NISTIR 8340

Voices of First Responders – Applying Human Factors and Ergonomics Knowledge to Improve the Usability of Public Safety Communications Technology

Findings from User-Centered Interviews Phase 1, Volume 5

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This publication is available free of charge from:
https://doi.org/10.6028/NIST.IR.8340

National Institute of Standards and Technology
U.S. Department of Commerce

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February 2021

U.S. Department of Commerce
Wynn Coggins, Acting Secretary

National Institute of Standards and Technology
James K. Olthoff, Performing the Non-Exclusive Functions and Duties of the Under Secretary of Commerce for Standards and Technology & Director, National Institute of Standards and Technology

National Institute of Standards and Technology Interagency or Internal Report 8340
Natl. Inst. Stand. Technol. Interag. Intern. Rep. 8340, 56 pages (February 2021)

This publication is available free of charge from:
https://doi.org/10.6028/NIST.IR.8340

Abstract

With the newly created Nationwide Public Safety Broadband Network (NPSBN), the public safety community is in the process of supplementing the use of land mobile radios with a technology ecosystem that will include a variety of new and improved communication tools, including a range of broadband data sharing platforms. As these technologies are being developed, researchers and industry alike need to focus on the end users – the first responders – in order to ensure successful and usable systems. Understanding the user population of first responders is key to improved usability. The National Institute of Standards and Technology (NIST) Public Safety Communications Research (PSCR) Usability Team took a multi-phase, mixed methods approach in order to provide greater understanding of public safety technology users, their experiences, and their technology needs and problems.

This report, Phase 1, Volume 5, is the 5th in a series of reports on the data from the Phase 1 in-depth interviews. This report is a companion document and should be used in conjunction with the Phase 1, Volume 2 report that identifies the technology problems and needs of first responders from the in-depth interview data. The current report focuses on providing practical guidance and recommendations for improving the usability of communication technology for first responders by applying human factors and ergonomics (HFE) principles and usability evaluation methodology. The field of HFE considers five major aspects (perceptual, cognitive, physical, environmental, and social & organizational) of human interactions with systems to optimize human well-being and overall system performance.

In Phase 1 in-depth interviews, 193 first responders–from Comm Center & 9-1-1 Services (COMMS), Emergency Medical Services (EMS), Fire Service (FF), and Law Enforcement (LE) – have been interviewed. A total of 107 categories of technology problems and needs were identified as documented in the Phase 1, Volume 2 report. In this report, from the usability and HFE perspectives, we performed further assessment on those 107 categories and divided them into two main groups. In the first group, 27 categories were clustered into 14 topics. For each of the 14 topics, specific HFE recommendations were made in order to ensure the usability of communication technology for first responders. In the other group, the remaining 80 categories of technology problems and needs were clustered into 6 topics in which generic HFE considerations are applicable.

To ensure the usability of communication technology for first responders, both groups require a two-stage human-centered process to be followed for technology development and implementation. The two-stage (requirement analysis and usability testing) process includes: (1) HFE professional(s) is integrated with the product team from the initiation and throughout the product development lifecycle; (2) at various stages, the product needs to go through usability evaluations before the final implementation. The HFE professional must approve that the product and technology meet the HFE and usability requirements to be ready for final implementation.

The objective of this report is to provide concise and actionable HFE guidance and recommendations to the PSCR R&D community without extensive discussions on the theoretical background information. Practitioners interested in addressing a specific topic can

take the recommendations, design and develop the technology following the two-stage human-centered process throughout the entire product development lifecycle to deliver the desirable and usable communication technology to first responders.

Key words

Communication technology; First responders; Human Factors and Ergonomics; Public safety communications research; Usability; Human-centered design; User needs and requirements.

Audience

This report is primarily intended for designers, developers, vendors, and researchers of public safety communication technology.

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Acknowledgments

The authors gratefully acknowledge and thank the 193 first responders who graciously participated in these interviews. The authors would also like to express their sincere gratitude to another 8 first responders (COMMS, EMS, FF, LE) for reviewing this report with invaluable feedback and insights.

Specific Operational HFE Guidelines to Improve the Usability of Communications Technology for First Responders

NIST Usability Team

Report available at: https://doi.org/10.6028/NIST.IR.8340

NISTIR 8340 Voices of First Responders – Applying Human Factors & Ergonomics Knowledge to Improve the Usability of Public Safety Communications Technology: Findings from User-Centered Interviews, Phase 1, Volume 5

This NIST report outlines Human Factors and Ergonomics (HFE), and usability-based methods for the development, improvement and implementation of public safety communications technology for first responders. HFE enables the design of products and services for efficient, effective, safe, and comfortable human use. Usability evaluation provides explicit information on where technology products and services need to be improved and how to improve.

Based on interviews of 193 first responders, 107 categories of communications technology problems and needs were identified.

Developers can use HFE and usability evaluation methodologies and apply the specific operational guidelines and recommendations to reduce or eliminate the problems and address the needs identified. Implementation of the recommendations will result in greater: efficiency through improved first responders' performance time; effectiveness by minimizing error rates; and first responder satisfaction of system operation.

Efficiency Effectiveness Satisfaction

NIST National Institute of Standards and Technology

PSCR

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Glossary

AI	Artificial Intelligence
AR	Augmented Reality
CAD	Computer-Aided Dispatch
COMMS	Comm Center & 9-1-1 Services
COOP	Continuity of operations
EMS	Emergency Medical Services
FF	Fire Service
HUD	Heads-Up Display
HFE	Human Factors and Ergonomics
HFES	Human Factors and Ergonomics Society
IC	Incident Commanders
IEA	International Ergonomics Association
LE	Law Enforcement
LMR	Land Mobile Radio
MDC	Mobile Data Computer
NG 911	Next Generation 911
NPSBN	National Public Safety Broadband Network
PCR	Patient Care Report
PPE	Personal Protective Equipment
PSCR	NