2017

Public Safety Enhanced User Interface R&D Roadmap

CTL Communications Technology Laboratory

NIST

PSCR

Executive Summary

The public safety community is in a period of great transition. Over the next 20 years, technology advancements will enable data, video, and eventually voice communications to migrate from disparate Land Mobile Radio (LMR) networks to a nationwide Long Term Evolution (LTE) broadband network, the Nationwide Public Safety Broadband Network (NPSBN). Emerging technologies within this new infrastructure present opportunities and challenges for public safety, and the process of modernizing responder communications requires significant coordination and planning. To facilitate the transition from LMR to LTE, the National Institute of Standards and Technology's (NIST) Public Safety Communications Research (PSCR) program initiated a research and development (R&D) planning process to determine what technology investments are of highest priority to the public safety community.

This document summarizes the results of PSCR's *Public Safety Enhanced User Interface R&D Roadmap.* This report is the third of several technology roadmaps that PSCR has developed over the past several years to better inform the investment decisions of R&D organizations supporting the public safety community. This document aims to assist in planning for public safety communications research and optimize the allocation of the $300 million apportioned to NIST from the AWS-3 spectrum auction, which concluded in January 2015. This report intends to outline the current state of user interface technologies, forecast the evolution of user interface capabilities and gaps, and identify potential R&D opportunities that would improve public safety's use of enhanced user interface technologies within operational settings. Upon completion of this roadmap, PSCR intends to identify R&D project ideas that pose the greatest operational benefit to public safety. These opportunities may be considered for inclusion in PSCR's Innovation Accelerator program, drives R&D through prize challenges, grants, and/or cooperative agreements. Given the scope of technology under consideration and level of effort required to deliver enhanced user interface technologies to public safety, PSCR hopes that these findings and recommendations will educate stakeholders across all levels of government, industry, and academia.

The roadmap was drafted by soliciting input from technology experts, end-users, and researchers across government, public safety, industry, and academia. This cross-disciplinary approach enabled PSCR to evaluate existing R&D efforts, potential partnerships, and future projects against public safety's unique set of priorities, requirements, and long-term goals. After reading this report, organizations will understand:

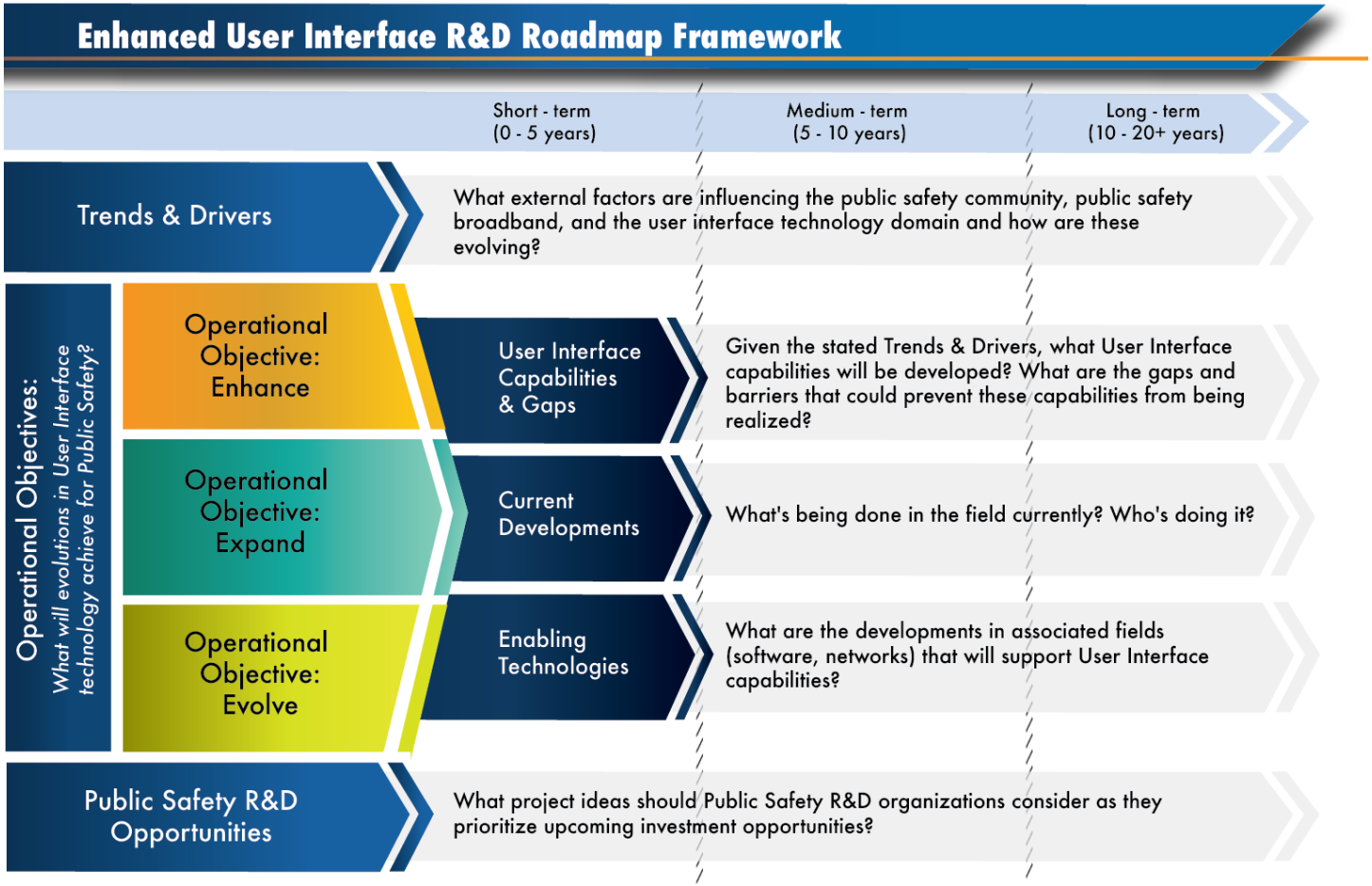
- The trends & drivers affecting public safety, public safety broadband, and the user interface technology domain.
- The projected evolution of user interface technologies over the next 20 years.
- The operational objectives that public safety stands to achieve by adopting the forecasted enhanced user interface technology capabilities.
- The critical software and network capabilities that will enable the evolution of user interface technologies.
- Technology gaps and barriers that need to be addressed before enhanced user interface technologies can fully benefit public safety operations.
- Potential R&D opportunities that would complement current developments in the field and help transform this technology area into an asset for public safety operations

Roadmap Approach and Framework:

PSCR has structured the bulk of its research on specific capabilities that will be enabled by the evolution of user interfaces, **defined as the means by which a user and a technology system interact[1], including how users input, access, and navigate data and communications through the technology.** Based on its findings, PSCR has organized the bulk of its final *Public Safety Enhanced User Interface R&D Roadmap* report around the three main operational objectives that public safety should look to achieve through the utilization of enhanced user interfaces. The operational objectives enabled by enhanced user interface technologies discussed in this report include:

Enhance User Experience	**Enhance the experience of a user's data/communications interaction** This objective examines the ability of new user interface technology to integrate and/or automate tasks typically conducted manually by users to interact with data/communications
Expand Data/Communications Access	**Expand the range of environments in which users interact with data/communications** This objective examines the ability of new user interface technology to provide first responders with data/communications and analytic products in environments once cut off from technological interfaces, including up-to-the-minute biometric data, situational awareness, tactical coordination, and life-saving alerts.
Evolve Human-Machine Interaction Paradigm	**Evolve the way in which public safety users interact with machines/computers** This objective examines the ability of new user interface technology to allow for virtually conducted public safety operations, training, and testing typically conducted by first responders or in public safety controlled physical locations

[1] http://searchmicroservices.techtarget.com/definition/user-interface-UI



To scope this report, the working group's input relating to user interface technology capabilities and gaps, current developments in the field, and enabling software and network technologies are embedded as supporting sections within the operational objectives. The report lists potential R&D opportunities relating to each operational objective.

Recommended Public Safety R&D Opportunities:

Below are highlights of the more extensive R&D Opportunities discussed in this report as identified by the Public Safety User Interface Working Group for the public safety R&D community to consider. These were identified based on environmental trends and drivers, forecasted technology evolutions, and anticipated public safety applications of enhanced user interface technologies. These opportunities are presented within the context of PSCR's specific R&D mission, the PSCR Innovation Accelerator Program, and capabilities of the broader public safety R&D community. These R&D project ideas are not intended to be an exhaustive list of the ways in which user interface technology needs to improve to better serve public safety. Rather, PSCR hopes that the readers of this report will recognize these opportunities as initial steps that would help make user interface more operationally viable for the public safety community.

R&D Opportunity Highlights

Operational Objective: Enhance

- Analyze the environmental conditions imposed on devices/sensors in public safety operational environments to define a set of ruggedization and performance technical standards for public safety devices/sensors
- Develop public safety specific methodologies to test for ruggedization performance as defined by public safety ruggedization standards
- Conduct testing and evaluation regarding the effects of interface alerts, visual layouts, and symbology on public safety user's cognitive abilities (attention, distraction, communication skills)
- Develop hardware supporting higher fidelity signal processing and noise filtering to enable clearer voice command transmission in high-stress response environments
- Pilot a gesture sensitivity analysis program to demonstrate the reliability of technology for public safety and to determine which gesture technologies may be viable for public safety

Operational Objective: Expand

- Test and evaluate body-worn wearable devices/sensors impact on the public safety user's ability to perform tasks in the operational environment, focusing on device weight, flexibility, and ergonomics
- Partner with research and academic communities currently evaluating alternative battery materials to stimulate the development of lighter, flexible, and longer lasting power solutions for devices/sensors
- Conduct and support development efforts for mmWave frequency technology and its potential to support wearable device/sensor connectivity enabled by high data transfer capacity and performance in crowded/dense signal environments
- Develop public safety data architecture and formatting standards for mobile devices/sensors to allow for rapid data sharing, integration, and analysis

- Develop algorithms that integrate multi-source device/sensor data and produce insights and analysis to support both first responders and public safety command centers

Operational Objective: Evolve

- Research crash avoidance, auto-arrest, and other safety precautions in unmanned ground and aerial vehicles to drive requirements framework for public safety operated unmanned devices
- Develop network monitoring, visualization, and control capabilities to sense and adjust bandwidth based on task requirement and user priority setting
- Research the ability of 5G broadband and other network solutions to provide the quality of service and low latency required to support public safety autonomous drone flight beyond the operator's line of sight
- Support development of a test bed in the VR (VR) environment that closely simulates a range of public safety operational environments and can be used to test interface equipment and train public safety staff
- Research signal transmission methodologies used in drones and robotics with the aim of driving interoperability between individual unmanned devices and device makers

Conclusion:

In addition to providing context and recommendations for future R&D investment, the report discusses PSCR's process of designing the *Public Safety Enhanced User Interface R&D Roadmap*, its stakeholder involvement strategy, and other priority areas that could become the subject of future technology roadmaps. For more information, please contact PSCR Division Chief Dereck Orr (dereck.orr@nist.gov), or PSCR support staff Ryan Felts (rfelts@corneralliance.com), Marc Leh (mleh@corneralliance.com), and Harris Feldman (hfeldman@corneralliance.com).

Purpose

Over the next 20 years, the public safety community will simultaneously face unprecedented challenges and opportunities with the emergence of revolutionary new communications technology. In light of this transitional period, the Public Safety Communications Research (PSCR) program within the National Institute of Standards and Technology (NIST) initiated a deliberate research and development (R&D) planning effort in 2013 to determine what technology R&D investments are necessary to transition public safety data, video, and eventually voice communications from the Land Mobile Radio (LMR) environment to a nationwide Long Term Evolution (LTE) broadband network. In order to optimize its investment resources, PSCR solicited input from first responders, officials from all levels of government, industry leaders, and academia. By leveraging expertise from across its diverse stakeholder base, PSCR can more accurately map the current state of the public safety and communications industries, identify current and future technology gaps, and make better-informed decisions on where its R&D initiatives will create the greatest impact.

User Interface is the third in a series of technology roadmaps PSCR has developed since 2013. PSCR initiated its R&D roadmapping by publishing the *Location-Based Services R&D Roadmap Report*[2] in Spring 2015, later publishing the *Public Safety Analytics R&D Roadmap Report* in Spring 2016. User Interface was selected by PSCR as an important R&D opportunity area because it demonstrated high leveragability, feasibility, impact, and return on investment to the public safety community. It also continues to receive tremendous attention from technology companies, universities, and other government organizations, which underscores the importance of systematically surveying and recommending investment opportunities in the data analytics sector. User Interface—and human-computer interaction (HCI) more broadly—represents a vast subject area.

Following publication of *Public Safety Enhanced User Interface R&D Roadmap*, PSCR will proceed to identify, prioritize, and launch formal R&D projects through its Innovation Accelerator Program.[3] The program, formally established in 2016, will use the $300 million allocated to NIST in the 2012 Middle Class Tax Relief and Job Creation Act for R&D efforts in support of the development and deployment of the National Public Safety Broadband Network (NPSBN). The Innovation Accelerator program leverages prize challenges, grants, and cooperative agreements to stimulate critical R&D for public safety communications technology including LMR to LTE, User Interface/User Experience, Location-based Services (LBS), Mission Critical Voice, and Public Safety Analytics. In order to optimize the allocation of public safety's R&D resources, PSCR will continue to engage stakeholders, coordinate activities, and create an understanding of the various actors advancing user interface (UI) technologies.

[2] http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1883.pdf
[3] http://www.firstnet.gov/newsroom/blog/pscr%E2%80%99s-innovation-accelerator-program-announces-30-million-grant-program-%E2%80%98pull-future

Intended Roadmap Audiences:

While PSCR has undertaken the process to create this *Public Safety Enhanced User Interface R&D Roadmap* (User Interface Roadmap), PSCR is not the sole intended audience for this report. The level of effort, resources, and capabilities needed to deliver improved analytics capabilities to the public safety community, both in the short and long term, are well beyond the scope of PSCR and cannot be addressed alone. Therefore, this roadmap is intended to inform other R&D efforts undertaken at the federal level as well as within industry at large and the academic community. This report is also intended to educate decision-makers at the federal, state, and local levels, as well as within the public safety community, about the capabilities that interfaces may provide in the future and actionable initiatives that will help bring about improved interface capabilities in public safety (Fig. 1).

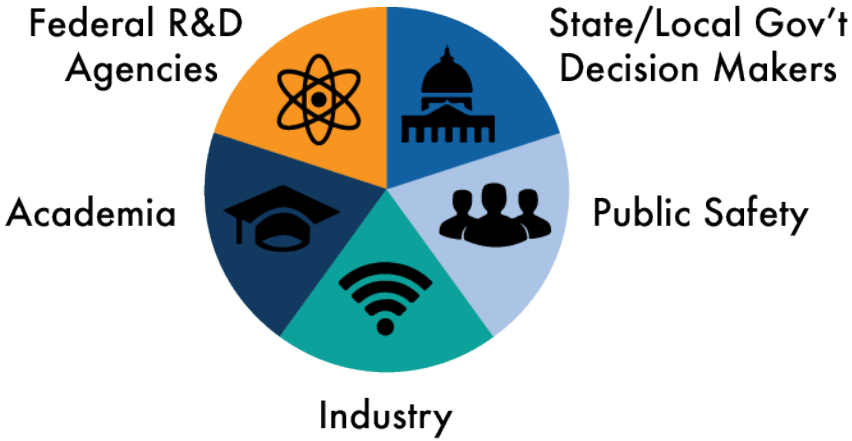


Figure 1: Intended Audiences of the PSCR Public Safety Enhanced User Interface R&D Roadmap

Roadmap Design Principles:

The following principles have guided the process as PSCR created the User Interface Roadmap and past roadmap reports:

- Build a vision of where the public safety community wants to go, determine what technologies are needed to get there, and provide a route for achieving the vision.
- Make R&D decisions based on capability requirements and priorities set by the public safety community.
- Assume that public safety may have to adjust operations to fully realize the benefits of new technologies.
- Leverage ongoing efforts by other partners to develop and implement the roadmap. This approach will allow PSCR to focus resources to complement and not duplicate ongoing efforts.
- Get far enough ahead of the technology development curve to influence commercial R&D and leverage economies of scale.
- Enable public safety to meet generational and public expectations.
- Employ a cross-disciplinary approach to gather input and develop R&D plans for PSCR initiatives.
- Identify R&D project opportunities in light of the evolution of technology capabilities and gaps forecasted by working group participants.

Introduction to PSCR Public Safety User Interface R&D Roadmap

Interface technology, in its purest form, is as old as the most rudimentary machines that we use today. Even humanity's oldest simple machines required simple interfaces to realize their utility. The screwdriver, for example, serves as a vital intermediary between its user and an original simple machine: the screw. As the intermediary, the screwdriver allows its user to convert rotational force to linear force and its ability to do so effectively would have vast utility, partly enabling our ability to build environments and establish settled economies.

In this light, humans have spent thousands of years using machines through an evolving set of interface technologies. However, never has the interface been so important to our technological capabilities as it has become in the computer age. Unlike the mechanical age in which humans processed information while machines conducted work, computer technology has achieved complexity such that both humans and computers are able to do "far more than the interface between them allows."[4]

The "user interface," defined as **the means by which a user and a technology system interact,**[5] **including how users input, access, and navigate data and communications through the technology,** serves now as the bottleneck between a human's contextual and emotional intelligence and a computer's processing speed and complex capacity. Thus, evolutions in our ability to interface with machines will serve as a key enabler of our innovative capacity and may be more influential in determining human operational modes than evolutions in the machines themselves.

We can see the impact of human-to-machine interfaces on our society over the last 50 years of interface technological development. Commonly cited as the first "intuitive" interface between human and machine, the RAND Tablet (released in 1961) was built around the natural interaction and allowed users to mark up maps on a screen using a stylus, introducing human-added layering to interface data.[6] Apple developed the first mouse in 1984, "bringing ergonomic touch to the desktop interface"[7] and largely enabling the modern office job. The mouse remained the primary mode of human-machine interaction (HMI) until the iPhone touch screen in 2007, which gave the sensation of moving and touching data with our skin for the first time. Interface innovation accelerated with the 2009 Microsoft Kinect giving a user the ability to control a machine with his or her body for the first time. This continued in 2011

[4] http://www.theatlantic.com/technology/archive/2016/07/what-comes-after-keyboards/490511/
[5] http://searchmicroservices.techtarget.com/definition/user-interface-UI
[6] https://www.fastcodesign.com/1671960/why-the-human-body-will-be-the-next-computer-interface
[7] https://www.fastcodesign.com/1671960/why-the-human-body-will-be-the-next-computer-interface

with Apple's Siri and the "no-interface" interface, in which the user did not have to view or control a screen to interface with a machine.[8]

It is through this lens of innovation that PSCR now looks to approach the coming innovations in the public safety user's interface with data/communications. Machines today are capable of winning Jeopardy, diagnosing cancer, and flying airplanes. As technology evolves to interface with these machines and bring their advanced capabilities into the public safety domain, we stand to see vast improvements in public safety communications and operational abilities. To help realize those improvements, this report aims to forecast how interface technology will emerge, what its impact on public safety communications may be, and how to strategically innovate user interface technology for public safety use.

Working Group Definitions and Approach

PSCR recognizes that there are multiple terms used to refer to the intended content of this roadmap report, each with its own series of interpretations and understandings. Some of these closely related terms include "user interface," "user experience," "usability," and "human-computer interaction," all of which commonly refer to "user devices." For reasons described below, this roadmap primarily focuses on **"user interface," defined as the means by which a user and a technology system interact,[9] including how users input, access, and navigate data and communications through the technology.**

To help scope the discussion and data collection process, the User Interface Working Group further examined a few of the general technological elements that support the user's interaction with data and communications. Within the category of "user interface," the working group added definitions to "user interface layout," "user interface technology," and "user interaction paradigm."

- **User Interface Layout** – The format, design, and layout presented to a user to facilitate the technology interaction. Each user interface layout will usually contain input controls (i.e., buttons and controls to command or input data), navigational components (i.e., architecture, pagination, or tabs to navigate technology components), and informational components (i.e., alerts or messages that assist the user interaction). It is important to note that one user interface layout may be accessed through multiple technologies. An example is Apple's FaceTime application, which is used on smartphones, tablets, and desktops.

[8] https://www.fastcodesign.com/1671960/why-the-human-body-will-be-the-next-computer-interface
[9] http://searchmicroservices.techtarget.com/definition/user-interface-UI

- **User Interface Technology** – The enabling or supporting technology through which the user interface layout is delivered to the user. This technology may be hardware and/or software, and one user interface technology may be used to support multiple user interface layouts. An example is the Samsung Gear Virtual Reality (VR) headset, which supports layouts for communications, gaming, navigation, and more in one piece of hardware.
- **User Interaction Paradigm** – The medium through which the interaction between a user and a device is transmitted. The paradigm of interaction may include a point-and-click mouse, physical touch, voice, haptics, eye-gaze, or other biological sensing. For example, laptop 'track pads' typically rely on touch and pressure to facilitate interaction whereas desktop computers are more likely to employ mouse control.

In addition, the working group further segmented user interface technology into several components to ensure that the full breadth of user interface capabilities was discussed. This enabled discussion of how users view information presented on an interface and how users navigate an interface. This report identifies technology capabilities, gaps, and opportunities related to these components of user interface technology. These components included:

- **Input Controls:** The controls (software or hardware components) that users interact with to command or input data into a technology. Examples of input controls include a touchscreen, keyboard, or radio buttons.
- **Navigational Components:** How users access or navigate through different components of a technology. Examples of navigational components include a search field, site architecture "breadcrumbs," pagination, topic tags, or a traditional desktop folder structure.
- **Informational Components:** Alerts or messages that assist the user in how to access, input, or navigate the information presented. Examples of informational components include push notifications, progress bars indicating completion of specified tasks, or scroll-over tips when interacting with a website.

For the purposes of this roadmap, PSCR and the User Interface Working Group have examined the user interface as it contains each and all of these three components. While the totality of these three categories includes a broader landscape than may typically be thought of by the user interface community, specifically as it overlaps with user experience (UX), described as a person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service;[10] PSCR sees a benefit in this expansion. First, it is under the broad purview of user interface—inclusive of layouts, technologies, and paradigms—that PSCR sees rapid and complex technological evolutions occurring, both currently and over the next generation of technological development. Furthermore, the potential impact of public safety's ability to capitalize on the new functionalities offered by cutting-edge technologies and evolving paradigms stands to serve as an immense operational benefit to the community.

It is important to note that in considering user interfaces as they relate to overall user experience and usability through the context of this roadmap, the working group has reaffirmed the importance of user-centered design in all technology R&D conducted at PSCR. "User experience," defined by the International Organization of Standards[11] (ISO) as the "perceptions and responses resulting from the use" of a technology, and "usability," defined as the "extent to which a product can be used by specified users to achieve specified goals,"[12] will continue to be viewed as "horizontals" that cut across each of the three technology roadmaps developed thus far.

[10] http://www.iso.org/iso/catalogue_detail.htm?csnumber=52075
[11] http://www.iso.org/iso/home.htm
[12] http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=31176

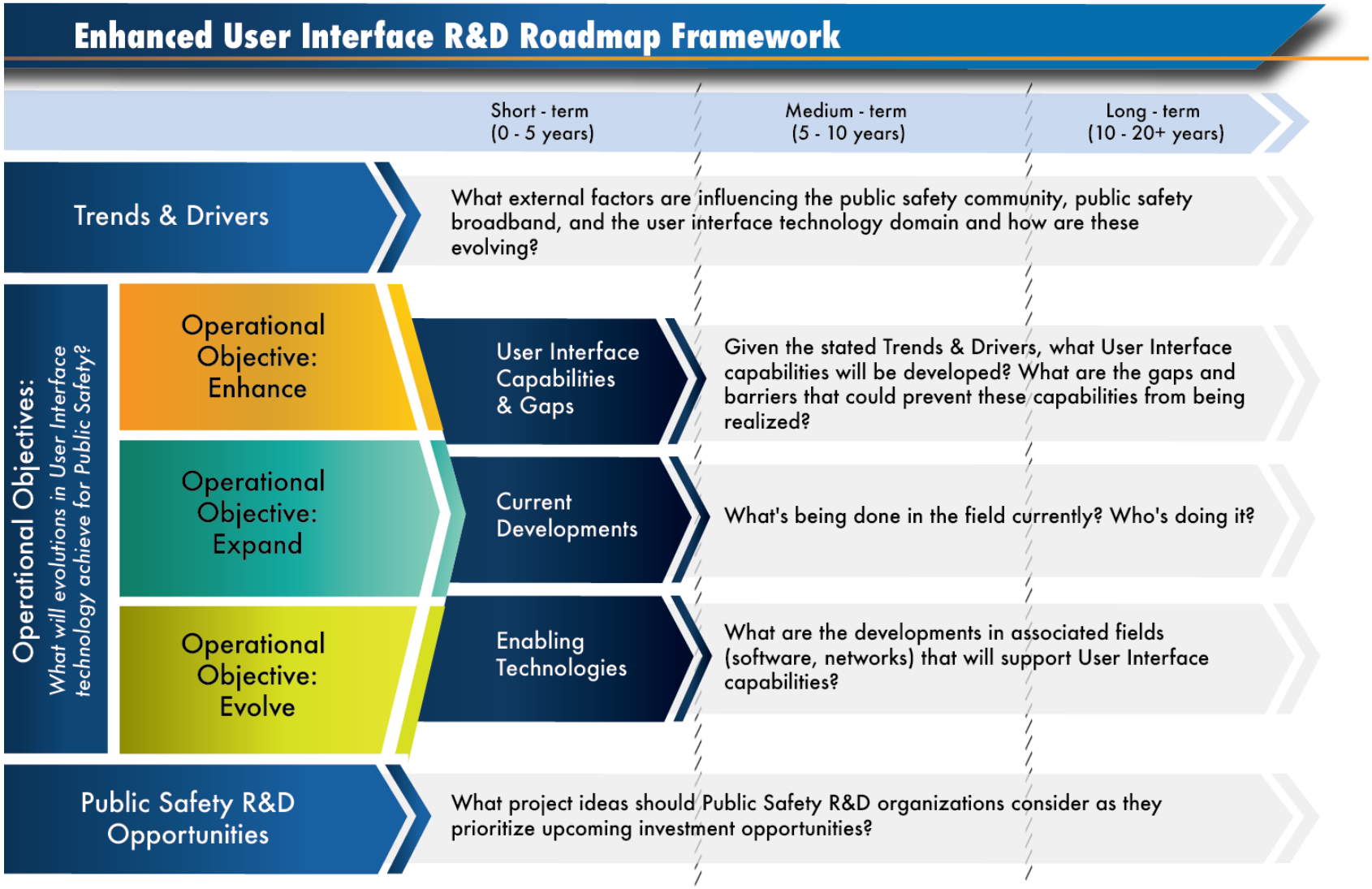


Figure 2: Public Safety Enhanced User Interface R&D Roadmap Framework

Roadmap Framework

Based on the results produced by using the LBS and Analytics R&D Roadmap framework, a similar framework was customized and created for PSCR's User Interface Working Group. This framework was used primarily to organize the order of discussions held with the User Interface Working Group. However, unlike both the LBS and Analytics R&D Roadmap frameworks, this User Interface Roadmap presents technical capabilities, associated gaps, and potential R&D opportunities organized by the public safety operational objective rather than by technology vertical (Software and Applications, Networks, and Devices). The three technology sections that provided structure to the working group process (Software and Applications, Networks, and Devices) have been integrated here so that the capabilities identified within each of the three sections are considered in the context of their ultimate effect on operations.

One key component of the roadmap framework is the presence of a timeline to give context to the roadmap details and elements. This timeline aims to serve the ultimate evaluation of investment leveragability, a major tenant of the PSCR investment criteria. By looking at emerging technology gaps and opportunities in the context of their evolution over a phased timeline, PSCR can better understand the progression from interim technologies to long-term solutions. This perspective allows PSCR to analyze how investment dollars will speed development cycles and which technology gaps serve as choke points for multiple future capabilities. For these purposes, the roadmap was divided into three time frames: short, medium, and long. These time frames were defined in the following manner:

- Short (0 to 5 years) – Straightforward extrapolation of current technology needs
- Medium (5 to 10 years) – Extension of current trends to their reasonable limits
- Long (10 to 20+ years) – Development of major new technologies needed to reach beyond capabilities of current applications

These time frames are only projections. Leveraging commercial technologies and targeting R&D investment to critical-path technology gaps can expedite the projected R&D timelines presented in this document significantly.

The User Interface Roadmap contains six major sections:

Trends and Drivers

PSCR acknowledges that technology is not developed in a vacuum. Commercial industry, rather than the public safety community, often drives advances in user interface technology, and broader events impact the evolution of technology. For these reasons,

among others, it was important to begin the roadmapping process by detailing the existing and anticipated trends and drivers within the public safety community, as well as those impacting public safety broadband, and finally, the user interface domain as a whole. The following questions were posed to User Interface Working Group members:

1. What external factors influence the public safety community and how are these evolving?
2. What external factors influence public safety broadband and how are these evolving?
3. What external factors influence the user interface technology domain and how are these evolving?

Enabled Operational Objectives

A key challenge facing public safety and the supporting R&D community is determining which evolved user interfaces provide value when integrated into operational use. One of the challenges posed by the development of public safety broadband is that the rapid development cycle of complex consumer devices will be afforded direct entry into a public safety environment based on stringent standards and a measured approach to adoption.

In an effort to keep a focus on the public safety users that PSCR serves, the roadmap team focused the technology findings of the working group's efforts around the specific operational objectives that new capabilities pose to serve. As mentioned earlier, the three technology sections that provided structure to the working group process—Devices, Software and Applications, and Networks—have been integrated here so that the capabilities identified within each of the three sections are planned for in the context of their ultimate effect on operations. Three operational capabilities surfaced as natural themes from the working group's discussions, capturing the primary mission areas that will realize greatest benefit from user interface technologies.

Each of the three operational objectives identified in the report comprise sections following the same general organization. Each section will begin with a summary of the operational objective, specifically focused on what operational benefits public safety will achieve as a result of enhancements to user interface technology. Following this operational objective summary, each section will describe:

User Interface Capabilities and Gaps

The majority of the User Interface Working Group's time and attention was dedicated to identifying the critical user interface technology capabilities that will go to market and their evolution over time. Once the high-priority technology capabilities were described, the working group identified critical-path technology barriers and gaps that may inhibit these capabilities from becoming

adopted by public safety and integrated into responders' daily operations. Whereas the technology capabilities identified often apply equally to public safety and commercial industries, the gaps and barriers described in this report are unique to user interface technologies deployed in public safety contexts.

While the working group initially identified technology capabilities and gaps according to the Software, Network, and Devices framework used in both the Public Safety Location-Based Services and Public Safety Analytics roadmaps, PSCR reorganized original working group input to reflect the three primary operational areas that stand to gain from enhanced user interface technology. In light of this new report organization, PSCR characterized the evolution of user interface technology by beginning each section with a description of key capabilities before identifying corresponding gaps and current developments related to advancing that capability. Given that a significant portion of working group input related to user interface devices, most of the highlighted capabilities identified before the "Enabling Technologies" sections represent device technologies. The enabling technologies section primarily describes software or network capabilities that support practical deployment and adoption of the user interface devices described earlier.

For each operational objective, the following questions were posed to User Interface Working Group members:

1. Given the stated trends and drivers, what technology capabilities need to be developed?
2. What are the gaps and barriers that will prevent these technology capabilities from being realized?

The data gathered from these questions, User Interface Working Group discussions, and additional market research can be found integrated into the narrative of the Operational Objective section.

Current Developments

After establishing the technology capabilities and gaps, mapping them to the appropriate sub-lane, and plotting them against the roadmap timeline, the User Interface Working Group members were asked to identify relevant actors in these fields and specific projects/products that are underway that should inform PSCR's efforts and eventual R&D projects. The following questions were posed to User Interface Working Group members and mapped against each technology capability and gap that was previously identified:

1. **What's being done?**
2. **Who's doing it?**
3. **How will remaining gaps and barriers be addressed?**

The data gathered from these questions, User Interface Working Group discussions, and additional market research is discussed briefly in each objective's sub-lane of "Technology Capabilities and Gaps." This concise summary is not intended to be comprehensive of the full spectrum of user-interface-related R&D occurring in today's technology marketplace. Rather, these enabling actions and actors represent leverage points for public safety to take advantage of market-ready technologies and make them public safety grade.

Enabling Technologies

While the "Technology Capabilities and Gaps" section highlights the major new user interface developments facing public safety, the working group also identified a set of supporting technologies that need to be developed before these user interface capabilities can be incorporated into public safety operations. The "Enabling Technologies" section touches on software and network capabilities that will support the evolution and use of user interfaces, but that do not signify new user interface capabilities on their own. Some of the enabling technologies will sound familiar to capabilities described in past PSCR roadmaps; this is to be expected given that enhanced user interfaces rely on many of the same software and network innovations that will support analytics or LBS technologies.

Public Safety R&D Opportunities

Given the technology capabilities, gaps and barriers, and enabling action and actors that are forecasted to impact the user interface domain over the next 20 years, the User Interface Working Group identified potential R&D efforts public safety R&D organizations should consider as they prioritize upcoming investment opportunities. These R&D opportunities will be expanded upon by a larger stakeholder group at the PSCR Public Safety User Interface R&D Summit, scheduled to take place in 2017.

Overall Capabilities, Gaps, and Developments

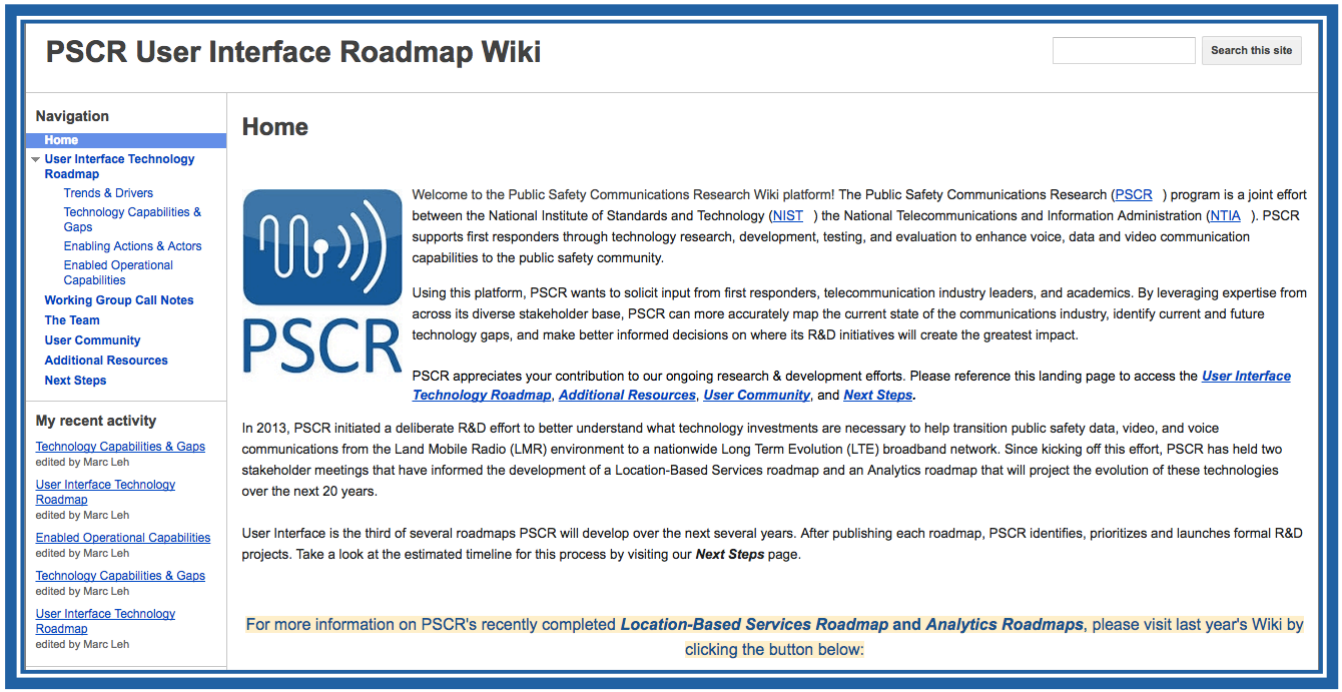
Given that PSCR's past roadmap summits have focused primarily on prioritizing the list of gaps facing emerging public safety technology, PSCR wanted to provide a comprehensive inventory of capabilities, gaps, and current developments for each operational objective. This summary table illustrates the relationship between capabilities, gaps, and developments across all technology verticals (i.e., Software, Devices, Networks), user interface capabilities, and enabling technologies.

Stakeholder Involvement Strategy

PSCR's User Interface Working Group consisted of more than 70 stakeholders from public safety, industry, academia, and all levels of government. To recruit these stakeholders, PSCR sent out formal invitations to its list of Cooperative Research and Development Agreement partners and working group participants from the *Location-Based Services R&D Roadmap* and *Public Safety Analytics R&D Roadmap.* PSCR also contacted usability subject matter experts and engaged with HCI specialists across the R&D community. PSCR officially kicked off the User Interface working group in May 2016 and convened conference call meetings through November 2016. PSCR also met with the NIST Information Access Division, Visualization and Usability Group[13] prior to working group meetings to gain a baseline understanding of the current state-of-the art, trends, use cases, and key organizations influencing the user interface technology domain. PSCR would like to pay special thanks to the stakeholders who volunteered to participate in the User Interface Working Group. A full list of working group participants is available in ***Appendix A.***

PSCR deployed an approach to engage with and collect input from stakeholders that was similar to the process used to develop the *Location-Based Services R&D Roadmap* and *Public Safety Analytics R&D Roadmap.* A public, collaborative Wiki platform that participants visited to capture their expertise, provide recommendations, and review past meeting materials remained central to PSCR's data collection process for this roadmap. Pairing the Wiki with biweekly conference calls allowed working group participants to provide input in a variety of ways and promoted flexibility, transparency, and traceability throughout the roadmap development process. Working group meeting minutes, content submission forms, original stakeholder input, and other supporting materials can be accessed on the PSCR User Interface Wiki Platform found at https://sites.google.com/a/corneralliance.com/pscr-user-interface-roadmap-wiki/

[13] https://www.nist.gov/staff/information-technology-laboratory/information-access-division/visualization-and-usability-group



PSCR User Interface Roadmap Wiki

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Home

PSCR

Welcome to the Public Safety Communications Research Wiki platform! The Public Safety Communications Research (PSCR) program is a joint effort between the National Institute of Standards and Technology (NIST) the National Telecommunications and Information Administration (NTIA). PSCR supports first responders through technology research, development, testing, and evaluation to enhance voice, data and video communication capabilities to the public safety community.

Using this platform, PSCR wants to solicit input from first responders, telecommunication industry leaders, and academics. By leveraging expertise from across its diverse stakeholder base, PSCR can more accurately map the current state of the communications industry, identify current and future technology gaps, and make better informed decisions on where its R&D initiatives will create the greatest impact.

PSCR appreciates your contribution to our ongoing research & development efforts. Please reference this landing page to access the ***User Interface Technology Roadmap***, ***Additional Resources***, ***User Community***, and ***Next Steps***.

In 2013, PSCR initiated a deliberate R&D effort to better understand what technology investments are necessary to help transition public safety data, video, and voice communications from the Land Mobile Radio (LMR) environment to a nationwide Long Term Evolution (LTE) broadband network. Since kicking off this effort, PSCR has held two stakeholder meetings that have informed the development of a Location-Based Services roadmap and an Analytics roadmap that will project the evolution of these technologies over the next 20 years.

User Interface is the third of several roadmaps PSCR will develop over the next several years. After publishing each roadmap, PSCR identifies, prioritizes and launches formal R&D projects. Take a look at the estimated timeline for this process by visiting our ***Next Steps*** page.

For more information on PSCR's recently completed ***Location-Based Services Roadmap*** and ***Analytics Roadmaps***, please visit last year's Wiki by clicking the button below:

Figure 3: User Interface Wiki created to capture working group input

Public Safety Use Case Environments

Before asking the working group to forecast the user interface technology capabilities and gaps that will affect public safety operations over the next 20 years, PSCR examined the requirements associated with three typical public safety usage scenarios. The three operational environments that working group members were instructed to keep in mind when discussing trends, capabilities, gaps, and opportunities included:

- **Office/Station** – can include a public safety agency's business functions, dispatch, command center, mobile command, etc.
- **Transit/En Route** – refers to when responders are traveling either on routine patrol or to an emergency scene.
- **Operational/On Scene** – refers to when public safety personnel are responding to an event on scene.

The working group identified high-level parameters for each environment and considered each environment when identifying impactful user interface technologies and critical-path gaps that public safety will need to address before integrating new capabilities with response functions. Although there may not always be a clear distinction between these environments, and the differentiation between "response" and "operational" may be much finer for a police officer on patrol versus a firefighter in station, PSCR asked the working group to consider "Office/Station" as environments in which public safety executes planning and administrative functions; "Response/In Transit" as any space in which public safety is traveling to respond to a situation; and "Operational/On Scene" as the environment in which public safety performs core mission functions.

New user interface technologies need to be designed in light of the unique requirements associated with each of these operational environments. For example, a vocal command input control to support hands-free route planning would need to incorporate audio filtering capabilities that would recognize inputs from both the driver and passenger during transit. The same input control technology deployed in an operational or on-scene environment would need to feature ruggedized hardware components and circuitry that could amplify vocal signals above the din of background noise during response. Throughout this roadmap, PSCR emphasizes the importance of use case considerations when evaluating, prioritizing, and developing viable next-generation user interface technologies for public safety.

Considerations for Public Safety's Expanded Use of User Interface

Since 2013, PSCR has emphasized the importance of public safety adopting new technologies in light of several environmental realities throughout its R&D planning process. The User Interface Working Group agreed that public safety will need to consider usability, security, interoperability, and regulatory concerns when evaluating the viability of future interface technologies. Although these topics are not the primary emphasis of this report, PSCR would like to reaffirm that stringent usability testing, security measures, and interoperability will be incorporated into any user interface R&D project that the agency pursues following the publication of this roadmap.

Given that user-centered design and usability are central to the effective development of user interface technologies, PSCR intends to build on the usability goals outlined in NIST's *Usability & Biometrics* report.[14] The report argues that user-centered design helps ensure that interface products and system are easy to learn, effective to use based on the task at hand, and enjoyable from the user's perspective. NIST defined usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use." PSCR will consider the attributes of usability identified in the *Usability & Biometrics* report as it begins to plan and launch formal user interface R&D projects:

- Effective to use (effectiveness)
- Efficient to use (efficiency)
- Enjoyable to use (satisfaction)
- Easy to learn (learnability)
- Easy to remember (memorability)

In addition to usability considerations, PSCR acknowledges that it will take into account public safety's privacy, budgetary, staffing, internal policy, and regulatory concerns as it continues to engage stakeholders to build on the capabilities and gaps identified in this report. To learn more about the importance of user-centered design and usability as related to interface development, please review NIST's Biometrics & Usability report linked to below.

NIST Biometrics & Usability Report: https://www.nist.gov/sites/default/files/usability_and_biometrics_final2.pdf

[14] https://www.nist.gov/sites/default/files/usability_and_biometrics_final2.pdf

Trends and Drivers

Key to PSCR's roadmapping efforts is the contextual understanding of how technology capabilities evolve—not only in terms of the technology itself, but also the larger environment in which the technology evolution takes place. To better understand this evolution, the User Interface working group members identified trends and drivers impacting the following three focus areas:

- **Public safety domain;**
- **Public safety broadband domain**; and
- **User interface domain.**

As stated in PSCR's *Public Safety Broadband Research and Development Roadmap – Beginning the Process* report, key trends and drivers impacting all of these areas include:

- **Shrinking budgets at the federal, state, and local levels;**
- **A move toward regionalization of response;**
- **The impact of the secondary responder community in a more broadly defined public safety response role; and**
- **The changing role of the public in emergency response due to social media, mobile applications, and citizen reporting**

While not a primary focus of this report, security and privacy concerns were discussed given the potential impact they have on the application and use of user interfaces in public safety planning and response. As technology evolves to allow user interface interaction in new ways and more environments, security and privacy issues must be addressed to ensure the appropriate use.

Public Safety Domain

Short Term – 0 to 5 years (A straightforward extrapolation of current technology needs)

Citizen engagement Public safety agencies are increasingly relying on data and communications to engage with public citizens. An estimated 55 percent of public safety agencies now share communications via social media and almost 30 percent of agencies receive information from citizens through Facebook and Twitter alone.[15] Not only are public safety agencies increasing citizen engagement, but citizens do and will continue to expect the openness and transparency from their public safety agencies. Increased citizen engagement will achieve multiple goals for public safety: stronger alliances with the public, improved citizen response to events through the distribution of emergency information, and increased transparency and accountability. The continued availability of high bandwidth cellular communication will continue to drive this trend moving forward.

Demand for data The demand for data access and broadband connection will continue to increase throughout all arenas of public safety operations. Largely driven by the ubiquity of broadband access in the commercial realm and availability of data on private devices, there is an expectation that data access and public safety operations will continue to integrate.

Medium Term – 5 to 10 years (Extension of current trends to their reasonable limits)

Communications becomes IT Communications departments within public safety agencies are increasingly performing roles that are traditionally aligned with information technology (IT) departments. This shift is driven by the increased use of modern communications devices, which rely on computer systems and networks managed by IT departments. There will continue to be a shift in the management of communications assets from a traditional "radio shop" model to that of an IT department as communications move to broadband infrastructure.

Demand for interoperability There is a large and continuing need for public safety to increase interoperability between agencies, as demonstrated by the fact that 75 percent of the community desires to connect to personnel "across different

[15] http://www.goldenstateinc.com/downloads/motorola/whitepapers/motorola_public_safety_survey.pdf

networks and devices." This trend will develop moving forward as public safety response evolves toward deploying assets based on capability rather than organization.

Long Term – 10 to 20 years (Development of major new technologies needed to reach beyond the current capabilities)

Automation of public safety tasks	Tasks performed by public safety officials today will be increasingly automated over the long term. First to be affected will be those tasks that are most easily performed by automation as well as tasks that expose responders to the highest degree of physical risk. Industrial advances in the reliability and sophistication of machine-to-machine communications will increasingly be leveraged in public safety settings. Incremental progress toward this trend will initially see public safety performing tasks in coordination with automated technologies and becoming networked with technologies, such as automobiles (e.g., car-as-a-platform).

Public Safety Broadband Domain

Short Term – 0 to 5 years (A straightforward extrapolation of current technology needs)

FirstNet and public safety broadband	As FirstNet's public safety broadband network capability develops, public safety agencies will migrate broadband capabilities into operations. As this occurs, LTE will move to the forefront of public safety discourse and current concerns, such as state data contracts, will dissipate.
Network consolidation	Disparate public safety networks will consolidate into a single, integrated internet protocol (IP) network that prioritizes data communications. The consolidation and integration of internet of things (IoT), geographic information system (GIS), and public-safety answering point (PSAP) data will be enabled by user interface technology advances as public safety seizes on capabilities to merge and analyze data. This will continue to improve situational awareness for public safety.
Data sharing and collection	As communications transition from LMR to LTE and broadband networks integrate, opportunities to collect and share data over broadband will become increasingly prevalent. GIS, FirstNet, and data sharing and collection agreements with non-government organizations will be data resources that public safety will increasingly need to rely on for effective communication.

Medium Term – 5 to 10 years (Extension of current trends to their reasonable limits)

Phased roll-out of LTE	The working group projects that public safety agencies will migrate communications to the NPSBN in phases as the network evolves. Uncertainty over the roll-out and timeline of certain capabilities, such as mission-critical push-to-talk over broadband, complicate purchasing strategies and technology investment amongst public safety agencies and may limit widespread adoption.
Increased requirements on network	Broadband usage and operations conducted over LTE networks will strain network data capacity. As public safety applications proliferate, social media feeds and associated immediate reporting capabilities will eventually become integrated with public safety workflows, increasing the demand on capacity, bandwidth, throughput, and analytical elements of wireless networks.

Short, Medium, and Long Term – 0 to 20+ years

Continued potential for cyberattacks	Public safety broadband will remain exposed to a range of potential cyber threats due to multiple factors. Increase in the number of connected devices, growing range of public safety broadband coverage/entry points, and continued sophistication of threatening actors will require a continuously evolving security posture.

User Interface Domain

Short Term – 0 to 5 years (A straightforward extrapolation of current technology needs)

Adoption of broadband devices	Public safety will continue to adopt the use of broadband devices for both official public safety use and private use. As personal device capabilities evolve, public safety will increasingly employ private devices in the operational realm. Broadband devices will provide public safety with evolved user interfaces from classic LMR technology historically used for public safety communications. The continued and increasing adoption of these devices is driven by decreasing broadband device size, improved processing speed, greater access to data, information provided by sensors and body-worn devices, and enhanced graphical user interfaces. Public safety will need organizational, operational, and technological changes to keep pace with the continued adoption of these devices whether they are agency-supplied or privately owned.
Design for everywhere	A major trend connected to the increase in adoption of broadband devices is the focus amongst interface and device developers of designing devices that can be deployed across a range of environments. This will increase the ability for a first responder to use a single device as he or she moves from the home, to the central command office, to an emergency response scene.
Centralization of data	Increased capabilities in back-end technologies including analytics, data sharing, and network strength will continue to enable the centralization of multiple data sources presented to public safety through data and communications interfaces. For example, GIS mapping tools will have increasing capabilities to layer multiple data dimensions over a single map, incorporating events, streets and routing, topography, and threat data, among other types of data. The trend toward centralization will drive public safety to understand and monitor the impact of increasing data availability on the public safety user. The ability for the public safety community to determine a user's capacity for processing data and requirement to receive data may be based on the specific user, task, and environment at any given time. The presentation of data will drive users' perception, trust, and use of the interface.
Available data is tailored to user needs	Interface technologies continue to present data that is tailored to the user and the precise context of their current operational environment ('smart' data), including the physiological/behavioral state of the user, his/her current field of view, and other factors. Customized work and information flows will be based on machine

knowledge of tasking, location, incident assignment, alerts, and sensors, removing a requirement for users to input environmental data specifically.

Devices for public safety

Commercial industry and federal R&D organizations will continue to develop more devices and interfaces specifically for public safety rather than adapting existing commercial off-the-shelf (COTS) market offerings for public safety sales and operation. Public-safety-specific development will require consistent, systematic input regarding design and requirements for public safety use. Increases in design specificity will enable devices to become tailored to individual users, creating complexities in the public safety domain where devices and infrastructure may be shared amongst agency personnel.

Device consolidation

The pace of technological innovation is creating increasingly compact or miniature devices. The miniaturization of devices and interfaces allows greater functionality to be delivered by a given device, and thus individual devices will be increasingly multi-functional. The trend shows a continued track toward devices serving as mini-computers that can support a wide range of functionality across multiple network types.

Medium Term – 5 to 10 years (Extension of current trends to their reasonable limits)

Wearables and gesture-recognition technology

The medium by which users interact with technology, also recognized as the "user interaction paradigm," has and will continue to shift from traditional graphical user interface (e.g., point, click, drag and drop) using an indirect device (e.g., a mouse) to more direct manipulation of UI objects using user's' hands (e.g., touch screen, swipe, tap). New interaction paradigms may include eye-tracking technologies (e.g., auto scrolling based on eye movement) as well as invisible or passive interfaces that may interact with the user without his or her knowledge.

Augmented reality/virtual reality

Augmented and virtual reality (VR) capabilities developed for the commercial market will continue to lend application to the public safety domain through direct use of commercial solutions, ruggedization of commercial solutions, and public-safety-specific design. These devices will enable public safety to receive data and communications in operation via augmented reality (AR), train public safety operators in the virtual environment, test and evaluate interface technologies, and remotely conduct public safety tasks through virtualized operation in remote command and control centers.

Long Term – 10 to 20 years (Development of major new technologies needed to reach beyond the current capabilities)

Human-machine interaction	Devices will continue to become closer and closer to the physical body, eventually becoming embedded within users. Forward thinking research looking at automating the connection between the human brain and our machine interfaces is underway and will enable direct, potentially sub-conscious interactions between humans and machines.

Operational Objective – Enhance User Experience

A primary objective that public safety should look to achieve through the adoption of innovative user interface technology is to **enhance the felt experience of a user's data/communications interaction.** This objective will examine **the ability of new user interface technology to integrate and/or automate tasks typically conducted manually by users to interact with data/communications**. The objective may be achieved by using less physically demanding input controls, more automated and intuitive data presentation, or more seamlessly integrated data sources on a single interface, among other approaches.

The working group characterized many of the capabilities outlined within this operational objective while forecasting the evolution of input controls, or "the controls (software or hardware components) that users interact with to command or input data into a technology."[16] As threats become more varied and the public expects more effective emergency response, responders will need to maintain total focus on specific tasks. Ideally, this would mean responders would not need to dedicate significant cognitive or physiological capacity to operating an interface device while on scene when his or her attention and resources can be better spent handling other tasks. As the volume of data and device options available to public safety increases over the next decade, interface input controls and commands will need to be designed to meet responders' heightened operational requirements for specific scenarios and tasks.

Enabled Operational Impacts:

The User Interface Working Group identified primary operational impacts that would benefit from R&D focused on user interface technology for public safety. The operational functions that stand to benefit the most from R&D towards the 'Enhance' objective include:

- **Reduced response time** – Reducing the manual or cognitive demands required for effective operation of an interface will enable responders to make decisions and recall data faster, and to provide services while in transit or on scene.
- **Production of actionable intelligence and data** – Interfaces that can more accurately predict responder decisions based on historical or environmental data can push more relevant supporting information to users during operations.

[16] https://www.usability.gov/how-to-and-tools/methods/user-interface-elements.html

- **Improved workload/workflow management** – By defining the user requirements associated with various public safety response tasks, R&D organizations can develop user interfaces that automate data input and presentation during steps of emergency response workflows.
- **Improved communication efficiency** – By leveraging a wider variety of user interface and input control paradigms designed to minimize cognitive and physical demands, responders will communicate with central command and others on scene more efficiently.

Technology Capabilities

Technologies that streamline the role of the device, application, or network operator will provide tremendous value to public safety by yielding greater cognitive and physical availability to dedicate to other response or public safety support functions. The capabilities presented within the *Enhance User Experience* operational objective will position individuals throughout a public safety agency to more effectively fetch and manipulate data optimized for improved business or operational intelligence. Interfaces will then leverage appropriate delivery mediums, alert technologies, and input controls based on the given usage scenario to optimize the presentation of decision-support data. While a variety of user interface solutions will hit the market in the coming years, this section looks to identify the underlying capabilities—rather than specific prototypes or commercial-off-the-shelf solutions—that will enable responders to more easily navigate and operate their communications tools. For example, the underlying capability for a user to summon data or broadcast a message utilizing gesture recognition as opposed to manually typing input allows a responder to keep his or her hands and eyes free to interact with the emergency scene (rather than the communications device). Other capabilities discussed within the *Enhance User Experience* operational objective include the proliferation of higher fidelity vocal commands in extreme acoustic conditions, more granular eye tracking and gesture recognition sensors, and automated biometric authentication of communications devices through a better understanding of a responder's heart rate, subvocal harmonic structure, and cognitive patterns.

1: Increased vocal command

One of the most common technology challenges cited by User Interface Working Group participants facing public safety was the difficulty of operating and manipulating handheld devices and tablets during emergency response. Devices currently available to public safety personnel often feature poor placement of input command buttons, small screen size, poor screen resolution, and/or require a mouse pad or other control device to operate. These device features significantly inhibit responders' ability to drive a vehicle or don personal protective equipment (PPE) or a self-contained breathing apparatus (SCBA), and they make performing otherwise routine response functions nearly impossible. However, the proliferation of more ubiquitous and precise vocal commands on these devices will allow responders to more seamlessly integrate hardware function operations with response actions. Having voice-activated, large button interfaces or contextual indicators will increase response efficiency and safety. Natural voice interaction will streamline access to data and information and make data retrieval more intuitive to responders in action. Vocal commands will greatly reduce cognitive load and allow responders to focus on the task at hand.

Recent research and development investments in voice recognition and command technologies primarily relate to developing code that can identify speakers based on their speech pattern; filter background noise or audio interference; and enhance audio signal strength while filtering white or colored noise.

Technology Gaps and Barriers:

Voice recognition

Current devices may be unable to accurately process voice commands under stress. Barriers to achieving complete voice recognition include the ability to properly filter background and non-essential noise, as well as detect and sort variance in speech patterns. Devices that use speech recognition capabilities also need to be designed to guide or limit the potential phrasing patterns input by the user. Current vocal recognition hardware (i.e., microphone, speaker, analog-to-digital signal converters) and supporting software (i.e., natural language processing [NLP] algorithms) capabilities easily misinterpret commands based on nuanced phrasing, and therefore experience difficulty categorizing ambiguous parts of speech and recognizing explicit instructions.[17] One potential path forward to shaping or prompting responder vocal inputs would be to develop standard vocal command protocols, which would help standardize the development of vocal interfaces and recognition capabilities. These interfaces would need to be equipped with analytical features that learn, or train, from the

[17] https://uxmag.com/articles/two-major-challenges-with-speech-recognition-technology

user's speech inflexion, habits, and vocabulary. A closed feedback loop would increase the responsiveness of responder inputs.

Natural language processing

NLP, or the automatic processing of human language by a computer interface,[18] has received significant attention from the data science and artificial intelligence communities in recent years. Although some NLP algorithms today can analyze human speech by parsing sentence structure, recognizing the overall sentiment of an expression, and translating vocal inputs into organized text (such as a structured database), these applications cannot process colloquial or misspoken content, and they are limited in scale.

Vocal authentication

Although voice recognition has been identified as a preferred form of user authentication in commercial applications,[19] ranking ahead of measures such as fingerprint, iris, or facial scan identification, commercial industry needs to improve the way that audio interfaces interpret vocal inputs and develop vocal models and templates for individual public safety personnel. Factors such as poor-quality vocal samples may decrease the reliability of using this technology to control and operate mission-critical information resources via voice. Internal device circuitry and signal processing capabilities also need to increase in reliability before vocal authentication can be deployed across public safety interfaces.

Current Developments:

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage vocal command technologies. Given the breadth of commercial, academic, and government activities relating to vocal command, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the vocal command domain.

[18] https://www.cl.cam.ac.uk/teaching/2002/NatLangProc/revised.pdf
[19] https://us.sourcesecurity.com/news/articles/co-3108-ga.4100.html

Operational Objective: Enhance

Defense Advanced Research Projects Agency (DARPA)

DARPA's Robust Automatic Transcription of Speech (RATS) program[20] aims to separate speech from background noise, determine which language is being spoken, and then isolate key words from that speech for analysis.[21] Much of the work on the RATS system has been done in laboratories in quiet and controlled environments. However, DARPA indicated that problems arise when researchers try to collect voice signals in environments with significant background noise and competing radio signals. Public safety operators trying to simultaneously monitor multiple signals will need to separate one signal from another and then focus on the actual words being spoken without the interference of static or background noise. Once the technology is able to filter background noise and static, it must rapidly translate spoken words that feature regional dialects or accents.

Amazon Echo

Amazon's Echo device pairs a seven-piece microphone array with artificial intelligence software to enable vocal commands that are activated through a customizable set of "wake words." To interact with users, the Echo device pairs NLP analytics methods with a speech-to-text synthesizer.[22]

Google Home

Google Home serves as a voice-activated speaker powered by its artificial intelligence platform Google Assistant. Vocal commands enable users to request audio applications such as iTunes, Spotify, or Pandora; and supports real-time data recall of current weather conditions, traffic patterns, and news alerts.[23]

MindMeld

MindMeld is a start-up developing next-generation conversation interfaces through artificial intelligence and NLP techniques. The core vocal recognition and processing technology can be embedded within commercial off-the-shelf (COTS) applications and devices to create an intelligent, predictive conversational interface between user and machine.

Waverly Labs

Waverly Labs has developed an earpiece device that supports real-time language translation while filtering out ambient noise. Speech recognition, machine learning, and speech synthesis techniques support the simultaneous communications between two different languages.[24]

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[20] http://www.usatoday.com/story/news/nation/militaryintelligence/2015/02/22/robust-speech-translation-transcription-software/23839041/
[21] http://www.darpa.mil/program/robust-atuomatic-transcription-of-speech
[22] https://www.cnet.com/products/amazon-echo-review/
[23] https://madeby.google.com/home/
[24] http://www.waverlylabs.com/

2: Gesture recognition and proliferation of sensors

User Interface Working Group participants also identified gesture recognition as an attractive alternative to traditional user controls because it would reduce the cognition and dexterity required to operate devices such as computer interfaces and in-vehicle dashboard controls. Given the state-of-the-art technology currently available, researchers believe that gesture controls will initially integrate with normal device operation workflows to replace secondary commands rather than primary commands. For example, within a vehicular context, primary controls refer to acceleration, deceleration, and steering while secondary controls refer to operating on-board applications such as navigation, radio, and data retrieval. Human-computer interaction studies have shown that secondary controls related to devices correlates with higher levels of distraction when operating primary functions. Gesture or facial operation of secondary controls will enable public safety personnel to dedicate more cognition and focus to executing primary commands and making mission-critical decisions.

When designing gesture-recognition technologies for secondary controls, researchers have argued that it is beneficial to categorize the tasks to be performed. These categories range from *manual only,* which requires the operator to physically command a device with his or her physical touch, to *visual only,* which requires no manual operator input and instead passively collects information and responds to this data.[25] *Manual Primary* tasks require visual recognition of an interface control before adjusting, and visual confirmation that the control adjustment was successful. For public safety, designing *manual only* and *manual primary* tasks to respond to gesture recognition represents the greatest opportunity to improve a user's experience and reduce the cognitive load associated with operating a device. However, before these gesture recognition technologies are introduced to the field, additional research is needed to establish standards for movement sensitivity within sensors, improve image capture and detection resolution in sensor-embedded cameras, and develop tripwire technologies that initiate decisions based on visual stimuli.

[25] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.135.7688&rep=rep1&type=pdf

Technology Gaps and Barriers:

Devices/sensors lack the ability to distinguish between close and far proximity gestures	Sensors and gesture-recognition cameras deployed in future emergency response settings must be improved to sense depth and key in on only users' gestures. Protective gear worn by public safety may hamper the technology's ability to recognize gestures, so must also be taken into account.
Need to develop gesture recognition standards and movement sensitivity thresholds	Additional requirements need to be gathered to define the standardized gestures used across public safety functions. After collecting an inventory of standardized public safety gestures, sensor and camera developers will need to establish movement thresholds and parameters that may constitute interface command functions. In addition to finalizing gesture recognition parameters, researchers need to clearly define what command functions mean within the context of specific support tasks for specific disciplines. The working group argued that in order for gesture recognition interfaces to be implemented successfully across disciplines, the user community will have to come together to agree what each gesture means.
Need to embed contextual awareness of public safety scenarios in gesture-reading devices/sensors	Given that public safety gestures will depend on the type of action or interaction with a specific device, hardware components will need to be able to recognize, process, and map human gestures to specific activities performed or device used during response. The working group envisions that public safety will standardize gesture recognition for specific scenario-dependent use cases rather than develop a comprehensive set of gestures that apply to all use cases.

Current Developments:

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to gesture recognition technologies. Given the breadth of commercial, academic, and government activities relating to gesture recognition,

continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the gesture recognition domain.

Gesture Recognition FocusMotion: FocusMotion has developed a machine-learning software development toolkit that quantifies human movement and gesture for wearable devices/sensors. FocusMotion's software enables developers to automatically track, quantify, and understand user movements through hardware- and operating-system-agnostic signal processing, machine learning, data training, and device integration.[26]

Microsoft Microsoft's long-standing commercial offering Kinect features a sensor array that supports full-body skeletal tracking. Since Kinect's entry to the commercial market in 2010, several researchers developed "plugin" algorithms to use in concert with Kinect's local hardware to support more granular finger and hand-motion gesture tracking.[27] These technologies are used to build a 3D map, or "point cloud," that users interact with to access new navigation menus, data sets, or command prompts within a specified application.

eyeSight Technologies eyeSight's sensing solutions for the in-car environment provide an enhanced driving experience by offering simple, touch-free interaction with the infotainment system—both the main infotainment system and in the back seats. Using simple hand gestures, the driver and passengers can control the infotainment system without touching or looking at the screen, thus reducing cognitive load.[28]

Texas Instruments Texas Instruments has pioneered z-axis depth tracking of gesture movements. Leveraging enabling technologies such as stereoscopic vision (two cameras capturing and tracking opposite angles of a single subject), structured light patterns, and time-of-flight measurements, Texas Instruments is able to triangulate objects and movement within a 3D spatial depth field.[29]

[26] http://focusmotion.io/
[27] https://brage.bibsys.no/xmlui/bitstream/handle/11250/181783/Ryan,%20Daniel%20James.pdf
[28] http://www.eyesight-tech.com/automotive.html
[29] http://www.ti.com/lit/wp/spry199/spry199.pdf

Operational Objective: Enhance

Georgia Institute of Technology (Georgia Tech)

Georgia Tech has embedded new signal processing technology and hardware design in an "always-on" camera to capture gesture recognition. This technology will be used to activate gesture recognition cameras once the user delivers a specified command prompt (such as waving a 'z' in the air). This camera technology is more power efficient than commercially available gesture recognition capabilities today.[30]

[30] http://www.news.gatech.edu/2016/08/11/researchers-develop-low-power-always-camera-gesture-recognition

3: Eye-gaze input command

Eye-gaze input control capabilities primarily fall into the *visual only* task category described above, and as a result, will yield similar user experience benefits as produced by gesture recognition controls. Many emergency response scenarios will require device operators to use their hands, which have a relatively limited range of motion, therefore making the gesture more difficult to recognize. Such scenarios will benefit greatly from eye gaze technology that can recognize more subtle movements. Emerging eye-gaze technologies primarily focus on tracking what users choose to observe through high-resolution cameras, and processing our eye movements within the context of 2D images. Current research activities have focused on translating data inputs captured by the eyes into output functions for human-computer interfaces. Hardware platforms, such as the Eyegaze Edge tablet and desktop developed by LC Technologies, enables persons with disabilities to communicate through assistive technology.[31] The underlying science supporting this hardware could be applied to developing or refining public safety training scenarios, or even creating next-generation heads-up display interfaces that track eye movements to individuals or infrastructure on scene and provide valuable contextual awareness to responders.

Technology Gaps and Barriers:

Lack of interoperability across image tracking and processing platforms	Today's eye-tracking cameras and processing technologies lack the ability to reconcile wide aperture images from body-worn cameras with the visual focus of first responders. Eye-gaze over the scene allows unambiguous determination of what information the first responder actually saw.
Limited ability to integrate eye tracking technology in AR environments	Today's providers of AR and contextual awareness solutions are unable to integrate eye movement data with virtual environments. Although machine vision and wearable cameras contribute to building a description of the environment being traversed by first responders, including the objects available to them, there is no way to ensure that what the camera captures is exactly what the responder is viewing with his or her gaze. Human vision can change focus up to 40 yards without actually moving the eye, and eyes move in rapid or uneven bursts when they focus on new objects. Given that eyes do not move smoothly and can focus very precisely

[31] http://www.eyegaze.com/eyegaze-assistive-technology-products/

without adjusting gaze, public safety needs much more granular tracking of attributes such as pupil dilation and gaze direction before reliable augmented realities can be leveraged in real-world response events. By combining wearable cameras and virtual reality paradigms with live eye-tracking data, researchers will make it possible to identify the sequence of identified objects that first responders encounter. The working group argued that this capability may facilitate automated task detection in the long term.

Current Developments:

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage eye-gaze technologies. Given the breadth of commercial, academic, and government activities relating to eye-gaze technologies, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the eye-gaze domain.

LC Technologies

LC Technologies' Eyegaze Edge tablet and desktop enables persons with disabilities to communicate through assistive technology.[32]

Tobii

Tobii has developed a suite of eye-tracking solutions related to assistive technology, gaming, and consumer-product interaction research.[33] The underlying technology supporting these offerings can be embedded within third-party devices, such as communication handsets, vehicular displays, and other user interfaces.

SensoMotoric Instruments (SMI)

SMI's miniaturized eye tracking cameras make it possible to include technology in wearables such as glasses. These cameras monitor gaze direction of 2D spatial fields and allow for monitoring of vergence information, or the simultaneous movement of both eyes in opposite directions when focusing,[34] to identify gaze targets in 3D fields. Glasses have an on-board camera that provides a first-person head direction view for overlaying gaze information. SMI is currently conducting market research, user training, and testing and evaluation for both the camera and glasses technology.[35]

[32] http://www.eyegaze.com/eyegaze-assistive-technology-products/
[33] http://www.tobii.com/group/about/business-units-and-fields-of-use/
[34] https://en.oxforddictionaries.com/definition/vergence
[35] http://www.smivision.com/en/gaze-and-eye-tracking-systems/home.html

4: Additional non-vocal input mediums (biometric, heart rate, tongue gesture)

Human-computer interaction experts represented within the working group cited a variety of non-vocal input mediums that would serve public safety well in the field. These include biometric sensors, heart rate monitors, and subvocal input commands, among others. Given the extreme environmental conditions inherent to many emergency scenarios, these non-vocal input commands will help responders communicate with others on scene or trigger specific support services when experiencing high noise, low visibility, limited dexterity, or physical impairment. The working group indicated that biological signals arise when reading or speaking to oneself with or without actual lip or facial movement.[36] Public safety may leverage this emerging technology to gain new insight into the cognitive demands on responders on-scene and to predict future actions or conditions given these more subtle, nuanced human behaviors. Since there is no requirement for sound, the technology eventually could be used for communication in high-noise environments, such as those firefighters encounter. Expanding speech recognition capabilities to include subvocal audio processing and enhanced filtering of ambient background noise may enable interfaces to more quickly listen, understand, and alert users to potential threats such as the status of unmanned vehicles from afar.

Technology Gaps and Barriers:

User authentication

Similar to the technology gaps discussed with vocal input commands, non-vocal biometric authentication presents challenges associated with user log-in, recognition, and authentication. Analytics supporting biometric pattern recognition (e.g., resting vs. elevated heart rate, iris profile, subvocal harmonic structure) need to develop biometric profiles of interface operators before biometric commands can confidently be deployed in public safety devices. Increased device authentication capabilities will ensure data is from reliable sources and prevent user interface intercept, spoofing, or jamming.

Current Developments:

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage non-vocal input technologies. Given the breadth of commercial, academic, and government activities relating to non-vocal input

[36] http://www.technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=4529

technologies, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the non-vocal input domain.

NASA	NASA is developing a subvocal speech recognition system that uses electrodes attached to the throat to detect biological signals that occur as a person reads or talks silently to him or herself. The signals are then converted into text or synthesized speech to use within traditional databases or decision-making tools.[37]
Department of Homeland Security	The Department of Homeland Security's (DHS) Science and Technology Directorate partnered with the University of California, Los Angeles (UCLA) to launch the Physiological Health Assessment System for Emergency Responders (PHASER) program.[38] Through this program, DHS and UCLA are working to advance the physiological monitoring of firefighters by developing equipment that monitors a firefighter's body temperature, blood pressure, and pulse, and transmits these back to the fireground incident commander.

[37] https://www.nasa.gov/centers/ames/news/releases/2004/subvocal/subvocal.html
[38] http://phaser.med.ucla.edu/

5: Haptic feedback and flexible/responsive physical displays

Touchscreens will become more responsive to touch, resistance, and motion both with and without gloves. These evolutions in touchscreen technology will allow for enhanced and nuanced interaction at the physical mesh point of the user and data/communications. In addition to developments in haptic responses, the screens themselves will evolve to incorporate textures and sensitivity that can provide a user feedback as if they are "feeling their way across a screen" or altering navigational tempo based on variable pressure. These enhanced haptic capabilities will provide the user an added layer of feedback from their data interface across user environments.

The first evolution of screen technology used resistive technologies that relied on dual-layered conductive sheets completing an electric circuit when conjoined under pressure. Current touchscreen technology uses capacitance. This method utilizes a built-up electrical charge in an electrostatic field; when disturbed by an energy transfer to the human finger, the disturbance causes a change in capacitance that can be detected and located. Recent innovations to capacitive technologies include the utilization of a sub-screen sensor to detect deformations and translate pressure sensitivity, allowing for richer user input. Future evolutions in capacitive technology will involve alternatives to the typical indium tin oxide material used for conduction. Using metals such as gold and silver will increase responsiveness, while developments in graphene material will allow for enhanced flexibility.[39]

Technology Gaps and Barriers

Limited screen responsiveness and flexibility in traditional materials

Alternatives to current indium tin oxide based capacitive touch screens will utilize metals and new carbon materials to increase screen responsiveness and flexibility. Specifically, metals such as gold and silver are better conductors than indium tin oxide but are not transparent and thus interfere with image display. The latticed carbon material graphene has the advantage of being pliable while also transparent enough for clean display. However, graphene's main advantage poses equal challenges. At essentially one atom thick, it is extremely thin but also two-dimensional and thus becomes contaminated by foreign electrons when contacted with metals.[40]

[39] http://www.economist.com/news/science-and-technology/21689515-researchers-find-new-ways-make-touchscreens-more-responsive-moving-finger
[40] http://indianexpress.com/article/technology/science/breaking-the-graphene-barrier-4465396/

Current Developments

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage haptic technologies. Given the breadth of commercial, academic, and government activities relating to haptic feedback, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the haptic technologies domain.

ETH Zurich

A research team within ETH Zurich's Laboratory of Thermodynamics in Emerging Technologies is attempting to utilize metals such as gold and silver in capacitative screens by trimming the materials to 80 to 500 nanometers, rendering them essentially transparent. The team is creating these "nanowalls" through a 3D printing method where nanoparticles of the metals are suspended in a solvent "ink," coaxed out of a tube by an electric field. This method will yield a greater degree of screen responsiveness and may be cheaper than current methods that rely on expensive hermetic environments to construct.[41]

Bosch

Bosch has developed a prototype for a haptic touchscreen called "Neosense" that provides a range of response and feedback to the user through textures in the screen interface. As the user scrolls a finger across a screen they will feel a texture similar to dragging a finger across a physical keyboard, with edges and ridges for each button. Pressing a button on the prototype screen will give a physical "click" sensation associated with pressing a physical button.[42]

[41] http://www.economist.com/news/science-and-technology/21689515-researchers-find-new-ways-make-touchscreens-more-responsive-moving-finger
[42] http://blog.caranddriver.com/we-try-boschs-haptic-feedback-touch-screen-are-touched-by-its-effectiveness/

Enabling Technologies

SOFTWARE

The Enabling Technologies included below are software/applications and network technologies that will support the evolution of user interface technologies towards Operational Objective: Enhance, but do not signify a new user interface capability on their own. Software/application technologies utilize the increased power of analytics, visualization and emergence of 'Big Data' to run programs on and between devices themselves. Enhanced user interfaces will largely present themselves visually through software/applications. Network technologies utilize new network architecture, band types, and physical infrastructure to provide a greater resiliency, lower latency, and improved quality of service. Enhanced user interfaces will largely rely on network technologies to connect devices/sensors to one another and other users on the network.

Dynamic data visualization interfaces:

Advancements in software programming techniques and the proliferation of user interface design application suites will enable developers and public safety support staff to build new displays for specific public safety tasks. These tools will greatly reduce the learning curve normally associated with developing graphical user interfaces and will create interfaces for public safety that are increasingly social, interactive, and more game-like. These added features will allow public safety to more easily embed specialized user interface design features in existing wearable, industrial, or transport displays.

Gaining access to a greater diversity of data visualization options will drive public safety data to become more social and interactive, all while reducing the required input controls previously needed to access or share desired information. For example, Altia[43] has developed a programming tool to develop new graphical user interfaces to embed in industrial, transport, and appliance hardware displays. Platforms like Altia's will reduce the learning curve associated with designing public-safety-specific user interfaces to integrate with vehicle dashboards, heads-up displays, wearables, or command center monitors.

[43] http://www.altia.com/

Master application to integrate multiple devices/sensors:

The User Interface Working Group indicated that public safety will expect next-generation user interfaces to seamlessly access disparate data sources from a variety of on-body devices/sensors, environmental sensors, and other individuals in the responding area. Responders consistently stated that wearing—and navigating through—multiple devices would be too cumbersome during an emergency event, so having multiple pieces of information within the same device/window/interface would be valuable to improving the responder's user experience. Intuitive query capability within public safety databases will enable applications to find appropriate pieces of information given the context of the event. For example, Motorola's PremierOne Computer Aided Dispatch (CAD) system provides public safety operators with a centralized interface that enables more granular tracking and management of mobile response units.[44]

Public safety will need to integrate its next-generation devices/sensors from a hardware, content, and interface perspective. In the current industry landscape, manufacturers are often incentivized to design specialized devices/sensors rather than integrated ones because the underlying sensor technology may differ significantly. Since industry providers will likely not be incentivized to develop an integrated device or user interface suite, public safety can pursue two avenues to achieve compatibility. The first avenue is user interface integration in which agencies choose a single provider to develop a device with all the functionality that public safety is expected to need on that device. The second avenue is user interface modularization in which a multitude of providers develop products to a single standard to ensure compatibility.

The PSCR Analytics Working Group cited several additional challenges associated with using applications to access and integrate data from multiple devices/sensors. These gaps included a lack of common data standards and public safety's inability to ingest and process unstructured data. The working group also cited that even structured datasets available to public safety today have varying levels of quality and formatting and that reconciling existing database structures with new data created by emerging technologies such as IoT and video streaming would pose additional challenges in the short to medium term.

Automated data capture and linkage:

Machine-learning algorithms, artificial intelligence, and other analytics tools will automatically populate future public safety interfaces with data from biometrics, location-based services, building data, and personnel data. Data science techniques will continue to reduce the manual input, computation, and retrieval required to use data in public safety agencies today. Automation

[44] http://www.motorolasolutions.com/en_us/products/smart-public-safety-solutions/integrated-command-control/premierone-cad.html#tabproductinfo

will enable public safety repositories to integrate previously untapped pieces of information, such as fatigue status, facial recognition software, and biometrics, as additional technology for user behavior monitoring becomes cheaper and more available.

Algorithms supporting automated database linkage, semantic analysis, and pattern recognition will enable public safety to more effectively track data records that refer or correspond to the same entity (e.g., person, location, organization) across the agency. This will improve data governance within public safety agencies and enable on-scene, in-vehicle, and command center interfaces to track and draw relationships from data, even when not explicitly requested. Record linkages also hold the ability to recall past user behavior as well as current needs to seek, filter, and integrate data sources as required.

Smart Alerts and context-based analytics:

The data science supporting improved information aggregation and display in next-generation public safety devices will become more contextually aware and will generate automatic alerts based on pre-existing machine-learning rules or thresholds. Smart Alerts will act as push notifications on the responder's device, delivering necessary information when certain conditions are met without the responder having to manually input retrieval commands. Based on the user's role and assignment, data visualization software embedded in the user interface will need to provide a usable visual display and/or an audible alert that dynamically changes the input interface based on current response conditions. Business rules based on the time of day, nature of the call, type of structure, and physical layout will determine the alert's medium (i.e., audio, visual, tactile), timing (e.g., before arrival, upon accessing a given floor), and placement (e.g., on the device, clothing, or headset).

Automated alert systems will rely on pattern recognition, prediction, and personalization when supporting responders in the field. The capability to collect data and provide analysis in nearly real time will present users with verified and certified, evidence-based knowledge that has been personalized to meet the unique needs of individuals receiving this knowledge and their usage scenario parameters (whether the responder is at the office, in a vehicle, or elsewhere). For example, most CAD systems today color code incidents based on emergency severity. A high-priority incident (e.g., robbery in progress, house fire, heart attack) displays in the color red, while a lower priority call (e.g., a residential burglary discovered after the fact) is displayed in blue. The working group believes that personalized alerts should utilize the same approach to allow a first responder to glance at his or her display and immediately determine whether the new information is a higher or lower priority. However, over the next 20 years the Pattern Recognition, Prediction, Presentation and Personalization model will develop and operate as a closed system, requiring the development of new system architectures, analytics, and interfaces possessing the capability to collect data, personalize that information to the user's needs, and present that information in an optimized format.

Smart Alert functionality will support more intuitive public safety applications that will archive users' habits to enable more accurate anticipation of preferred alert mediums, screen displays, response techniques, and sources of information. This technology may be used to adjust route planning to expedite transit to an incident, or support "directive presentation" in which users are prompted or alerted to next steps in response depending on their chosen action (rather than data manually input into the system). Pairing machine-learning-supported alert mechanisms with various user interface paradigms will greatly minimize the input commands required of a responder, regardless of whether he or she is on scene, en route, or at central command.

NETWORKS

Advanced network resource management and optimization:

Given the increasing diversity of data-intensive applications and services being made available to public safety, expanded use of analytics to support more granular, intelligent network resource management will enable public safety data to be presented in the most digestible form based on a user's environment, cognitive capacity, and attention levels. For example, video requested via a smart phone will be optimized for the device's specific form factor and the number of devices/sensors utilizing bandwidth on the given public safety network. Different devices/sensors and applications will feature disparate bandwidth, throughput, and latency requirements, so public safety networks will need to have more visibility to evaluate prioritization of data sources or services based on mission requirements.

Network data visualization tools such as Commetrix[45] may enable public safety to more clearly monitor and manipulate the quality, resolution, or source of dynamic network data supporting collaborative response, intra-agency messaging, or digital telephony. The working group indicated that data sources will need to be optimized while traveling over networks, depending on the interface being used, because different devices/users will feature different capacity to digest input. Network interfaces that support automated or more intuitive control of data resolution, refresh rates, or cross-validation practices will need to be deployed on public safety networks to meet data integrity and mission requirements.

[45] http://www.commetrix.de/

Network visualization tools:

A suite of different network analysis and visualization tools have emerged on the marketplace in recent years, giving network operators the ability to better support simultaneous, real-time network analysis. With more visibility into and graphical control of data interaction, integration, and performance across communication networks, operators without programming expertise can better explore the relationships between users or data objects on networks. Examples of current network visualization solutions available to public safety include Gephi,[46] Cytoscape,[47] and OrgNet.[48] Capabilities featured in these and other platforms will allow public safety to more clearly map and understand the communications relationship between their users, between users and data sources, or even between a given agency and another jurisdiction without the steep learning curve associated with developing a data visualization platform internally.

Data transportability and processing power at the network edge:

Increased local processing of data at the network edge will enable faster, more responsive user interface performance by reducing transport time, latency, and backhaul requirements. As PSCR stated in the *Public Safety Analytics R&D Roadmap* report,[49] moving transport and processing functions from the network core to the edge will enable larger data sets, such as video across wireless systems, without putting undo stress on normal network performance. Edge processing capabilities will ensure that public safety personnel possess the most current, validated information on whichever user interface technology he or she is using. Responders and public safety support staff will also be able to more easily update data used to make decisions in real time on a more reliable network if edge nodes handle a greater portion of data transport and processing functions.

However, the working group also noted that public safety today lacks a backup/resiliency plan for a broadband environment in which one edge network device may serve as a single point of failure in the communications landscape.

[46] https://gephi.org/
[47] http://www.cytoscape.org/what_is_cytoscape.html
[48] http://orgnet.com/index.html
[49] http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1917.pdf

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Integrated network and application software:

The integration of network and application software will allow for a continuous data stream into mission-critical public safety databases. Public safety software will cull data relevant to the response task at hand to provide the user with necessary alerts and types of alerts based on potential hazards. However, public safety needs to establish standardized pre-planned file parameters (e.g., data structure, naming conventions) and database applications to fetch information from these files to effectively alert responders to adjust their operations based on environmental factors, such as weather, blueprints, forest health, or hospital bed availability.

Introducing centralized cloud network services will enable public safety agencies across jurisdictions to interface with localized data centers. One cloud center will service an area the size of a Federal Emergency Management Agency (FEMA) region and facilitate more resilient, redundant, public safety grade communications throughout a given region. In addition, these cloud interfaces will provide hierarchical accessibility for multiple tenants (e.g., system administrators within a single public safety agency) who would only be able to view and/or administrate their own state/city.

Enhance User Experience: Public Safety R&D Opportunities

Given the technology capabilities, gaps and barriers, and current developments that are forecasted to impact the User Interface domain over the next 20 years, the working group identified several potential R&D efforts that would enable the enhancement of the user experience. Public Safety R&D organizations should consider the following project areas as they prioritize upcoming investment opportunities:

Vocal Commands

- Develop hardware supporting higher fidelity signal processing and noise filtering to enable clearer voice command transmission in high-stress response environments.
- Develop a standardized set of vocal command prompts for emerging user interface designs.
- Establish standards for converting unstructured audio data into structured text files within public safety databases.
- Integrate social media sentiment analysis with NLP to more accurately interpret the “real” meaning of social media chatter.
- Integrate existing NLP algorithms with public safety analytics workflows.

Gesture Recognition

- Establish gesture recognition standards and movement sensitivity thresholds.
- Conduct gesture recognition measurement campaigns in 3D spatial fields, with a special emphasis on tracking z-axis movements (depth).
- Pilot a gesture sensitivity analysis program to demonstrate the reliability of technology for public safety and to determine which gesture technologies may be viable for public safety.
- Develop tripwire or smart alert technologies that initiate decisions or commands within public safety devices based on visual stimuli provided by the user.

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EYE-GAZE INPUT

- Develop high-resolution cameras that feature more granular tracking of attributes such as pupil dilation and gaze direction.
- Establish formatting standards for archiving eye tracking data.

ADDITIONAL BIOMETRIC INPUT CONTROLS

- Conduct measurement campaigns that monitor the cognitive demand of controlling various user interface paradigms during specific response tasks.
- Develop algorithms that support improved biometric pattern recognition (e.g., resting versus elevated heart rate, iris profile, subvocal harmonic structure).
- Integrate subvocal microphone sensors and circuitry with public safety broadband devices.
- Develop new standards and protocols supporting biometric authentication of devices and user interfaces.
- Improve network resource and bandwidth management to accommodate increased data flow associated with new sensor technology capturing non-vocal inputs.

SMART ALERTS

- Establish conditions and business rules to assign the interface medium and placement of Smart Alerts.
- Build triggers and process controls into analytical systems that can alert, support, or shut down operations.
- Build alert conditions into edge processing sensors that notify public safety agencies when devices/sensors reach low battery levels or in need of maintenance.

DEVICE/SENSOR INTEGRATION

- Develop a modularization standard to promote user interface compatibility across disparate devices/sensors and/or applications.
- Map redundant technology and the duplication of hardware functions (e.g., speakers, microphones, sensors on devices on person) within various user interface paradigms to

Operational Objective: Enhance

improve resiliency of and protection against a single point-of-failure for future user interface systems.

SECURITY AND AUTHENTICATION

- Develop an electronic or virtual identification/authentication model with specified standards and policies for authenticating voice, gesture, or other biometric activation and command of public safety devices.

AUTOMATED DATA RECORD CAPTURE AND LINKAGE

- Establish data governance policies and procedures to more effectively track data records that refer to the same entity (e.g., person, location, organization) throughout a public safety agency.

OTHER

- Develop new sensor technologies that feature increased response sensitivity to haptic input and muscle firing.
- Gather physiological requirements associated with using various emerging input control technology.

Enhance User Experience: Overall Gaps and Developments

Capability	Gaps	Developments
INCREASED VOCAL COMMAND	• Current devices cannot accurately process voice commands under stress • Inability to properly filter background and non-essential noise • Inability to detect and sort variance in speech patterns • Lack standardized vocal command prompts for specific public safety tasks • Lack audio analytic capability to translate vocal inputs into organized text that is interoperable with existing public safety databases • Lack natural language processing algorithms that learn or train from user speech inflexion and vocabulary • Need to improve vocal authentication and identification measures • Need to improve device circuitry and signal processing capabilities to increase vocal recognition	**Speech processing and noise filtration** ➢ DARPA, Robust Automatic Transmission of Speech (RATS) Program[50] ➢ Waverly Labs[51] **Voice command assistants** ➢ Amazon Echo[52] ➢ Google Home[53] **Natural language processing** ➢ MindMeld[54]
GESTURE RECOGNITION AND PROLIFERATION OF SENSORS	• Devices lack ability to distinguish between close and far proximity gestures • Need to develop gesture recognition standards and movement sensitivity thresholds • Need to embed contextual awareness of public safety scenarios in gesture reading devices • Lack camera technology that effectively recognizes z-axis movement (depth) • Lack of a mission-critical standard amongst gesture recognition devices that are currently being developed for commercial use	**Gesture recognition software development** ➢ FocusMotion[55] **Gesture recognition systems** ➢ Microsoft Kinect[56] ➢ Texas Instruments[57] ➢ Georgia Tech[58] **In-car gesture recognition** ➢ eyesight Technologies[59]
EYE-GAZE INPUT COMMAND	• Lack of interoperability across image tracking and processing platforms • Limited ability to integrate eye tracking technology in VR environments • Lack cameras that feature tracking of granular attributes such as pupil dilation and gaze direction	**Eye-tracking hardware** ➢ SensoMotoric Instruments[60] **Eye-gaze assistive technology** ➢ LC Technologies[61] **Eye-tracking and cognition research** ➢ Tobii[62]

[50] http://www.usatoday.com/story/news/nation/militaryintelligence/2015/02/22/robust-speech-translation-transcription-software/23839041/
[51] http://www.waverlylabs.com/
[52] https://www.cnet.com/products/amazon-echo-review/
[53] https://madeby.google.com/home/
[54] http://www.dataversity.net/big-data-and-artificial-intelligence-advances-in-natural-language-processing/
[55] http://focusmotion.io/
[56] https://brage.bibsys.no/xmlui/bitstream/handle/11250/181783/Ryan,%20Daniel%20James.pdf
[57] http://www.ti.com/lit/wp/spry199/spry199.pdf
[58] http://www.news.gatech.edu/2016/08/11/researchers-develop-low-power-always-camera-gesture-recognition
[59] http://www.eyesight-tech.com/automotive.html
[60] http://www.smivision.com/en/gaze-and-eye-tracking-systems/home.html
[61] http://www.eyegaze.com/eyegaze-assistive-technology-products/
[62] http://www.tobii.com/group/about/business-units-and-fields-of-use/

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ADDITIONAL NON-VOCAL INPUT MEDIUMS (BIOMETRIC, HEART RATE, TONGUE GESTURE)	• Need to develop biometric profiles of interface operators • Need to integrate subvocal microphone sensors and circuitry with public safety broadband devices • Lack analytics supporting biometric pattern recognition (resting vs. elevated heart rate, iris profile, subvocal harmonic structure) • Lack biometric authentication standards to prevent device intercept, spoofing, or jamming • Need to gather physiological requirements associated with using various emerging input control technology • Lack bandwidth for increased data flow associated with new sensor technology capturing non-vocal inputs	**Sub-vocal speech recognition** ➢ NASA Ames Research Center[63] **Biological sensor input** ➢ Department of Homeland Security, Physiological Health Assessment System for Emergency Responders (PHASER) program[64]
HAPTIC FEEDBACK AND FLEXIBLE/RESPONSIVE PHYSICAL DISPLAYS	• Limited screen responsiveness and flexibility • Lack sensor technologies that support increased response sensitivity to haptic input and muscle firing • Need to embed software that provides feedback to user upon haptic input directly in hardware screens • Traditional screen materials (indium tin oxide) are inherently inflexible • Flexible metals are not transparent enough for screen use • Thin materials (such as graphene) are not electronically stable enough for use in devices	**Alternative screen materials** ➢ ETH Zurich Laboratory of Thermodynamics in Emerging Technologies[65] **Haptic touchscreen** ➢ Bosch Neosense[66]
DYNAMIC DATA VISUALIZATION INTERFACES	• Limited data visualization programming expertise within public safety agencies • Lack of interoperability between data visualization applications and existing public safety communications handsets and vehicular interfaces. • Lack of development community focused on usability and user experience for public sector applications • Lack of research and testing for interface and alert effects on cognition in the public safety sector	**Graphical user interface programming tools** ➢ Altia[67]
MASTER APPLICATION TO INTEGRATE MULTIPLE DEVICES/SENSORS	• Lack of common data formatting standards • Public safety does not possess software that can ingest and process unstructured data • Need to develop standards ensuring that user interface designs are interoperable across public safety devices • Data integration software must seamlessly transmit aggregated datasets across WiFi, Bluetooth, 4G, and 5G LTE broadband networks • Public safety lacks the ability to discern "golden source" information – or deciphering multiple, overlapping records for the 'true' data point	**Computer aided dispatch applications** ➢ Motorola's PremierOne[68] **Data integration standards and tools** ➢ International Organization for Standardization (ISO) Release 8601[69] ➢ US Geological Survey Data Lifecycle Format[70]

[63] https://www.nasa.gov/centers/ames/news/releases/2004/subvocal/subvocal.html
[64] http://phaser.med.ucla.edu/
[65] http://www.economist.com/news/science-and-technology/21689515-researchers-find-new-ways-make-touchscreens-more-responsive-moving-finger
[66] http://blog.caranddriver.com/we-try-boschs-haptic-feedback-touch-screen-are-touched-by-its-effectiveness/
[67] http://www.altia.com/
[68] http://www.motorolasolutions.com/en_us/products/smart-public-safety-solutions/integrated-command-control/premierone-cad.html#tabproductinfo
[69] http://www.iso.org/iso/home/standards/iso8601.htm
[70] https://www2.usgs.gov/datamanagement/plan/dataformats.php

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	• Different sensors do not integrate to common frame of reference (timestamp) for data	➢ Hadoop[71] **Data management solutions** ➢ GoldenSource Corporation[72]
AUTOMATED DATA CAPTURE AND LINKAGE	• Lack analytics to automate record linkage, semantic analysis, and pattern analysis across public safety devices / sensors • Need stronger data governance policies and procedures to more effectively track data records that refer to the same entity (person, location, organization, etc.) across the public safety agency • Public safety records management systems cannot effectively read and verify evolving identification mediums such as physical documents becoming digital	**Data linkage modeling** ➢ American Statistical Association[73] **Data exchange security standards** ➢ Federal Bureau of Investigation, Criminal Justice Information Services (CJIS)[74]
SMART ALERTS AND CONTEXT-BASED ANALYTICS	• Need to establish alert conditions based on time of day, nature of call, type of structure, physical layout to assign the alert's medium (audio, visual, tactile) and placement (on the device, clothing, before arrival, expediting transit and logistics) on the responder • Lack ability to generate automated alerts or actions based on rules, machine learning, or artificial intelligence software	**Alert management software** ➢ Monitis[75] ➢ Teramind[76]
ADVANCED NETWORK RESOURCE MANAGEMENT AND OPTIMIZATION	• Need to define bandwidth, throughput, and latency requirements for applications supporting specific response tasks • Lack of ability to adjust network performance on a device-by-device basis	**Standards and requirements research** ➢ International Telecommunications Union (ITU)[77] ➢ Institute of Electrical and Electronics Engineers (IEEE)[78] ➢ Third Generation Partnership Project (3GPP)[79]
NETWORK VISUALIZATION TOOLS	• Lack of data visualization programming experience among public safety support staff • Lack of holistic, 'systems-level' view of network performance that could be used to drive visualization tools	**Graphic user interfaces for network management** ➢ Gephi[80] ➢ OrgNet[81]
DATA TRANSPORTABILITY	• Need greater processing power for simultaneous triage of data from social, mobile, analytics, and cloud technologies	**Analytics 'at-the-edge' software** ➢ Cisco[82]

[71] http://hadoop.apache.org/
[72] http://www.thegoldensource.com/en/
[73] http://www.tandfonline.com/doi/abs/10.1198/016214501750332956
[74] https://www.fbi.gov/services/cjis/cjis-security-policy-resource-center
[75] https://www.monitis.com/support/alerts/managing-alert-rules
[76] https://www.teramind.co/solutions/employee-monitoring/smart-rules-automated-alerts
[77] http://www.itu.int/en/about/Pages/default.aspx
[78] https://www.ieee.org/index.html
[79] http://www.3gpp.org/
[80] http://www.martingrandjean.ch/introduction-to-network-visualization-gephi/
[81] http://www.orgnet.com/MCO.html
[82] http://blogs.cisco.com/tag/analytics-at-the-edge

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AND PROCESSING POWER AT THE NETWORK EDGE	• "Passive" applications need to include a command/control function to trigger the active state and deliver high-priority data to the responder.	➢ Axis Video Analytics[83]
INTEGRATED NETWORK AND APPLICATION SOFTWARE	• Current device processing speed & battery life does not support evolved UI applications and may cause latency	
CENTRALIZED CLOUD DATA STORAGE SERVICES	• Privacy issues associated with increased data consolidation between public safety agencies • Lack of data architecture and formatting standard between agencies to enable consistency in central storage location • Issues with migrating legacy data to a centralized model	**Hybrid cloud model** ➢ State of Texas, Department of Information Resources[84] ➢ City of Ogden and NetApp[85]

[83] https://www.axis.com/files/whitepaper/wp_video_analytics_65216_en_1509_lo.pdf
[84] http://publishingext.dir.texas.gov/portal/internal/resources/DocumentLibrary/Lessons Learned - Pilot Texas Cloud Offering.pdf
[85] https://s3.amazonaws.com/static.ziftsolutions.com/clients/netapp/resources/ds-netapp-solutions-for-microsoft-sql-server.pdf

Operational Objective: Enhance

Capabilities Development Timeline

Capability	Short - term (0 - 5 years)	Medium - term (5 - 10 years)	Long - term (10 - 20+ years)
Increased vocal command	Initial requirements gathering process to define vocal command "wake words" for devices	Vocal command prompts are standardized and integrated with public safety communications interfaces	
	Development of more efficient audio signal processors and algorithms increase the resoultion of voice communications	Automatic speech recognition technologies gain ability to process syllables, rather than words	Applied artificial intelligence and lingustics integrate with speech recognition technology to better predict vocal commands
	Digital audio filters that nullify background noise become more effective and available in mobile device speakers and microphones		
		Audio interfaces interpret vocal inputs and develop vocal models and templates for individual public safety personnel	Vocal authentication of devices and applications become widely adopted
	Natural Language Processing (NLP) algorithms embedded in public safety devices conduct sentiment analysis on vocal inputs	NLP algorithms gain ability to parse vocal inputs into organized text data	NLP algorithms route vocal inputs to centralized public safety databases to understand usage patterns in vocal commands
	Analog-to-Digital signal converters become integrated with public safety communications systems		
Gesture Recognition	Initial requirements gathering process to define gesture recognition standards and movement sensitivity thresholds		Gesture recogntion standards and movement sensitivity thresholds become finalized
			Interface hardware components gain ability to recognize, process, and map human gestures to specific response tasks
	Device-embedded cameras improve ability to track		
Eye-Gaze input commands	Eye tracking cameras process user eye movements within the context of 2D images	Eye tracking cameras process user eye movements in 3D spatial fields	Eye tracking cameras begin tracking and processing pupil dilation and gaze direction
	Eye Gaze input controls limited primarily to assistive medical	Eye Gaze input controls expand to gaming and product / consumer research technologies	Public safety pilots eye gaze input control testing and training programs
	Machine vision and wearable cameras approximate what responders see during transit and response operations		Wearable cameras and virtual reality paradigms combine with live eye-tracking data to monitor, predict, and optimize the sequence of objects a responder encounters
Biometric / non-vocal input mediums	Subvocal speech recognition systems are piloted within aerospace and assistive medical industriesrecognition standards and movement sensitivity thresholds		Subvocal speech recognition sensors become integrated with public safety equipment and communications interfaces
	Public safety early adopters begin integrating physiological sensors monitoring responders' biometric vitals into wearable equipment	Public safety physiological monitoring becomes more widespread. Public Safety begins monitoring cognitive capacity / demands associated with response tasks	Public safety develops biometric and cognitive capacity profiles for specific response tasks
Haptic Feedback	Mobile device touchscreens become more responsive to touch, resistance, and motion with or without gloves	Touchscreens begin utilizing new materials (carbon, gold, silver) to increase screen responsiveness and flexibility	Touchscreens begin utilizing latticed carbon material graphene to produce pliable, flexible device interfaces for public safety
	Touchscreen technology relies on capacitance to process user input	Capacitive technologies advance to include the utilization of a sub-screen sensors to more accurately detect deformations and translate pressure sensitivity	

Operational Objective -- Expand Data/Communications Access

An additional objective that public safety should look to achieve through the adoption of innovative user interface technology is to **expand the range of environments in which users interact with data/communications**. This objective is twofold, as public safety should focus on using evolved user interface technology to both bring data/communications to environments they have not been suitable for, as well as provide more refined and advanced data/communications to existing interface environments. By using ruggedized interfaces, devices/sensors that are integrated with the human body and with clothing, and collaborative command interfaces that share data in real time, public safety will be able to **provide first responders with data/communications and analytic products in environments once cut off from technological interfaces, including up-to-the-minute biometric data, situational awareness, tactical coordination, and life-saving alerts.**

The User Interface Working Group characterized many of the capabilities outlined within this operational objective in the context of the response/on-scene operational environment. The public safety community acknowledged that broadband capabilities and modern devices bring revolutionary planning and analysis to the public safety stations. However, they expressed a concern that unless researched and developed for use in the dangerous and variable domain of response/on-scene environments, the innovations would fail to achieve real results. As interface technology and devices evolve, consideration and planning must be given to ensure new capabilities are provided to public safety where they are needed most.

Enabled Operational Impacts:

The User Interface Working Group identified primary operational impacts that will benefit from R&D focusing on expanding public safety's user experience through improved user interface technology. The specific operational functions that stand most to benefit through enhanced public safety user experience include:

- **Improved situational awareness** – Presenting first responders with live mapping, communications, and data through AR and smart suit technology will enable constant awareness in rapidly changing environments.
- **Increased interoperability between teams/agencies** – Body-worn devices/sensors as well as AR interfaces will allow for a live exchange of data/communications between agencies and create opportunities to integrate tactics and coordination with no pre-planning required.

- **Improved communications efficiency** – Building communications interfaces directly into the body, clothing, and helmets of first responders will allow for hands-free direct communications in environments unsuited for handling unwieldy LMR interfaces.
- **Reduction of loss of life** – Positive impacts in all of the above mentioned lanes will create a safer and more informed first responder who is able to better avoid hazards and coordinate response, reducing the risk for loss of life to both public safety and citizens.

Technology Capabilities, Gaps, and Barriers

There will be a number of specific technology offerings developed over the coming years that can help accomplish this objective for public safety. Rather than evaluate each technology, the working group forecasted the overall interface capabilities that will be developed and that may be targeted specifically for this objective. Ruggedized devices/sensors will bring all the capabilities of the modern era's commercially focused smartphones to the operational environment; wearable devices/sensors will capture data and monitor the environment while the user conducts their task; AR interfaces will present wearable device/sensor data as well as outside communications and alerts in a safe, non-distracting manner; smart suits will build upon AR interfaces to integrate incoming data, making automated adjustments to the user's protective layer to best suit the current environment; and shared, virtual workspaces will provide open hubs for public safety to rapidly collaborate on tactics and resources with little planning in an on-the-fly manner.

1: Ruggedized devices/sensors

As the NPSBN develops and agencies begin to structure hardware investments around LTE capabilities, device manufacturers will develop devices ruggedized for the specific challenges of the public safety operational environment. The User Interface Working Group continuously expressed that the major factor in determining the effectiveness of emerging device technologies is reliability and that reliability in the public safety space means ruggedization. Typical emerging device technologies increase in fragility as they increase in complexity, but through ruggedization, public safety's 'devices of tomorrow' will allow a firefighter to enter a hazardous and variable environment with all of the same technology interfaces as a worker in a modern office. Specific ruggedized capabilities for public safety devices will include safeguards against emissions of flammable gasses, chemicals that may be present in hazardous environments, fluids on the skin (e.g., sweat, salt), and dustproofing for desert environments.

Ruggedization classification for mobile devices is typically expressed through a combination of two metrics: Ingress protection ratings as standardized by the International Electrotechnical Commission; and Military Standard, as standardized by the U.S. Department of Defense (DoD) and outlined in US MIL-STD-810G.[86] The working group forecasts that innovations will evolve to satisfy higher ratings along these two metrics but also may move beyond the ruggedization specifications as currently developed or coalesce around a set of ruggedization characteristics that combines aspects of each metric.

Ingress protection ratings are expressed through a two-digit rating (i.e., IPXX) and grade devices for protection against dust and protection against water. The first digit in an ingress protection rating grades for dust protection (scale: 0–6) and the second digit grades for water protection (scale: 0–8).[87] Multiple devices exist today with an IP68 rating (highest possible), and thus further consideration may be needed to express continued ruggedization capabilities.

Military Standards for ruggedized devices consist of 29 separate compliance tests outlined individually within the 810G standard document. An 810G-compliant device may be compliant with one or any combination of these 29 ruggedization standards; however, the test methodologies for each are not certified by a central body.[88]

[86] http://www.androidpolice.com/2013/07/01/ingress-protection-and-us-mil-810g-explained-what-these-ratings-really-tell-you-about-a-smartphones-toughness/
[87] http://www.handheldgroup.com/why-rugged-handheld-computers/what-is-rugged/
[88] http://www.androidpolice.com/2013/07/01/ingress-protection-and-us-mil-810g-explained-what-these-ratings-really-tell-you-about-a-smartphones-toughness/

Technology Gaps and Barriers

Ruggedization inhibits other essential device functionality	Device housings that are ruggedized to withstand extreme operational environments may inhibit other device functions, such as the ability to change the battery in a smartphone or use a touch-sensitive screen.
Weight of ruggedized devices is overly burdensome	Common devices that meet the highest degrees of ruggedization requirements can weigh up to four times as much as a standard smartphone or commercially developed device.[89] Added weight in ruggedized devices is largely due to the aluminum added to disperse shock within the device and the bumpers added to absorb shock on the exterior.[90]
Processing speed for ruggedized devices lags behind commercial solutions	Ruggedized devices lack the speed and mobility available in the consumer electronics realm. Lags in processing time may endanger public safety users who rely on ruggedized devices for critical alerts; in turn, this will hamper public safety's adoption of ruggedized solutions, instead encouraging the use of bring-your-own-device (BYOD) approaches.

Current Developments

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage ruggedized devices/sensors. Given the breadth of commercial, academic, and government activities relating to device/sensor ruggedization, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the ruggedization domain.

[89] http://www.connectech.se/Nyheter/the-need-for-speed-rugged-mobile-devices-in-the-military.html
[90] http://www.handheldgroup.com/why-rugged-handheld-computers/testing-rugged/

Operational Objective: Expand

Sonim Technologies Inc.	Sonim has developed multiple devices specifically for public safety. The Sonim XP7 device was designed with public safety in mind and operates on both commercial and 700 MHz Band 14 LTE spectrums. The XP7 functions with gloves, is resistant to chemicals, has a wide range of temperature operability, and includes a large battery.[91] Sonim devices were tested for use by public safety officials at the 2015 Super Bowl as well as the 2015 FIS World Ski Championships in Vail, Colorado.[92]
Cat Phones	In addition to dust-proofing, water-proofing, and structural reinforcements, the Cat S60 GSM Smartphone provides a built-in thermal imaging camera.[93]
Spectrum Camera Solutions	Spectrum Camera Solutions' UL Explosion Proof IoT Panel Shop manufactures ruggedized and explosion-proof cameras that support video analytics at the edge. Capabilities include cross-line detection, hard-hat detection, facial recognition, fire detection, man-down, and detection.

[91] https://www.toughgadget.com/best-rugged-smartphones-unlocked/
[92] http://www.mobilesportsreport.com/2015/01/sonims-rugged-lte-phones-get-public-safety-trials-at-super-bowl-world-ski-championships/
[93] https://www.toughgadget.com/best-rugged-smartphones-unlocked/

2: Wearables and devices/sensors in clothing

Personal wearables have long been envisioned as a key future generation hardware capability that will result in greater amounts of more accurate data. Based on the current trends in wearable technology, the User Interface Working Group forecasts that future public safety users will be equipped with clothing that measures heart rate, electrical activity from the muscles, and body temperature—important performance data that will lead to more informed resource allocation and operational decision making.

In addition to improved analytics, personal wearables, such as personal accountability tags, may enhance responder situational awareness and user experience. Personal accountability tags provide fire-line officers and incident command (IC) with Personal Accountability Report (PAR) data and firefighter location information. Integrating enhanced contextual data from personal accountability tags with thermal imaging camera (TIC) technologies can provide hands-free operation and enable users to transmit live video of fire conditions to the IC. These capabilities will also aid in more precise tracking and route optimization for personnel on the fireground, and could be applied to other public safety disciplines in the medium- to long-term.

Evolutions in wearable technology will utilize more flexible and longer lasting battery technology that is currently in development and prototype phases. The projected growth in the market for flexible batteries—from $69.6 million in 2015 to $958.4 million by 2022[94]—is expected to usher in flexible batteries less than 1 mm thick that can charge in minutes and last as long as the most ruggedized solutions currently available.

Technology Gaps and Barriers

Lithium-based battery technology is too heavy per charge capacity

Existing battery technology is limiting the capability of breakthroughs in device miniaturization, which could provide first responders with user interface interaction in a range of scenarios. Traditional lithium-ion batteries are overly bulky and do not provide enough energy density to power wearable and miniaturized devices/sensors for a sufficient period of time. The bulkiness is derived from lithium ion's highly reactive properties, which require the material to be surrounded in protective materials. Additionally, lithium-ion batteries have improved just 1.6 times over in energy density in 24 years and are not being seriously considered for miniature/wearable devices.[95]

[94] http://www.prnewswire.com/news-releases/flexible-battery-market-worth-9584-million-usd-by-2022-609879895.html
[95] http://www.energyharvestingjournal.com/articles/7590/apple-samsung-lg-chem-move-into-the-flexible-batteries-business

Wearable technologies require flexible battery power hardware

Wearable device/sensor integration must also be powered by a flexible battery, able to adapt to the natural motion of the user. While thin and flexible batteries have powered skin patches and radio-frequency identification (RFID) tags for years, existing capabilities are not powerful enough to power devices/sensors and data interface technology. Innovation in the flexible battery field largely relies on two approaches. The first approach is to achieve flexibility through the thinness of the material, and looks to alternative materials such as "aluminum ion, magnesium, lithium sulfur, lithium air, [and] sodium ion"[96] to do so. The second approach looks to create an intrinsically flexible battery. While prototypes and demonstrated capabilities exist, this technology is limited in that "bending and curving" reduce battery life.[97] No standard has been developed to test and measure for flexibility.

Current Developments

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage wearable technologies. Given the breadth of commercial, academic, and government activities relating to wearables, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the wearables domain.

Imprint Energy

Imprint Energy received $6 million in venture capital funding to develop a zinc-based flexible battery for on-body application. The technology relies on an in-house-developed, zinc-based polymer that utilizes the relative stability of zinc compared to lithium-ion but is able to avoid the short circuiting typical of zinc-based battery solutions. The omission of lithium-ion has allowed the company to strip the protective materials and associate bulk of typical battery technologies.[98]

[96] http://www.idtechex.com/research/articles/new-design-strategies-make-batteries-flexible-and-wearable-00007976.asp
[97] http://www.idtechex.com/research/articles/new-design-strategies-make-batteries-flexible-and-wearable-00007976.asp
[98] https://www.technologyreview.com/s/528996/flexible-printed-batteries-for-wearable-devices/

Operational Objective: Expand

Samsung	Samsung has developed battery technologies called the "Stripe" and "Band," which are as thin as 0.3 mm. The company claims that the products will improve battery life by up to 50 percent and achieve flexibility for miniature and wearable devices/sensors.[99]
Athos	The Athos smart pants use electromyography sensors to measure electrical activity produced by the leg muscles. "The sensors track the glutes, inner and outer quadriceps, and hamstrings" and can sense over-reliance or over-exertion on specific muscles. This data is fed from the sensors to a hub on the pants that then connects over Bluetooth to a software application.[100]
Human Condition Safety (HCS)	HCS is a recently funded start-up developing wearable devices for use at the worksite. "HCS … says its tools will incorporate wearable devices, artificial intelligence, building information modeling, and cloud computing, and be designed for industries that hold the highest risk for workers, including manufacturing, energy, warehousing and distribution and construction." This technology may be able to "detect when a worker carries too much weight, makes a bad bend, [or] enters an environmentally risky area."[101]

[99] http://www.wearabletechnology-news.com/news/2015/oct/26/samsung-lg-hope-solve-wearable-battery-issues-new-designs/
[100] https://www.liveathos.com/
[101] http://www.insurancejournal.com/news/national/2016/01/06/394158.htm

3. Augmented reality interfaces

AR interfaces will replace today's hand-carried interfaces and become increasingly prevalent in vehicles and non-personal devices. AR technology "enables users to interact with their physical environment through the overlay of digital information."[102] Public safety representatives in the working group advocated that the ability to overlay contextual information and background knowledge on an AR headset would increase the operator's awareness in the field. The concept is that the AR headset would provide a series of visual cues that prompt a responder as he or she moves between environments. For example, hazardous materials may be marked and overlaid with safety instructions, or multi-spectral sensors may be used to enhance visibility in denied environments or give responders access to parts of the spectrum they may not have otherwise. The working group also indicated that such AR headsets would need to proactively anticipate responders' operational needs and environments (e.g., route planning based on digital floorplan databases) and application requirements to ensure a continuous, contextually aware experience.

Thermal imaging represents another attractive AR capability for future public safety operations. Within the context of the fire service, thermal imaging technology would enable firefighters to distinguish heat-radiating objects, such as flames or the human body, from fallen debris, smoke, and building infrastructure. Thermal imaging technology is anticipated to be integrated with existing protective fire equipment to create an automated, contextually aware face-mask imaging system that may be operated with input commands described in earlier capabilities.

Technology Gaps and Barriers:

New chip design and technology required to provide sufficient bandwidth, processing power, and rendering resolution	Conventional computer processing architectures do not provide the processing power and data throughput necessary for realistic virtual renderings of public safety scenarios. The relationship between central processing units (CPUs) and graphics processing units (GPUs) will need to undergo fundamental redesign to handle the massive amounts of data input and visual output required to render fully virtual environments or support real-world response environments with contextual awareness.

[102] https://www.ncbi.nlm.nih.gov/pubmed/27008668

Operational Objective: Expand

required for life-like AR environments	
Sensors embedded within AR devices do not capture user and environmental input with sufficient resolution	The microphones, sensors, and cameras charged with relaying a user's interaction with a VR or AR environment are not yet responsive or high-resolution enough to support mission- critical public safety operations.
AR platforms do not feature real-time spatial awareness capabilities	Current artificial intelligence agents in AR headsets are neither contextually aware, nor do they have significant memory capacity.
Lack of standardized symbology for public safety AR interfaces	Public safety lacks a usability-tested AR graphical interface format to maintain standardization and consistency across devices and agencies. One of the main enabled capabilities of an effective AR interface is the rapid delivery of simple, actionable information to the user. So long as interface formats remain fractured across software developers and hardware devices, the alerts within the interface will be inconsistent and therefore potentially unfamiliar and distracting to the user. Public safety AR symbology needs to render the same way, regardless of the system or software used, just as HTML appears the same regardless of the browser. An AR style guide with common symbology for the public safety user base will enable common protocols across agencies based on commonly recognized visuals.
Distracting alerts in AR interface	A main barrier voiced by the working group is that alerts and visuals presented in current AR interfaces could be dangerously distracting or interfering to the public safety user when executing critical tasks in

that lack contextual awareness

emergency environments. To capitalize on usability testing and academic research into human cognitive abilities, AR devices must be intensely contextually aware so that alerting modes and patterns can be updated in real-time to suit the available cognitive load of the user.

Current Developments:

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage AR interfaces. Given the breadth of commercial, academic, and government activities relating to AR interfaces, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the AR interface domain.

Microsoft

Microsoft's HoloLens headset enables users to interact with holograms that are superimposed on the real-world environment through an AR display.[103] This AR capability does not need to be wirelessly tethered to a central computer, and it uses high-definition images and sound to create an immersive mixed-reality environment that could benefit public safety training scenarios in the short- to medium-term. Although the commercial release date has not yet been announced, Microsoft has distributed software development kits to programmers interested in piloting the technology.

Leap Motion

Leap Motion recognizes gestures to control software commands, enabling users to interact with digital content through AR or VR.[104] Integrated software and hardware track hand and finger movement with minimal latency to support 3D input controls.

BAE Systems

BAE Systems has developed thermal imaging technology, known as Thermal on Demand, that will enable firefighters to distinguish heat-radiating objects, such as flames or the human body, from fallen debris, smoke, and building infrastructure.[105]

[103] https://www.microsoft.com/microsoft-hololens/en-us
[104] https://www.leapmotion.com/about-us
[105] http://www.lowellsun.com/news/ci_28763768/power-see-heat

Operational Objective: Expand

Ultrahaptics

Ultrahaptics supports haptic interaction with objects presented in AR and VR environments. The company has published software development kits that device or application providers can integrate with their products to enable tactile command and response feedback from the user.[106]

MetaVR

MetaVR creates 3D real-time PC-based visual systems that provide the fidelity of geo-specific simulation with game-quality graphics. MetaVR applications enable users to build high-fidelity, geographically specific virtual worlds with a graphical user interface.[107]

[106] http://www.ultrahaptics.com/
[107] http://www.metavr.com/

4: Smart suit interfaces and cooperative devices/sensors

Working group members and experts in the public safety communications industry pointed to the emergence and continued evolution of "smart suits" as examples where multiple user interface capabilities are coalescing into an integrated product design. The smart suit technology for public safety looks to incorporate data, communications, sensors, displays, and cameras with the protective layer of the operational uniform.[108] Although not yet ready for operational environments, the smart suit technology can act as a form of ruggedization for devices/sensors, such as environmental sensors or location devices, that provide the user with new forms of data in the interim. Research suggests that the long-term development of smart suit capabilities will rely on heads-up displays—a form of AR technology that will provide an interface to data and communications on the inside of a user's helmet or mask. If a public safety operator with current technology is carrying a fire hose through a building or pursuing a suspect on foot, they are not able to easily use phones, radios, or tablet/data interfaces. Heads-up displays built into public safety protective equipment will provide the user with easily accessible data in these critical situations.

Heads-up display technologies will be ultimately be used to display interfaces from a host of technologies and provide the user with battery levels, heart rate, location, local hazards, internal and external temperatures, and communications from fellow public safety personnel. The long-term forecasts for smart suits suggest that the multitude of devices/sensors populating a singular display will function as a system. For example, heating or cooling technologies will trigger when a body sensor indicates the user's temperature is at a dangerous level, or oxygen supplements will flow through a mask when a sensor detects low levels of oxygen in the atmosphere.

Technology Gaps and Barriers

Weight and rigidity of a smart suit

While developments are underway to bring fully integrated smart suit technology to public safety agencies across the nation, there remain a range of gaps preventing current use. Major issues with current solutions are added weight and limited dynamic functionality associated with the additional "sensors, computers for processing information, transmitters (if used) and power supplies" that make up a full smart suit.[109] While a public safety user may prioritize select devices/sensors for his or her smart suit, there is apprehension to adopt a fully integrated suit that might add 15 to 30 pounds of gear and restrict the user's range of motion.

[108] http://spectrum.ieee.org/consumer-electronics/portable-devices/futuristic-firefighter-suit-has-sensors-headup-display
[109] https://www.firerecruit.com/articles/400760-The-Electronic-Firefighter

Operational Objective: Expand

For this reason it will be important to focus on modularity so that elements of the smartsuit may be added or removed based on mission requirements.

Interoperability of wearable devices/sensors

Unlike single-function wearable devices, smart suits for public safety will rely on a high degree of communication and synchronization between the array of connected devices/sensors within the suit. Public safety will benefit from the ability to invest in modular smart suit components rather than complete pre-packaged solutions, allowing for task-based customization. Current smart suit component devices/sensors are not interoperable between manufacturers, and middleware or other integration capabilities require development in the data integration hub of the smart suit.

Network connectivity and interference in Personal Area Networks

Personal Area Networks (PANs), which are used currently to network wearable devices/sensors, present a host of challenges for use in public safety smart suits. The current PANs use Bluetooth and ZigBee technology to interface with one another, but PANs related to smart suits require common network mediums, making them not ideal for communication to a central node. The small size and low-power requirements for PANs present limits to the amount of security that can be established between devices/sensors. Additionally, PANs are highly susceptible to network interference and can be disturbed by the human body, clothes, walls, and other common elements. Lastly, Bluetooth and ZigBee largely process simple sensor data and sensors, posing challenges for future smart suits that will connect video streams and enable complex analytics.[110]

Challenges for use of mmWave in support of networked wearables

Millimeter wave (mmWave) frequency is considered a viable method for networking devices/sensors within an integrated smart suit due to the high data rates mmWave supports. However, research published by the Institute of Electrical and Electronics Engineers outlines several technology challenges facing mmWave in wearable networks, including the following: when held close to the body, mmWave can expose a user to radiation; radio frequency (RF) circuits may not support the high bandwidth of mmWave and could cause energy loss; and a user's hands may interfere with mmWave transmission, causing blockage and propagation issues.[111]

[110] http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=7445132
[111] http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=7445132

Current Developments

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage smart suit interfaces. Given the breadth of commercial, academic, and government activities relating to smart suit interfaces, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the smart suit domain.

Defense Advanced Research Projects Agency

In coordination with United States Special Operations Command (USSOCOM) and the Massachusetts Institute of Technology (MIT), DARPA began to work on the Tactical Assault Light Operator Suit (TALOS) in 2013. The TALOS project aims to create a wearable solution for the American soldier that provides "integrated heating and cooling systems; embedded sensors, antennas, and computers; 3D audio (to indicate where a fellow warfighter is by the sound of his voice); optics for vision in various light conditions; life-saving oxygen and hemorrhage controls; and more."[112] The suit presents information to the user through a heads-up display in the helmet. Additionally, TALOS focuses on a ballistics-proof exoskeleton that will augment the physical strength of the user while shielding him/her from "chemical, biological, electromagnetic, and ballistic threats."[113] USSOCOM plans to produce a TALOS prototype by 2018 and is working to overcome challenges in device power and sensor technology.[114]

Umeå Fire Brigade

The Umeå Fire Brigade (Umeå, Sweden) is sponsoring the development of a new heads-up display helmet design called the "C-Thru." The C-Thru helmet integrates a number of functions, including thermal sensors and communication devices. A lead firefighter with a C-Thru helmet will be able to view a 3D interface projected through the visor of the helmet. This interface will show environmental, video, and thermal data from a front-mounted camera that has been processed by the user's handheld device and sent back to the heads-up display. The processed information will then be distributed to all the team members and displayed on their heads-up display visors as a wireframe overlay of their surroundings.[115]

[112] http://www.defenseone.com/technology/2015/09/engineering-humans-war/122189/
[113] http://www.defenseone.com/technology/2015/09/engineering-humans-war/122189/
[114] https://www.defense.gov/News/Article/Article/604009
[115] https://www.firerescue1.com/fire-products/personal-protective-equipment-ppe/helmets/articles/1315543-Futuristic-new-helmet-helps-firefighters-see-through-smoke/

5: Shared and virtual workspace interfaces

The application workspaces of the future will increasingly be lean, shared, and open for collaboration with multiple users based on location proximity or tasks/roles. When multiple agencies arrive to a response scene, they will use a shared application interface, which is populated with real-time data from both on-site and command data sources to view a common picture of the operational environment. The ability to share a virtual workspace both intra- and inter-agency will provide public safety with a wide array of information in an arena where access was once limited to data owned within a proprietary application or limited to a single agency. The working group projects that an incident commander will one day use a shared interface to see that an engine company from a neighboring district is en route to a scene, including the number of firefighters en route; the tools and supplies of the responders; and additional resources that may be on board, such as a rapid intervention team/firefighter assist and search team (RIC/FAST), high-rise team, or confined space team.

The shared application interfaces of the future will be enabled by a few key capabilities. Research suggests that middleware will soon be able to better support interoperability, sitting between the data and the interface so that the user is presented terminology, format, layout, and alerts that are consistent with his or her training and experience. Cloud services will continue to increase storage and virtualization capabilities, moving data once stored on physical devices or within proprietary applications to a more agile framework able to move across traditional sharing boundaries. Additionally, shared interfaces will use “smart city” and “smart building” technology to provide data, infrastructure, and networking in real-time. To achieve this capability, the working group recommended public safety continue to invest in lean technology, shared infrastructure, and security to enable trusted sharing.

Technology Gaps and Barriers

Data sharing between agencies	Virtual workspaces created between agencies upon arrival at a first response scene will require standardized data architecture, a common visual interface, and advanced middleware to support data transfer and compatibility between agencies.
Limited ability to rapidly develop a peer-to-peer network	In many situations, the development of a shared virtual workspace will require users to work from a common network and data source. Cellular networks pose inherent challenges for developing shared workspaces because coverage and bandwidth may be limited or unreliable in many environments. Wireless Local Area Networks (WLANs) satisfy most cost and performance requirements, but a limited range of supporting Wi-Fi technologies and potential interference from civilian Wi-Fi use pose challenges. Wireless

mesh networks provide the most promising solution for public safety; however, these networks can be extremely expensive to stand up on short notice in remote environments.

Need for rapid security and authentication for entrance to a shared workspace

Security will be a primary concern for sharing data rapidly across agencies in dynamic environments. Public safety will rely on a shared environment restricted to authorized users and impermeable to infiltration by foreign devices. The ability to quickly verify devices and grant access across agencies does not exist today.

Current Developments

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage shared and virtual workspace interfaces. Given the breadth of commercial, academic, and government activities relating to shared and virtual workspace interfaces, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the shared/virtual workspace domain.

Defense Advanced Research Projects Agency

In response to the death of 19 firefighters during a 2014 Arizona forest fire, DARPA began developing the Fire Line Advanced Situational Awareness for Handhelds (FLASH) system. The FLASH system uses GPS data, aerial visuals, thermal maps, and sensors to track response elements and fire locations so that "command units can coordinate how best to fight the flames."[116] Data from the mapping and sensors is presented to command through ruggedized, handheld tablet computers "to create an interactive 'battlefield' for fighting fires."[117] Developed specifically for public safety, the FLASH interface presents the user with "iconology for fire trucks, safety zones, water sources or emergency vehicles."[118] A FLASH unit weighs around 15 pounds, lasts for 12 to 15 hours on a single charge, and costs around $12,000 per unit.[119]

[116] http://www.govtech.com/em/disaster/Military-Technology-Could-Save-Firefighters-Lives.html
[117] http://www.govtech.com/em/disaster/Military-Technology-Could-Save-Firefighters-Lives.html
[118] http://www.afcea.org/content/?q=darpa-modifies-military-equipment-be-used-firefighters
[119] http://www.govtech.com/em/disaster/Military-Technology-Could-Save-Firefighters-Lives.html

Raytheon

Raytheon's One Force Mobile Collaboration is an application that provides public safety with collaborative "voice, maps, drawing tools, chat, real-time position tracking with GPS, streaming video and image sharing"[120] all from a single application on their mobile device. This application is a modified version of a Raytheon product developed for military use known as "Blue Force Tracking."[121]

[120] http://www.govtech.com/em/disaster/Military-Technology-Could-Save-Firefighters-Lives.html
[121] http://gsnmagazine.com/article/28343/raytheon_unveils_its_one_force_platform_enable_fir

6: Physically embedded devices/sensors

The last five years of innovation in user interface and HMI have been characterized by a large trend toward wearable technology, including smart watches, Bluetooth headsets, and heart-rate monitors. The outlook of the working group and the interface paradigm academic community suggests that these technologies will remain relevant in the short-term but will be seen as a mere stopgap in the long-term. The trend lines in wearable technology suggest that in the medium- to long-term future, wearable technology features will be physically embedded in the user's body.

Embedded interfaces will be used to capture commands through gestures (e.g., clicking two fingers together), eye motion (e.g., staring at something to select it), and eventually, directly from the brain itself (e.g., translating thoughts into commands or messages). The working group envisions a first responder relaying medical information for a citizen in need of rescue straight to the hospital; police officers silently communicating tactical information when approaching an armed suspect; and firefighting command units viewing a full suite of vital biological information across a response unit. Embedded technology stands to bring a full suite of data and communication interface capabilities into any operational environment fit for the user, completely eliminating environmental limitations on interface interaction.

Technology Gaps and Barriers

Invasiveness of application	For a functional adoption of embedded technology by common citizens or public safety officials, the technology must be designed to be minimally invasive, both in function and the method of application. Current embedded applications, including subcutaneous, cochlear, retina, and brain, suffer due to a lack of functional utility. The current state-of-the-art technologies are either overly large, poorly integrated with human physiology, or require repeated insertion and retrieval.
Inability to clearly identify coding within the human brain	Research teams have demonstrated the ability to monitor and sense brain activity, but the ability to derive definitive meaning from the coded activity in the brain remains out of reach. A highly advanced understanding of the wiring and message streams within the human brain will be required to decode and transmit messaging.

Current Developments

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage physically embedded device/sensor interfaces. Given the breadth of commercial, academic, and government activities relating to physically embedded device/sensor interfaces, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the physically embedded device/sensor domain.

Amal Graafstra

The entrepreneur and founder of Dangerous Things has developed embeddable near-field communication (NFC) chips that can be implanted under the skin of a user's hand. These chips use RFID technology to perform simple tasks normally performed by a fob, such as tapping a keycard for authentication, opening a garage, or storing up to 1000 bytes of memory.[122]

Brian McEvoy

McEvoy, an electronic engineer and biohacker, has designed an internal compass called the "Southpaw." The product functions "by sealing a miniature compass inside a silicon coat, within a rounded Titanium shell, to be implanted under the skin. An ultra-thin whisker juts out, which is activated when the user faces north, to lightly brush an alert on the underside of the skin."[123]

EU HIVE Program

European Union (EU) Future Emerging Technologies (FET) Open Hyper Interaction Viability Experiments (HIVE) sponsored researchers developed the first human-to-human, brain-to-brain interface in 2014. This demonstration allowed one researcher in India to send words into the brain of a researcher in France utilizing a brain-to-computer interface (BCI), internet connection, and computer-to-brain (CBI) interface. The BCI used an electroencephalogram (EEG) to read the sender's thoughts, which were then translated to binary code and transmitted via transcranial magnetic stimulation (TMS) to the recipient.[124] This method falls short of qualifying as a fully embedded technology but represents a breakthrough interim technology solution.

[122] http://www.popsci.com/my-boring-cyborg-implant
[123] http://www.cnn.com/2014/04/08/tech/forget-wearable-tech-embeddable-implants/
[124] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4138179/

Enabling Technologies

SOFTWARE

The Enabling Technologies included below are software/applications and network technologies that will support the evolution of user interface technologies towards Operational Objective Expand, but do not signify a new user interface capability on their own. Software/application technologies utilize the increased power of analytics, visualization and emergence of 'Big Data' to run programs on and between devices themselves. Enhanced user interfaces will largely present themselves visually through software/applications. Network technologies utilize new network architecture, band types, and physical infrastructure to provide a greater resiliency, lower latency, and improved quality of service. Enhanced user interfaces will largely rely on network technologies to connect devices/sensors to one another and other users on the network.

Data federation:

The shared and virtual workspace interface technology, specifically, will rely on public safety's adoption of a secure and federated data model. Data federation capabilities combine the security and autonomy of "siloed" data with the integration ability of a common storage model. In a federated structure, all data is "made accessible to data consumers as one integrated data store by using on-demand data integration."[125] Using this capability, public safety agencies will be able to rapidly collaborate in an emergency environment, sharing location, communication, and resource information while enabling individual agencies to maintain ownership of proprietary data. Federation software will need to integrate, transform, and provide access (using APIs) to segregated data within the application. Blockchain and/or tokenization security procedures may be used to support public safety data federation applications.

Transfer and continuity of tasks/communications:

A major enabler of expanding the range of a user interface is software technology that transfers live interfaces, tasks, and communications (e.g., phone calls) from one device to another as the user migrates between environments. A seamless handoff of tasks and interfaces between devices will allow a public safety official to answer a call in a station or at headquarters, transfer the call to speakerphone through a car's hardware en route, and continue the call on a ruggedized mobile device upon arrival at the

[125] http://www.b-eye-network.com/view/14815

operational environment. Apple devices use the "Handoff" feature to transfer tasks between Apple devices while Samsung has a similar application called "Flow." As the underlying technologies, these applications will function across hardware providers and networks.[126]

Accessibility enhancements:

With the development of accessibility features designed to reach users in strained physical environments, the public safety community will experience an expansion in the number and types of environments in which they can interact with user interfaces. These enhancements will likely follow enabling developments in both ruggedization and sensor technologies. These accessibility features will be designed to provide data and communications to users in smoky, noisy, dark, and/or chemically active environments. These devices will use sensors as well as gesture-recognition technology to trigger accessibility enhancements.

NETWORKS

Mini-mesh networks:

A critical capability for the operation of data and communication interfaces in an expanding range of public safety environments is the ability to create mini-mesh networks. The working group projects that the proliferation of devices/sensors "at the edge" will see the end of a reliance on the hub-and-spoke structure typical of WLANs in which each device connects to a central point for internet access. Mini-mesh networks instead connect devices/sensors to each other (multi-hop connectivity) rather than directly to a source router (single-hop connectivity). Multi-hop mesh networks deliver data more efficiently by finding the shortest available route to the router, delivered through the node on the network closest to the router. As outlined in NIST's *Research Roadmap for Smart Fire Fighting* report[127] , mesh networks portability is ideal for structural fires and while interconnecting mesh networks can be expensive for remote fires, the cost is expected to come down as development for public safety continues. As public safety continues to operate in a multi-network environment (LMR, commercial broadband, and eventually the FirstNet network), mini-mesh networks may provide a critical capability for public safety operations.

[126] https://www.wired.com/2014/06/apple-continuity/
[127] http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1191.pdf

Wearable network development:

Current wearable networking solutions rely on PANs, which provide short data ranges and low power consumption, ideal for many low data devices/sensors with long battery life.[128] Because AR, VR, and integrated smart suits rely on high-end applications with high-data rates, the working group projects that these interface systems will use wearable networks run through a hub device such as a smartphone. Projected improvements in mmWave frequency communications will allow the public safety community to utilize the "large bandwidth, good isolation, and better co-existence due to directional antennas" typical of mmWave networks.[129]

Network resiliency and self-optimization:

As public safety agencies continue to rapidly expand their use of devices/sensors, they will need to address how to integrate all of the data collected; this, in turn, will place a greater requirement on connectivity and network reliability. It will be critical that users are made aware of the "freshness" of the data they are receiving via dashboards and other tools. PSCR outlined a vision for the resiliency capabilities of future networks in the *Public Safety Analytics R&D Roadmap* report, stating that network equipment will use APIs to enable self-healing and self-monitoring of Software-Defined Networks (SDNs). "Software-Defined Networking is the physical separation of the network control plane from the forwarding plane, and where a control plan controls several devices… this architecture allows the network control to become directly programmable."[130] SDNs allow integration between the applications riding on top of a network and the underlying network infrastructure, allowing the network to self-configure in real time. These capabilities will allow public safety agencies to ensure optimal network operations in support of their communications requirements.

Bandwidth management and control:

One of the inherent challenges with expanding the range of environments in which public safety interfaces with data/communications is a variance in bandwidth as the user moves within and between networks. A key enabler of the expanded access to interfaces will be the ability of image/video/sound quality to adjust "on the fly" based on bandwidth availability and connection priority. The first responder may have some ability to "turn the knob," enhancing or degrading his or her connection based on need, but it is more likely that analytics will be used to determine connection priority based on a user's role, task, and environmental context, among other elements, and to allocate bandwidth to users in real time.

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[128] http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1191.pdf
[129] http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=7445132
[130] https://www.opennetworking.org/sdn-resources/sdn-definition

Expand Data/Communications Access: Public Safety R&D Opportunities

Given the technology capabilities, gaps and barriers, and current developments that are forecasted to impact the User Interface domain over the next 20 years, the working group identified several potential R&D efforts that would enable the expansion of data/communication access. Public safety R&D organizations should consider the following project areas as they prioritize upcoming investment opportunities:

Ruggedization Performance and Standards

- Determine specific ruggedization performance categories pertinent to public safety devices/sensors (e.g., dust protection, water protection, shock absorption).
- Define thresholds for mission-critical performance within each ruggedization category.
- Develop specific, repeatable, and verifiable test methodologies by which to measure ruggedization performance for each ruggedization category.
- Research physical materials or methods that could achieve ruggedization in alignment with form-factor equivalence (not adding weight or bulk); for example, aluminum is used currently to disperse shock but significantly adds to overall device weight.

Wearables Usability and Materials

- Develop lighter, pliable sensor-integrated clothing.
- Research usability and performance requirements for integrated clothing solutions, including ruggedization requirements specific to public safety.
- Develop modular devices/sensors that can integrate components with discrete functionality to compile task-specific smart suits, reducing extraneous weight when appropriate.
- Research the suitability of embedded devices/sensors for public safety and permissible thresholds of invasive device integration.

Operational Objective: Expand

BATTERY PERFORMANCE ENHANCEMENTS

- Engage with academia and the industry community on alternative battery materials and methods, including gold nanowire (University of California, Irvine[131]); aluminum graphite (Stanford University[132]); kirigami flexible structure (Arizona State University[133]); graphene (Graphenano[134]); and magnesium (Toyota Research Institute[135]).
- Research intrinsically flexible batteries impervious to cracking and degradation.

WEARABLE INTERFACE ALERTS AND IMPACTS ON COGNITIVE LOAD

- Conduct testing and evaluation of AR alert protocols and visual interface design for effects on cognitive load, attention, distraction, and other factors that may positively or negatively impact the utility of AR interfaces for public safety.
- Drive development of contextually aware AR devices including sensors to determine environmental factors and current suitability for alerts.
- Create symbology, a style guide, and a language taxonomy for public safety AR displays based on usability studies and cognitive impact analyses.
- Study biological metrics and sensor types to determine public-safety-pertinent data types derived from wearable technology, including both data for live alerting and post-operational analysis.
- Research AR data/communications impacts on team dynamics and coordination, including the impact of personalized analytic products on the ability for a team to share a common situational awareness.
- Research the impacts of a self-adjusting smart suit on public safety operations and the potential thresholds and protocols at which the smart suit will govern adjustments to the user's protective layer (e.g., automatically triggered heating or cooling).

[131] http://www.pocket-lint.com/news/137387-nanowire-battery-can-extend-your-phone-battery-life-by-hundreds-of-thousands-of-times
[132] https://www.sciencedaily.com/releases/2016/04/160405175659.htm
[133] https://www.element14.com/community/groups/power-management/blog/2015/10/23/japanese-art-of-kirigami-makes-this-battery-stretchable-and-flexible
[134] https://futurism.com/scientists-develop-better-battery-thanks-graphene/
[135] http://www.pocket-lint.com/news/137556-toyota-cracks-magnesium-batteries-for-longer-lasting-smaller-devices

Operational Objective: Expand

NETWORKS AND SENSOR INTEGRATION

- Make advancements in PAN abilities to overcome interference and increase bandwidth capacity to support smart suit and wearable devices/sensors.
- Research the potential for wearable and smart suit device/sensor communications through mmWave networking; specifically mmWave networks potential to mitigate interference and handle the overlap of neighboring users' networks.[136]
- Research the ability to transfer software tasks and cellular communications between networks and network types to allow for continuity of service as a user travels between LTE, local, Wi-Fi, and mesh networks.
- Develop a capability for all networks to sense and adjust bandwidth across connected devices/sensors based on task requirement and user priority.
- Research ability for unmanned aerial vehicles to provide wireless network coverage in remote areas lacking network infrastructure.

DATA SHARING, ARCHITECTURE, AND INTEROPERABILITY

- Drive the development of interoperable wearable devices/sensors between manufacturers to enable compatibility between devices/sensors, body-worn processing/analytic hubs, and helmet/AR screen interfaces through the development of standards and public safety specifications.
- Develop interagency data architecture and formatting standards for mobile devices/sensors to allow for rapid data integration and analysis in shared, collaborative workspaces.
- Develop middleware to support interagency data transfer from devices/sensors, smart suits, and other wearable technologies.
- Develop Wi-Fi technologies and other WLAN solutions that support the rapid development of interagency shared networks.
- Research tokenization, blockchain, and associated security/authentication techniques for linked devices/sensors and interagency operations.

[136] http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=7445132

Operational Objective: Expand

OTHER

- Drive the development of computer processing power and system architecture (relationship between CPUs and GPUs) to support the rendering of realistic virtual elements through AR interfaces.
- Engage the military community and academia on projects to understand and decode message streams within the human brain to enable direct communications through embedded devices.

Expand Data/Communications Access: Overall Gaps and Developments

Capability	Gaps	Developments
RUGGEDIZED DEVICES/SENSORS	• Ruggedization modifications inhibit some device functionality • Devices not equipped with intrinsically-safe protective qualities • Devices not developed to anti-explosive requirements • Test methodologies for military ruggedization standards are not centrally certified and may yield unreliable results • Battery technology limits performance of ruggedized devices • Device component pieces require ruggedization including standards and testing • Ruggedization improvements add weight and detract from usability • Public safety specific ruggedization performance requirements are not defined	**Ruggedized mobile devices** ➢ Sonim, XP7 ruggedized mobile device, ➢ CAT Phones, S60 GSM Smartphone **Explosion proof, ruggedized cameras** ➢ Spectrum Camera Solutions, D200 cameras
WEARABLES AND DEVICES/SENSORS IN CLOTHING	• Limited battery power for wearable devices/sensors inhibits usability and dependability • Commonly used in device/sensor batteries, lithium-ion material is highly reactive and requires protective casing to be suitable for use in device/sensor • Wearable devices/sensors are limited by rigid batteries that inhibit ability to move with the user's physiology • Lack of developments in intrinsically flexible battery materials • Devices/sensors require overall usability testing to determine suitability for public safety operations • Wearable devices from different manufacturers may not be interoperable and will not share data	**Flexible battery technology** ➢ Imprint energy[137] ➢ Samsung[138] **Electromyography sensors in clothing** ➢ Athos[139] **Wearable devices for industrial worksite** ➢ Human Condition Safety[140]
AUGMENTED REALITY INTERFACES	• Inability to understand what others are seeing can lead to miscommunication and misunderstanding between individuals, possibly caused by erroneous assumptions that the other can see the same information • Customized settings for AR alerts and visual interfaces may prevent agencies from switching devices between users • Chip design and technology doesn't provide sufficient bandwidth, processing power, and rendering resolution required for life-like AR environments • Sensors embedded within AR devices do not capture user and environmental input with sufficient resolution • AR platforms do not feature strong real-time spatial awareness to alert the user of potential hazards	**AR headsets** ➢ Microsoft HoloLens[141] **Gesture recognition in AR** ➢ Leap Motion[142] **Haptic interaction in AR** ➢ Ultrahaptics[143] **Thermal imaging in AR** ➢ BAE Systems[144]

[137] https://www.technologyreview.com/s/528996/flexible-printed-batteries-for-wearable-devices/
[138] http://www.wearabletechnology-news.com/news/2015/oct/26/samsung-lg-hope-solve-wearable-battery-issues-new-designs/
[139] https://www.liveathos.com/
[140] http://www.insurancejournal.com/news/national/2016/01/06/394158.htm
[141] https://www.microsoft.com/microsoft-hololens/en-us
[142] https://www.leapmotion.com/about-us
[143] http://www.ultrahaptics.com/
[144] http://www.lowellsun.com/news/ci_28763768/power-see-heat

	• AR alerts are not contextually aware of user's surroundings, current cognitive load, or task requirements and may be distracting	
SMART SUIT INTERFACES AND COOPERATIVE DEVICES/SENSORS	• Combined weight of the sensors, components and interfaces that make-up suit is too heavy for common use in operations • Usability issues with overload of restricting on-person/belt devices/sensors • Touch/sensory screens to control smart suit are not built for use with gloves • Lack of integration between devices/sensors to align timestamps and enable common frame of reference for data • Lack of interoperability between devices/sensors manufacturers • Lack of interoperability standards to enable body worn device/sensor data integration and synchronization • Inability to provide and manage bandwidth for increased data flow associated with personal area networks and associated 'wearables' requirements • Current batteries may only power smart suits for 12-15 hours and are not reliable for multi-shift, multi-user operations • User interface applications in smart suit technology may cause interference and latency in other mission critical services such as Mission Critical PTT • Processing speed of smart suit data integration hubs are not improved enough to support real-time integration and analytics • Lack of public safety data architecture and formatting to make semantic sense of the data exchanged between systems • PANs used to host and connect body-worn devices/sensors do not support high data transfer rates and are unsuitable for video and other large data types • mmWave technology under development for networked device/sensor use may cause radiation when close to the body and is susceptible to transmission interference	**Military smart suit** ➢ DARPA, TALOS[145] ➢ Gentex Corporation[146] ➢ Revision Military, Ltd.[147] **Heads-up display for public safety** ➢ Umeå Fire Brigade, C-Thru helmet[148]
SHARED AND VIRTUAL WORKSPACE INTERFACES	• Lack of public safety data architecture and formatting to allow for easy data sharing between agencies • Lack of advanced data integration middleware to support sharing and compatibility between public safety agencies • Lacking or unreliable cellular data coverage in some areas prevents rapid development of peer-to-peer networks • Limited range in Wi-Fi technologies prevents rapid development of peer-to-peer networks • Wireless mesh networks are expensive and difficult to set up on short notice in remote environments, preventing their advantages from being fully realized in public safety data sharing	**Military mobile collaboration applications** ➢ DARPA, Fire Line Advanced Situational Awareness for Handhelds (FLASH) system[149] ➢ Raytheon, One Force Mobile Collaboration[150]

[145] https://www.defense.gov/News/Article/Article/604009
[146] http://www.gentexcorp.com/shopaviationhelmets
[147] https://www.revisionmilitary.com/product/batlskin-viper/
[148] https://www.firerescue1.com/fire-products/personal-protective-equipment-ppe/helmets/articles/1315543-Futuristic-new-helmet-helps-firefighters-see-through-smoke/
[149] http://www.govtech.com/em/disaster/Military-Technology-Could-Save-Firefighters-Lives.html
[150] http://www.govtech.com/em/disaster/Military-Technology-Could-Save-Firefighters-Lives.html

Operational Objective: Expand

PHYSICALLY EMBEDDED DEVICES/SENSORS	• Current embedded devices/sensors are exceedingly invasive and do not support the degree of temporality required for public safety's adoption of embedded technology • Lack of ability to decode and decipher monitored electrical activity within the human brain	**Near-field communication embedded chips research** ➢ Amal Graafstra[151] **Embedded compass research** ➢ Brian McEvoy[152] **Brain-to-computer interface technology research** ➢ EU HIVE Program[153]
DATA FEDERATION	• Lack of software to allow on-demand sharing of partitioned data between authenticated devices • Lack of blockchain and/or tokenization security procedures to rapidly verify and connect devices/sensors • Lack of information sharing or open data standards between public safety agencies	**Blockchain security** ➢ R3CEV[154] **Data federation** ➢ United States Data Federation[155]
TRANSFER AND CONTINUITY OF TASKS/COMMUNICATIONS	• Task transfer is limited to devices made by same hardware provider • Need a capability to manage user activity and cloud storage synchronization based on user identity/profile rather than proprietary device manufacturer software • Task transfer devices must currently be on the same WiFi network • Task transfer does not exist with ruggedized devices	**Proprietary continuity applications** ➢ Apple Handoff ➢ Samsung Flow
MINI-MESH NETWORKS	• Networks are expensive and difficult to stand-up quickly in remote environments • Lack of mechanism to secure public safety data on mesh network and establish priority access	**Military and public safety focused mesh networks** ➢ Mesh Dynamics[156]
WEARABLE NETWORK DEVELOPMENT	• PANs used to host and connect body-worn devices/sensors do not support high data transfer rates and are unsuitable for video and other large data types • mmWave technology under development for networked device/sensor use may cause radiation when close to the body and is susceptible to transmission interference	**mmWave research** ➢ University of Texas Austin[157]
NETWORK RESILIENCY	• Lack of APIs to monitor and heal network infrastructure • Lack of integration between network applications and underlying network infrastructure • Lack of Software-Defined Networking architecture for device-to-device communications	**Self-organizing networks** ➢ Reverb InteliSON **Software-Defined Networking** ➢ Open Networking Foundation[158]

[151] http://www.popsci.com/my-boring-cyborg-implant
[152] http://www.cnn.com/2014/04/08/tech/forget-wearable-tech-embeddable-implants/
[153] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4138179/
[154] http://uk.reuters.com/article/uk-banking-trading-blockchain-idUKKCN0UY28W
[155] https://www.gsa.gov/portal/content/150542
[156] http://meshdynamics.com/military-mesh-networks.html
[157] http://www.profheath.org/
[158] https://www.opennetworking.org/about/onf-overview

Operational Objective: Expand

BANDWIDTH MANAGEMENT AND CONTROL	• Lack of integration between network applications and underlying network infrastructure • Networks and bandwidth management tools do not support ability to customize bandwidth	**Bandwidth prioritization** ➢ Cisco IronPort Web Security[159]

[159] http://www.edtechmagazine.com/k12/article/2014/03/schools-turn-bandwidth-management-handle-surge-mobile-demand

Operational Objective: Expand

Capabilities Development Timeline

Capability	Short - term (0 - 5 years)	Medium - term (5 - 10 years)	Long - term (10 - 20+ years)
Ruggedized data and communications interfaces	Initial analysis of ruggedization requirements across different public safety operating environments Manufacturers produce public safety broadband devices with a variety of ruggedization capabilities	Codification of an official set of public safety ruggedization standards and accompanying testing methodologies Manufacturers produce public safety broadband devices to address specific ruggedization operational requirements, standardized across manufacturers	
Wearables and device / sensor integration into clothing	Early adopters incorporate single function wearable devices/sensors into public safety uniforms Alternative battery materials demonstrated for use in wearables	Multiple wearable devices/sensors become fully integrated into public safety uniforms and PPE Battery technology allows for lightweight, flexible wearable devices with multi-day power capacity	Clothing, uniforms, and PPE become devices/sensors themselves
Augmented Reality	Limited use of thermal imaging and message alerts in AR headsets Standardization of icons, visual interface, and alert protocols	AR headsets, alerts, and communications data layers become commonplace	Full AR capability including spatial/contextual awareness and haptic feedback
Smart Suit	Heads-up displays in public safety visors and SCBA Mesh-networking solutions support data transfer amongst network of wearable devices/sensors	On-body device/sensor data is integrated as holistic system and presented to user through visual interface	Public safety uniform is holistic technology system monitoring and adjusting user's conditions based on contextual awareness
Shared Virtual Workspace	Data formatting and architecture development and standardization	Rapid authentication and integration of device data based on common formatting and security protocols Resilient peer-to-peer networking capabilities developed in remote locations 'on-the-fly'	
Wearable technology embedding into user	Low-power, single function sensors embedded under skin (biohacking)	Embedded sensors track gestures and eye-motion and inform analytic models and smart alerts Brain mapping and modelling deciphers simple meaning from specific brain activity	Brain-to-computer interfaces allow silent and subconscious messaging as thoughts are converted to commands Holistic understanding and mapping of brain allows for automated decoding of complete brain functionality

Operational Objective – Evolve Human-Machine Interaction Paradigm

Reduce risk to personnel and property through virtual/remote operation

A third objective that public safety should look to achieve through the adoption of innovative user interface technology is to **evolve the way in which public safety users interact with machines/computers.** This objective will examine the ability of new user interfaces to allow for **virtually conducted public safety operations, training, and testing typically conducted by first responders or in public safety controlled physical locations**. The objective may be achieved by using a combination of VR visuals, remote devices/sensors, and simulated environments to accomplish tasks from the remote environment, greatly reducing the risk for loss of life and damage to property.

This objective can be accomplished by adopting some of the most forward-looking user interface technology capabilities forecasted by the User Interface Working Group. At the core of these interface forecasts is the ability for humans to aid machines/computers in simulating/conducting public safety tasks rather than vice versa. As interface technologies develop in their ability to communicate the tactile sensations of reality through a virtualized or computerized interface, public safety will be able to strategically integrate automated capabilities with operational tasks.

Enabled Operational Impacts:

The User Interface Working Group identified primary operational impacts that will benefit from R&D focused on user interface technology for public safety. The operational functions that stand to benefit the most R&D towards the 'Evolve' objective include:

- **Reduction of loss of life** – By removing first responders from the riskiest and most dangerous operating scenarios and conducting remotely controlled operations in their stead, the public safety community will greatly reduce staff exposure to injury and loss of life.
- **Fully trained response staff** – Using virtualized scenarios and VR headsets, the public safety community will be able to repeatedly train response staff for a wide range of response scenarios and agency protocols without the requirement of constructing the scenario in the physical domain.

Technology Capabilities

User interface technologies that accomplish aspects of this objective have and will continue to develop on the market over the projected innovation timeline. Rather than look at discrete offerings, the working group forecast the core capabilities that will be enabled by these interfaces, including VR systems to train public safety officials and test equipment in a range of simulated environments, reducing demands on testing infrastructure; remote operations conducted through rich device/sensor data and VR control from the safety of a remote command center; and co-participation in tasks with machines and computers through developments in HMI technology.

1: Virtual reality systems

VR devices and the accompanying software—often referred to as "VR experiences"—have been one of the liveliest areas in recent consumer technology innovation. The technology's projected application to the public safety environment will evolve the basic nature of interaction not only between human and computer but also between public safety officials and the physical response environment. VR systems will be used to train public safety and conduct controlled equipment and interface testing. The ability to completely virtualize the operational environment from the safety of a controlled, indoor location will reduce risk to the lives of first responders, costs of training staff, and difficulty in testing equipment for operational suitability.

VR systems use a headset-mounted screen display and accompanying headphones which, when worn by a user, blanket the field of vision and immerse the senses with VR images and sounds. Through the display, the user assumes a 360-degree virtual perspective. In a virtual living room, for example, the user would physically look around with their head and see a virtual ceiling above them, floor below them; they may even turn around to find a couch behind them. The user's experience can be generated through graphics software (much like a video game) or captured from the real world using a 3D camera.

A full VR system consists of a series of components. The headset, as mentioned, straps around the user's head and blocks out the peripheral world. The headset holds a screen, which can be built in or provided via a mounted device such as a smartphone. Also in the headset is a motherboard including LED screen chips, a magnetometer, gyroscope, and accelerometer. Headphones are typically mounted on the headset straps, and a positional tracker is used to track the user's physical movements/location in 3D space. Controllers, which are handheld by the user, are generic items in the real world but may represent a range of objects in the virtual world (e.g., gun, axe, bottle). Finally, software, which is used to generate the virtualization, runs on the computer connected to the headset via a cable.[160]

When developed and applied specifically for the public safety domain, VR will have a range of applications. The working group forecasts that VR will be used in public safety training or police academies to familiarize new members of the community with the types of environments they will experience in the field. By simulating in a controlled environment a shoot/don't-shoot scenario, a

[160] https://www.wareable.com/oculus-rift/how-oculus-rift-works

violent protest, or a growing fire, public safety will enter the field with practice executing protocol in high-stress environments with almost zero exposure to risks typically associated with public safety training.

In addition to training, VR technologies will be used to reduce costs and difficulties associated with testing equipment and communications interfaces. Currently, public safety testing is either done in a laboratory, where operating conditions are nearly impossible to simulate, or in a physically simulated environment, which is expensive to construct and does not lend itself to controlled, repeatable testing conditions. With VR, public safety will use a range of simulated test bed environments to conduct usability testing on emerging interfaces, or audio connectivity performance with controlled interference. VR will also be utilized for the remote conduction of public safety operational tasks, greatly reducing the risk for loss of life, as discussed in in the next capability section.

Technology Gaps and Barriers

Size and complexity of VR video	VR experiences are captured using high-tech, 360-degree cameras or expensive camera add-ons. The complexity of the capture methodology means that VR files may be as much as 200 MB for a one-minute video, thus presenting challenges for file storage and video rendering/processing time.
Wireless video streaming limitations	Due to the file size and density of VR software files, high-end headsets rely on HDMI and USB cable connectivity to a computer to provide a signal without significant degradation. The cable reduces the mobility of the VR user, decreasing the vividness and range of the virtualization.
Expensive hardware requirements	High-end VR devices retail currently for $500 to $700 but also require a supporting computer with high-end graphics chips (NVIDIA GTX 970 or an AMD R9 390), significant storage, and the processing ability to run VR software.[161]
Lack of a public-safety-specific test bed	The public safety community requires the development of purpose-specific VR experiences that can be used to train and test public safety personnel. This environment will include narrative experiences as dictated by training requirements in addition to common hazards such as fire, smoke, noise, and potential threats. VR environments are currently single-device compatible, so interoperability and standardization will be important considerations in software development.

[161] http://thenextweb.com/insider/2016/05/20/hurdles-virtual-reality-mainstream/

Current Developments

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage VR systems. Given the breadth of commercial, academic, and government activities relating to VR systems, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the VR systems domain.

HTC

The HTC VIVE was considered the most advanced VR system on the market when it debuted in 2016. The key breakthrough of the VIVE was the ability to walk around a physical room and interact with objects in the virtual world. The headset includes a front-facing camera to alert the user if they are near a hazard, and two handheld controllers are used to simulate tactile function in the virtual environment.

Oculus

The Oculus Rift headset was one of the first truly high-end VR headsets developed for commercial use. Now owned by Facebook, Oculus sells the premium Rift as well as Oculus Touch controllers and is supported by one of the widest swaths of compatible VR experiences.

Duke immersive Virtual Environment (DiVE)

DiVE is a physical testing and research platform focusing on developing greater understanding of the human interaction with the virtual environment. Unlike a VR headset, the DiVE is a 3m x 3m x 3m cube, which has been used to study the effects of the virtual environment on emotions, training ability, navigation techniques, and many other topics.[162]

ImmersiveTouch:

While not integrated with a VR headset, ImmersiveTouch has developed software for the healthcare industry that simulates a 3D scan of a patient. The software adds haptic feedback to the 3D model so that a surgeon can rehearse the specific surgery he or she will perform and find a minimally invasive path with little risk to the patient.[163]

[162] http://virtualreality.duke.edu/about/
[163] http://www.immersivetouch.com/technology_and_services_feel.html

2: Remote operation of unmanned ground and aerial vehicles

Major reductions in risk to the lives of first responders will be achieved through an evolution in the user interface paradigm, allowing virtualized public safety operations to be conducted from remote locations. Remote operations can be thought of as a separation between the human operator and the physical execution of public safety tasks where control is maintained via a virtualized interface.

For example, a remote operator will fly a thermal camera-equipped unmanned aerial vehicle (UAV)—aka, a drone—over a burning or compromised building, streaming live video and providing situational awareness back to the command center, saving valuable resources in the process by eliminating the need for a costly helicopter flight. The remote operator will rely on VR goggles or a combination of screen interfaces and sensor readings to operate the device when completely remote from the drone's physical location. Once a response scene is surveyed by a drone, a remote operator will deploy unmanned vehicles and/or robots to buttress a compromised structure, clear obstacles, or even conduct rescue, all without putting a first responder in physical danger. Much like a surgeon is able to conduct surgeries remotely, robotic capabilities on scene will become refined enough to facilitate fine motor skills such as turning knobs or configuring electronic wiring. Initial applications for remote operations are going to be seen in hazardous materials environments, bomb/explosive diffusion, forest fires, and other high-risk, specialty response situations.

As referenced, the working group envisions high-tech command and control "nerve centers" from which remote operators will initiate and direct remote response. These command and control centers will act as information hubs, presenting officials with the most complete situational awareness available and ensuring that remote operations are conducted in a safe, collaborative manner. Depending on specific network and/or device requirements, these command and control centers may be augmented by mobile command and control units from which remote operations are conducted in certain localities.

Technology Gaps and Barriers

Off-site command and control infrastructure	Remote operation of devices through virtual interfaces requires an advanced command and control center to host the remote operator, support the virtual interface, and serve as the up and downlink for signals between the device and the operator. A remote command center will require a range of VR goggles, tablets, and data displays to manage a fleet of robotic responders, and it may need to be augmented by a mobile command center to operate the remote fleet in certain environments.

Operational Objective: Evolve

Reliability of drone connectivity and performance beyond line of sight

Current Federal Aviation Administration (FAA) rules governing UAVs prohibit flight beyond the operator's line of sight. UAV capability must demonstrate the ability to manage network interference, maintain quality of service, and handle the handoff between networks before the technology can be used for public safety remote operations.[164]

End-to-end latency requirement for drone and robot control

For a drone or robotic device to be deemed fit for remote use in the operational environment it must demonstrate very low latency, or lag time, between the operator's action and the device movement. 3rd Generation Partnership Project (3GPP) specification 22.282 defines specific latency requirements for drone/robotic control as:

- 50 milliseconds (ms) for a UAV
- 200 ms for an aquatic or submarine vehicle
- 400 ms for a terrestrial robot[165]

End-to-end latency requirement for video camera controls

There are also stringent requirements for the responsiveness of a drone-mounted camera. Maximum allowable latency between the operator's action and the camera functions is defined in 3GPP specification 22.281 as follows:

- 100 ms during take-off and landing of a UAV
- 300 ms when flying a UAV
- 400 ms for a terrestrial unmanned vehicle moving less than 120 km/h[166]

End-to-end latency requirement for video delivery to receiving device

Drones or other unmanned robotics transmitting live video streams are subject to maximum latency requirements as well. It is important to note that video delivery requirements are more stringent for streams used by a remote pilot to control the device, meaning that "fly-by-sight" devices may be a cheaper interim solution to provide users with an overhead view of a scene. Requirements for video delivery from a transmitting drone to an operator are defined in 3GPP specification 22.281:

[164] http://gpsworld.com/qualcomm-att-to-trial-network-requirements-for-drone-operations/
[165] http://www.3gpp.org/ftp/specs/archive/22_series/22.282/
[166] http://www.3gpp.org/ftp/specs/archive/22_series/22.282/

- 500 ms when video is used by the pilot to operate the device
- 1 second (s) for high-priority/emergency video
- 10 s for normal video[167]

Extremely high degree of customization in robotics

Current robotics devices with capabilities suited for public safety response tasks contain extremely complex hardware and software components. From a hardware perspective, most robots are "built by hand for a specific purpose"[168] rather than mass produced; from a software perspective, today's robotic devices require programming specific to their owner/agency and operational environment. For a robot to integrate with the range of supporting technologies in a given agency, they may require "a team that understands electronics, circuits and wiring" as well as "software developers that understand firmware, people who are experts in machine vision, machine learning, security, wireless networking."[169]

Current Developments

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage remote operation of unmanned ground and aerial vehicles. Given the breadth of commercial, academic, and government activities relating to remote operation of unmanned ground and aerial vehicles, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the UAV domain.

Smart Emergency Response System (SERS):

The SERS project is a collaboration between nine organizations that focuses on minimizing risk and reducing response time for search and rescue operations through an integrated suite of "human first responders, heterogeneous ground and aerial autonomous vehicles, human-operated telerobots, and trained search and rescue dogs."[170] The system is centralized at a control center that processes help requests through a mobile application; these help requests are then combined with "surveillance data from multiple sensors attached to drones and rescue-dog suites as well as from first responders and other sources."[171] A key element of the SERS

[167] http://www.3gpp.org/ftp/specs/archive/22_series/22.282/
[168] http://www.robolliance.com/
[169] http://www.roboticstrends.com/article/4_challenges_holding_back_robotics/P2
[170] http://www.statetechmagazine.com/article/2014/06/are-drones-and-robots-future-public-safety
[171] http://www.statetechmagazine.com/article/2014/06/are-drones-and-robots-future-public-safety

system is the Boston Dynamics Atlas robot, a 6-foot 2-inch robot weighing 330 pounds that provides remotely operated physical response. A complete inventory of SERS system elements is found on the program's website[172] and includes:

- Hardware[173]
  - Drones mounted with routers and antennas for a Wi-Fi network
  - Dogs equipped with sensors and gas detectors
  - Mobile robotic arm for field activities
  - Haptic devices for remote operation
  - Atlas robot
  - Fleet of drones and unmanned ground vehicles
- Software
  - "Simulink to Google Earth interface for visualization of the simulated field operations"[174]
  - A component for the video stream analysis of the cameras placed on the drones to perform real-time face detection of the survivors in the field
  - Wearable computing for observing and manipulating certain elements of SERS"[175]

Michigan State Police (MSP)

MSP used a federal grant to purchase an Aeryon SkyRanger drone to support public safety missions, including "search and rescue, crime scene and crash investigations."[176] MSP worked with the Federal Aviation Administration on safety requirements and received approval to conduct training flights at the MSP training facility. An MSP-developed policy mandates that the drone is flown by a two-person crew, operates below 400 feet, and is within line of sight of the pilot. "The pilot operates the drone with a tablet that uses global positioning system that includes programmable variables, such as boundaries set by altitude and longitude. When the pilot touches the tablet with a stylus the drone will hover over that spot identified on the tablet."[177]

[172] http://smartamerica.org/wp-content/uploads/2014/05/SERS_FactualBlog.pdf
[173] http://smartamerica.org/wp-content/uploads/2014/05/SERS_FactualBlog.pdf
[174] http://smartamerica.org/wp-content/uploads/2014/05/SERS_FactualBlog.pdf
[175] http://smartamerica.org/wp-content/uploads/2014/05/SERS_FactualBlog.pdf
[176] http://www.michigan.gov/msp/0,4643,7-123-72297_60152_62783-346390--,00.html
[177] http://www.freep.com/story/news/local/michigan/2015/03/12/michigan-state-police-drone/70214866/

Operational Objective: Evolve

Department of Defense

The Department of Defense has developed Deployable Joint Command and Control (DJC2)—an integrated command and control headquarters system that enables a commander to set up a self-contained, self-powered, computer-network-enabled temporary headquarters facility anywhere in the world within 6 to 24 hours of arrival at a location.

Motorola Solutions

Motorola has demonstrated a proof of concept for a virtual command center built upon technology from Eyefluence, an acquired start-up technology, and the proprietary CommandCentral platform. Eyefluence uses eye-tracking and interaction to communicate virtually while CommandCentral aggregates and presents real-time intelligence/data to a remote command and control center.[178]

Qualcomm Technologies, Inc.

Qualcomm tested their Snapdragon Flight drone project on commercial 4G LTE networks in a joint trial with AT&T, after receiving a certification of authorization from the FAA. The aim of the trial was to conduct research on "connectivity technologies for small unmanned aircraft systems (SUAS), including optimization of LTE networks and advancement of 5G technology for drones."[179] The trial is part of a larger Qualcomm effort to optimize LTE networks for autonomous drone flight, which includes focuses on interference management, handover optimization, and drone-specific requirements for LTE connectivity.[180]

European Commission

The European Commission Directorate-General for Enterprise and Industry spent 17.5M€ to fund ICARUS, a project that "aims to develop robotic tools which can assist 'human' crisis intervention teams."[181] The research focuses specifically on deploying unmanned search and rescue devices to provide response management command units with situational awareness in both urban and maritime search and rescue.

Sharp

Sharp is developing the INTELLOS Automated Unmanned Ground Vehicle (A-UGV) to provide public safety and security organizations with a robotic security function with both autonomous and remote-operated navigational modes. The INTELLOS robot will carry cameras, chemical and gas sensors, sirens, two-way

[178] http://www.officer.com/press_release/12246613/motorola-solutions-envisions-virtual-reality-transforming-public-safety
[179] http://www.fiercewireless.com/sponsored/qualcomm-working-to-accelerate-wide-scale-deployment-drones
[180] http://www.fiercewireless.com/sponsored/qualcomm-working-to-accelerate-wide-scale-deployment-drones
[181] http://www.fp7-icarus.eu/project-overview

megaphones, and a telescoping boom arm, all within a ruggedized design. The product is still in testing and trial mode as of late 2016.[182]

3D Robotics

3D Robotics pairs its "Solo" drone product and "Site Scan" application in a public-safety-specific offering. The offering is extremely high resolution (0.5 in/pixel at 200 feet), can fly and survey a specified site on its own, and creates maps and 3D models through the application interface.[183]

[182] http://www.roboticstrends.com/article/intellos_a_ugv_security_robot_provides_24_7_surveillance
[183] https://3dr.com/enterprise/industries/public-safety/

3: Human-machine interaction and co-participation

One of the long-term developments in the user interface domain will be the ability for first responders to interact directly with machines (e.g., robots), both presenting and receiving data and communications in the same manner as they would with a human. For public safety, this means that machines will become co-participants in tasks alongside responders, able to interact in a conversational manner. While elements of HMI are prevalent in both data presentation interfaces (e.g. AR, Smart Alerts) and remote operation interfaces (e.g., controlling and directing machines from afar), these interfaces are largely either give (i.e., human directs the machine) or take (i.e., machine informs the human). Advanced HMI capabilities will allow for true co-participation where machines are able to process subtleties (e.g., context, mood, tone, uncertainty) and react in real time: simultaneous give and take.

