simulates and processes human conversation (typed or spoken), allowing humans to interact with digital devices like communicating with a real person. Performs tasks and/or provides information (proactively and/or reactively).

GESTURE CONTROL: Interaction method that enables users to communicate with electronic devices, systems, or computers through natural body movements and gestures.

TOUCH SCREEN CONTROL: Interaction method that requires users to interact with electronic devices, systems, or computers by directly touching them with 1+ fingers.

TRADITIONAL CONTROL: The use of mice, keyboards, and/or touchpads to control a device.

USER EXPERIENCE CUSTOMIZATION: Modification of the user interface and available information to suit the needs of a specific user or various groups of users.

VOICE CONTROL: The ability to control applications or devices by means of human voice.

Appendix D – Technology Profile Template

Name Assigned **Process Step**

Main Pain Point Addressed

General Technology Description

Capabilities: What can this technology do?

Interfaces and Interactions: What does this technology look like? How do we interact with
this Technology?

List the unique advantages of this technology when compared to existing technologies.

How does this technology improve how *[process step]* is currently done? What pain points does it mitigate?

Does this technology replace current technology(ies) or augment them?

How might this technology change current tasks and subtasks related to *[process step]*?

Why might someone hesitate to use this technology?
Privacy concerns, lack of transparency, risk to mission objectives, negative public perception, etc.

How should customization for this technology occur?
By user, role, EOC, region, or N/A?

How might this technology be misused or abused? Intentionally? Accidentally?

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