HMI and co-participation will give public safety mechanized support in the operational environment for dangerous and difficult tasks as well as provide an analytics-informed information resource. For example, machine agents will be capable of learning both repetitive behaviors and patterns, as well as responding to human variability (e.g., noticing meaningful deviations from plans).

Primitive forms of forecasted co-participation can be seen in collaborative robots or "cobots," used today in manufacturing alongside human workers. Today's cobots show a glimpse of a future in which robots will use advancements in HMI technology (e.g., sensors, vision, computing power) to accomplish increasingly complex tasks. The most advanced HMI technology will use direct brain-to-computer communication, where precise measurements of brain activity are decoded and communicated directly to the machine, "essentially creat[ing] a symbiotic relationship between technology and the brain."[184]

Technology Gaps & Barriers

Safety and governance

A major risk in introducing HMI and co-participation to the public safety environment is the potential for a machine to cause harm to its human co-participants or public citizens. Current safety standards are outlined in ISO 10218-1, which governs collaborative operation (defined as the "state in which purposely designed robots work in direct cooperation with a human within a defined workspace").[185] Cobots must include one of the four safety features outlined in the guidance: safety-rated monitored stop; hand guiding; speed and separation monitoring; and power and force limiting. Public safety will need a unique set of

[184] http://www.theatlantic.com/technology/archive/2016/07/what-comes-after-keyboards/490511/
[185] http://www.digikey.com/en/articles/techzone/2016/aug/rise-of-the-cobots-inspires-safety-innovation

safety and governance technologies that account for the complex tasks machines may be asked to accomplish.

Sensors and dependability

Co-participant machines will require a suite of integrated sensors (e.g., range, proximity, touch, vision, sound, temperature) to process their environment and inform their actions. Dependability of the machine will depend on the arrangement and integration of the sensor system as well as the reliability of individual sensors.[186]

Multi-modal perception and processing

While technology exists, and will continue to develop for each type of sensor to be used on an HMI machine (e.g., range, proximity, touch, vision, sound, temperature), technology to integrate sensor data and make connections between "visual and linguistic data and combining them toward improved sensing and expression" is a major challenge in HMI.[187] Doing this integration and analysis with a low enough latency for human interaction represents an additional challenge.

Spatial modeling and anticipatory perception

In advanced HMIs, machines will need to locate their human co-participants and other humans as well as differentiate between the two. This will require vision sensors to feed advanced models of the human form and movement patterns so that the machine can anticipate motion and properly adjust its posture.[188]

Brain measurement and mapping

Direct brain-to-computer communication will require huge advancements in humans' ability to detect and decode brain activity. While research exists proving the ability to derive meaning from brain activity alone, the capability (called "brain-hacking") is simple and limited by humans' ability to translate activity to meaning. Additionally, current sensors that precisely measure brain activity are still massively invasive and are not suitable to facilitate HMI.[189]

Human-to-machine middleware

While direct brain-to-computer communications are still evolving, interim HMIs will rely on sophisticated middleware to process sensor information, derive meaning, select action, and govern response, all in real

[186] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.905.3104&rep=rep1&type=pdf
[187] http://robotics.usc.edu/publications/media/uploads/pubs/585.pdf
[188] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.905.3104&rep=rep1&type=pdf
[189] http://www.theatlantic.com/technology/archive/2016/07/what-comes-after-keyboards/490511/

time. Middleware will likely be specific to the use case, requiring particular software for public safety and associated proprietary protocols.

Current Developments

This section is not intended to serve as an exhaustive review of all current developments related to public safety's ability to leverage human-machine interaction. Given the breadth of commercial, academic, and government activities relating to human-machine interaction, continued market research will be necessary to ensure awareness for PSCR of current efforts and account for new actors in the human-machine interaction and co-participation domain.

Honda ASIMO

Honda's ASIMO project has developed a "humanoid" robot designed to perform tasks in indoor environments and operate alongside human co-participants. The robot has a visual-auditory system and contains subsystems "for perception, planning, and action with the goal of enabling human-robot interaction."[190] Current ASIMO technology can recognize pre-programmed faces and respond to hand gestures.[191]

National Center for Adaptive Neurotechnologies

A research team led by Gerwin Schalk was able to use electrocorticography (ECoG) to prove a concept for brain-to-text communications. The research worked with epileptic patients with ECoG grids and recorded neural data as the subjects dictated sections of text. The experiment was successful in converting the neural data into speech using predictive language, and the results "bore more than a passing resemblance" to the spoken text, proving the relationship correlation.[192]

Kuka Robot Group

The German company and one of the "big four" industrial robot producers has produced the LBR iiwa cobot product. The product complies with ISO 120218 and can adjust to changes in conditions in real time, monitoring the zone between machine and human. The product has been used to perform more than 500,000 transmissions in the Daimler transmission plant.[193]

[190] http://robotics.usc.edu/publications/media/uploads/pubs/585.pdf
[191] http://asimo.honda.com/inside-asimo/
[192] https://www.wired.com/2016/01/phil-kennedy-mind-control-computer/
[193] http://spectrum.ieee.org/automaton/robotics/industrial-robots/collaborative-robots-innovation-growth-driver

Enabling Technologies

SOFTWARE

The Enabling Technologies included below are software/applications and network technologies that will support the evolution of user interface technologies towards Operational Objective Evolve, but do not signify a new user interface capability on their own. Software/application technologies utilize the increased power of analytics, visualization and emergence of 'Big Data' to run programs on and between devices themselves. Enhanced user interfaces will largely present themselves visually through software/applications. Network technologies utilize new network architecture, band types, and physical infrastructure to provide a greater resiliency, lower latency, and improved quality of service. Enhanced user interfaces will largely rely on network technologies to connect devices/sensors to one another and other users on the network.

Rapid data linkage/data analysis tools:

Remotely conducted operations rely on devices/sensors to collect data from the operational environment, rather than humans. Because of this reliance, the success of remotely conducted operations is dependent on the quality of and insights gained from devices/sensors used, and will require robust analytic tools at command to inform the remote operator. Data flowing into the command center will contain biometric data from operators on-scene, thermal imagery, video streams, weather/environmental conditions, etc. The remote operator will rely on data-linkage middleware tools, machine-learning and algorithms that support semantic analysis and pattern recognition to direct responses. For example, analytics will detect an elevated heart rate (biometric data), an increasing local temperature reading (sensor data), and combined with thermal imaging (video data), alert the remote operator to a trapped first responder. The remote operator will then use the alert to direct his/her VR controlled robot to clear an escape for the trapped first responder. The ability to rapidly link disparate data sources and produce actionable insights will enhance the virtualized response capability.

Network monitoring and control tools:

VR video, remote operations, and unmanned response technologies each put immense demands on communications networks ability to support data transfer, latency, reliability, and security. Research suggests that software interfaces and underlying network management tools will continue to develop, enabling public safety to perform broad network optimization actions to support

mission requirements as they develop. Initial solutions developed by the European Commission's ICARUS project are being planned to allow for central control of "radio bands and channels," "antennas polarization and transceiver features for every node in the network," as well as assessment for "need and location of network relays."[194]

Fire pattern analysis, simulation, and forecast models:

Introducing a suite of unmanned machines to the response environment that lack an ability to sense subtle changes in environment or structural integrity presents a risk for loss or damage to expensive public safety assets. Developments in simulation models will be used to safely manage these expensive assets by using machine mounted sensors and other situational awareness data to "forecast fire spread," provide safe egress and activate building systems upon detection of fire threat, as well as "monitor the health of a structure."[195]

NETWORKS

5G broadband and network reliability:

Remote operation of drones and robotics for public safety will rely on extremely low levels of latency, high data transfer, and 'always-on' reliability, much of which will be enabled by the development of a 5G broadband network. From a number of industry, governmental, and public-private coordinating bodies working on 5G broadband development, a general set of eight requirements for 5G have emerged: "1-10Gbps connections to endpoints in the field; 1 millisecond end-to-end round trip delay (latency); 1000x bandwidth per unit area; 10-100x number of connected devices; (perception of) 99.999% availability; (perception of) 100% coverage; 90% reduction in network energy usage; up to ten year battery life for low power, machine-type devices."[196]

[194] http://www.fp7-icarus.eu/sites/fp7-icarus.eu/files/publications/Public%20Report%20-%20ICARUS.pdf
[195] http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1191.pdf
[196] https://www.gsmaintelligence.com/research/?file=141208-5g.pdf&download

Mesh-networking:

Remote operation teams with a suite of unmanned response elements will rely on developments in mesh-networking capabilities to allow for "rapid deployments under unknown spectrum occupancy conditions, harsh propagation environments, large throughput demands and varying platforms constraints."[197] Mesh-network capabilities currently manage WLAN and data mobile radio (DMR) links but will evolve to easily integrate new datalink technologies, new frequency bands, and integrate commercial and public safety specific LTE services.[198] Evolved mesh network technologies will be crucial in connecting sensors within an unmanned response system to one another and to remote operations control centers as machines within the system move between connectivity providers.

[197] http://www.fp7-icarus.eu/sites/fp7-icarus.eu/files/publications/Public%20Report%20-%20ICARUS.pdf
[198] http://www.fp7-icarus.eu/sites/fp7-icarus.eu/files/publications/Public%20Report%20-%20ICARUS.pdf

Evolve Human-Machine Interaction Paradigm: Public Safety R&D Opportunities

Given the technology capabilities, gaps and barriers, and current developments that are forecasted to impact the User Interface domain over the next 20 years, the working group identified several potential R&D efforts that would enable the evolution of the human-machine interaction paradigm. Public safety R&D organizations should consider the following project areas as they prioritize upcoming investment opportunities:

BROADBAND NETWORK PERFORMANCE FOR REMOTE OPERATIONS

- Engage with industry actors working to develop capabilities, regulations, and specifications for drone operations beyond the line of sight over 5G broadband. Trials and testing to analyze current performance on 4G LTE networks will help optimize 5G specifications so that drones can use LTE connectivity to "deliver optimal flight plans, transmit flight clearances, track drone location and adjust flight routes in near real-time."[199]

ANALYTIC TOOLS

- Develop algorithms that integrate multi-source data, creating insights to alert command about local conditions at the scene of response.
- Develop algorithms that integrate multi-sensor data inherent to human-robot interaction, allowing a "robot to detect the attention of human users in order to determine if a user is addressing the robot, integrating person tracking, face recognition, sound source localization, and leg detection."[200]
- Develop parameter inference analytic tools predict fire spread and plume patterns from sensor data for integration to fire-prediction simulation and models.[201]

[199] http://gpsworld.com/qualcomm-att-to-trial-network-requirements-for-drone-operations/
[200] http://robotics.usc.edu/publications/media/uploads/pubs/585.pdf
[201] http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1191.pdf

Operational Objective: Evolve

VIRTUAL PUBLIC SAFETY ENVIRONMENT FOR VR INTERFACES

- Drive development of public safety specific VR environment to be used to train employees and study cognitive impacts of enhanced user interfaces. The public safety virtual test environment could be open-source, adaptable, and device interoperable so that agencies can access simulations tailored to their specific operational environment and develop task-based training experiences.
- Utilize public safety VR environment to study impacts of enhanced user interfaces on the public safety official's cognition, attention, and distraction. Research should focus on; visual layouts, sounds, and triggering protocols for alerts; utility to the user provided by various data/communication types across response scenarios; suitability for alert based on variability in environmental context of user. Results can be used to inform user interface and alert standardization frameworks. Data-tested and standardized interfaces will help provide consistency across devices and agencies for remote operators of unmanned machines by minimizing distraction and maximizing utility of data presented in a visual interface.

HUMAN-MACHINE INTERACTION

- Research human physical expressions and speech patterns to derive meaning from multi-source sensor data in the HMI.[202]
- Drive development of middleware to facilitate HMI, including supporting research on common commands and interactions specific to the HMI for public safety.
- Research human factors in the HMI, including studies evaluating ideal robot behavior norms, personality traits, and feedback mechanisms best suited for human interaction in the public safety domain.

202 http://robotics.usc.edu/publications/media/uploads/pubs/585.pdf

Operational Objective: Evolve

DEVICE INTEROPERABILITY

- Research signal transmission methodologies used in drones and robotics with the aim of driving interoperability between individual unmanned devices and device makers. Public safety will benefit from interoperable unmanned devices, allowing each agency to procure assets across manufacturers in accordance with agency need.
- Drive development of device sensing applications and discoverability tools for unmanned devices/sensors to enable automatic connection of cooperating machines and provide upstream analytic capabilities.

BATTERY PERFORMANCE IN UNMANNED DEVICES

- Engage with academia and the industry community on alternative battery materials and methods, including gold nanowire (University of California, Irvine[203]); aluminum graphite (Stanford University[204]); kirigami flexible structure (Arizona State University[205]); graphene (Graphenano[206]); and magnesium (Toyota Research Institute[207]).
- Research capability of solar power to support public safety drone surveillance missions and potential limitations in power drones conducting direct operations.

OTHER

- Research crash avoidance, auto-arrest and other safety precautions in unmanned ground and aerial vehicles for the public safety environment. Development of a requirements framework and performance standards specific to public safety task, physical environment, and geological features will aid the acceptance and adoption of unmanned devices.

[203] http://www.pocket-lint.com/news/137387-nanowire-battery-can-extend-your-phone-battery-life-by-hundreds-of-thousands-of-times
[204] https://www.sciencedaily.com/releases/2016/04/160405175659.htm
[205] https://www.element14.com/community/groups/power-management/blog/2015/10/23/japanese-art-of-kirigami-makes-this-battery-stretchable-and-flexible
[206] https://futurism.com/scientists-develop-better-battery-thanks-graphene/
[207] http://www.pocket-lint.com/news/137556-toyota-cracks-magnesium-batteries-for-longer-lasting-smaller-devices

Evolve Human-Machine Interaction Paradigm: Overall Gaps and Developments

Capability	Gaps	Developments
VIRTUAL REALITY SYSTEMS	• Size of VR experience software creates file storage and video rendering/processing issues • Limited by requirement to connect VR headset to a computer via cables or body-worn computer hardware • Hardware requirements include expensive VR headsets, computer with high-end processing ability, storage capacity, and graphics chip • Lack of virtual test bed that simulates public safety operational environment and training modules • Nausea and dizziness associated with prolonged immersion in virtual environment	**VR headset makers** ➢ HTC Vive ➢ Oculus Rift **Virtual experience creation software** ➢ MetaVR[208] **Human-computer interaction research** ➢ Duke immersive Virtual Environment (DiVE)[209] **Haptic feedback in simulated environment** ➢ ImmersiveTouch[210]
REMOTE OPERATION OF UNMANNED GROUND AND AERIAL VEHICLES	• Public safety lacks the command and control center infrastructure to support virtual operations, which will include an array of visual interfaces and data displays to enable remote interaction • Lack of data integration tools and frameworks to process remotely collected device/sensor data and present insights to remote operators • Ability to safely and reliability fly drones autonomously beyond the operator's line of sight has not been demonstrated • Lack of ability to hand off drone connectivity between networks on remote operations • Lack of consistent network coverage and demonstrated latency performance in accordance with 3GPP specifications • Lack of off-the-shelf robotics solution for public safety response scenario, current products are custom manufactured • Lack of battery/charging solutions to power unmanned ground and aerial vehicles for extended operations • Jurisdictional issues as financial incentives to centralize remote commands increase	**Remote operations system** ➢ Smart Emergency Response System (SERS)[211] **Drone technology** ➢ Michigan State Police[212] ➢ Qualcomm Technologies, Inc.[213] ➢ 3D Robotics[214] **Remote command and control center** ➢ Department of Defense Distributed Joint Command and Control[215] ➢ Motorola CommandCentral[216] **Unmanned search and rescue** ➢ European Commission Directorate-General for Enterprise and Industry ICARUS project[217]

[208] http://www.metavr.com/
[209] http://virtualreality.duke.edu/about/
[210] http://www.immersivetouch.com/technology_and_services_feel.html
[211] http://smartamerica.org/wp-content/uploads/2014/05/SERS_FactualBlog.pdf
[212] http://www.michigan.gov/msp/0,4643,7-123-72297_60152_62783-346390--,00.html
[213] http://www.fiercewireless.com/sponsored/qualcomm-working-to-accelerate-wide-scale-deployment-drones
[214] https://3dr.com/enterprise/industries/public-safety/
[215] http://www.rh.gatech.edu/news/340981/tackling-global-cybersecurity-threats-georgia-tech-developing-technologies-and-0
[216] http://www.officer.com/press_release/12246613/motorola-solutions-envisions-virtual-reality-transforming-public-safety
[217] http://www.fp7-icarus.eu/project-overview

		➢ Sharp INTELLOS Automated Unmanned Ground Vehicle[218] **Alternative battery materials** ➢ University of California, Irvine[219] ➢ Stanford University[220] ➢ Arizona State University[221] ➢ Graphenano[222] ➢ Toyota Research Institute[223]
HUMAN-MACHINE INTERACTION AND CO-PARTICIPATION	• Lack of safety standards, testing, governance, and policy for publicly-owned unmanned robotics in the first response environment • Lack of reliability in sensor technology to provide inter-device connection resilience • Lack of proven research to produce reliable perceptions of human behavior, intentions, and cognitive states from integrated sensor data • HMI requires a data integration and processing capability to link sensor data, derive meaning, and dictate robotic response with low enough latency to facilitate natural human interaction • Lack of spatial awareness and anticipatory motion in robotics technology to ensure safe operation during co-participation • Research is required to better understand brain activity and patterns to decode messages and facilitate brain-to-computer communication	**Robotics systems** ➢ Honda ASIMO[224] **Brain-to-text communications research** ➢ National Center for Adaptive Neurotechnologies[225] **Cobots** ➢ Kuka Robot Group[226]
RAPID DATA LINKAGE/ANALYSIS TOOLS	• Processing speed of integration hubs are not improved enough to support real-time integration and analytics • Lack of data architecture and formatting standards to promote rapid interoperability and data sharing between devices and agencies • Lack of ability to rapidly link devices/sensors as they become available on the network through 'sensing'	**Open-source data linkage** ➢ Australian National University, Freely Extensible Biomedical Record Linkage (FEBRL)[227]
NETWORK MONITORING AND CONTROL TOOLS	• Lack of ability to connect network management software tools with underlying network infrastructure to facilitate monitor and control of bandwidth • Need to view a network as a holistic entity rather than separate local nodes, creating a systems-level view and chokepoint analysis	**Local response network controls** ➢ European Commission Directorate-General for Enterprise and Industry ICARUS project[228]

[218] http://www.roboticstrends.com/article/intellos_a_ugv_security_robot_provides_24_7_surveillance
[219] http://www.pocket-lint.com/news/137387-nanowire-battery-can-extend-your-phone-battery-life-by-hundreds-of-thousands-of-times
[220] https://www.sciencedaily.com/releases/2016/04/160405175659.htm
[221] https://www.element14.com/community/groups/power-management/blog/2015/10/23/japanese-art-of-kirigami-makes-this-battery-stretchable-and-flexible
[222] https://futurism.com/scientists-develop-better-battery-thanks-graphene/
[223] http://www.pocket-lint.com/news/137556-toyota-cracks-magnesium-batteries-for-longer-lasting-smaller-devices
[224] http://asimo.honda.com/inside-asimo/
[225] https://www.wired.com/2016/01/phil-kennedy-mind-control-computer/
[226] http://spectrum.ieee.org/automaton/robotics/industrial-robots/collaborative-robots-innovation-growth-driver
[227] http://www1.unece.org/stat/platform/display/msis/Software+for+Data+Integration%3A+Record+Linkage
[228] http://www.fp7-icarus.eu/project-overview

Operational Objective: Evolve

FIRE PATTERN ANALYSIS, SIMULATION, AND FORECAST MODELS	• Lack of software capabilities to decipher local conditions, predict potential threats, and guide/protect unmanned machines in the operational environment	**Fire resilience and risk mitigation** ➢ National Science Foundation Engineering Research Center[229]
5G BROADBAND AND NETWORK RELIABILITY	• Ability to safely and reliability fly drones autonomously beyond the operator's line of sight has not been demonstrated • Lack of ability to hand off drone connectivity between networks on remote operations • Lack of consistent network coverage and demonstrated latency performance in accordance with 3GPP specifications	**Research alliances** ➢ ITU Radiocommunication Sector[230] ➢ Next Generation Mobile Networks Alliance[231] **Industry Research** ➢ SK Telecom[232] ➢ NTT DoCoMo[233]
MESH-NETWORKING	• Lack of data architecture and formatting standards to promote rapid interoperability and data sharing between devices and agencies • Lack of ability to rapidly link devices/sensors as they become available on the network through 'sensing' • PANs used to host and connect body-worn devices/sensors do not support high data transfer rates and are unsuitable for video and other large data types	**Public safety mesh-networks** ➢ Meshdynamics[234]

[229] http://www.nfpa.org/~/media/files/news-and-research/resources/research-foundation/foundation-proceedings/next-five-years/marshall.pdf?la=en
[230] https://www.gsmaintelligence.com/research/?file=141208-5g.pdf&download
[231] https://www.gsmaintelligence.com/research/?file=141208-5g.pdf&download
[232] https://www.gsmaintelligence.com/research/?file=141208-5g.pdf&download
[233] https://www.gsmaintelligence.com/research/?file=141208-5g.pdf&download
[234] http://meshdynamics.com/military-mesh-networks.html

Operational Objective: Evolve

Capabilities Development Timeline

Capability	Short - term (0 - 5 years)	Medium - term (5 - 10 years)	Long - term (10 - 20+ years)
VR Systems to train public safety	Primary set of public safety virtual environments developed Informal training conducted through VR interfaces to orient new public safety staff to operating environment Research to test and develop alerting standards and visual interfaces begins, using VR systems Streaming technology allows for richer wireless VR experience	Rich and interoperable test bed of virtualized public safety environments Training in virtual environment is formalized and adopted across public safety agencies	
Remote operation of vehicles / unmanned UAVs	Fly by sight drones used to add increased situational awareness in operating environment Robots used to complete most dangerous public safety tasks Command centers collect and present operational data/analytic products collected from operating envrionment in	Automous flight drones are deployed from command center to operating environment to assist in response Robots conduct tasks in public safety environment, operated by remote command using VR systems Command centers are centralized data hubs and 'flight centers' hosting teams of remote public safety officials conducting response through virtualization interfaces 5G broadband allows for continuous drone operations across network areas through low latency and high resiliency	Network of public safety drones maintain continuous operation over large population center and are tasked for reponse based on AI and analytics Full suite of unmanned ground machines maintain regular public safety operations while monitored and managed from central command and data center Data integration and remote operation centers become primary public safety 'office/station' environment
Human-Machine Interaction and co-participation in tasks	Cobots perform tasks alongside public safety in controlled and stable environments	Cobots enter public safety operating environment and perform limited set of predefined tasks when prompted by human official Cobot are able to detect simple gesture commands from a predefined set Brain mapping research allows for brain-to-computer connection in controlled test environment	Cobots become integral part of public safety reponse team operating with alongside humans with autonomy Cobots use rich set of sensors to perceive human intent, anticipate movement, and interact seamlessly Brain-to-computer interface is wireless and suited for operating environment creating symbiotic connection between human and machine

Conclusion

The process by which this initial *Public Safety Enhanced User Interface R&D Roadmap* was created generated a great deal of input, ideas, and opportunities for PSCR and other R&D-focused agencies, industry, and academia to consider. The potential impact on the public safety community can be tremendous given the appropriate and successful application of R&D funds to address some of the opportunities listed in this report. PSCR intends to continue to build upon the *Public Safety Enhanced User Interface R&D Roadmap* as it identifies, vets, and plans R&D projects.

PSCR would again like to thank those who contributed to the completion of this roadmap; those who attended the June 2016 PSCR Stakeholder Meeting in San Diego, California; and particularly those who were members of the PSCR Public Safety Enhanced User Interface working group listed in Appendix A.

For more information on PSCR and its programs, please visit https://www.nist.gov/ctl/pscr

Appendix A: Enhanced User Interface Working Group Members

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Robert A Green	IBM
Robert Escalle	Sonim
Robert King	AT&T
Robert Paski	NYC IT Department
Roger Skidmore	EDX Wireless
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Wade Carrol	Southlake Texas
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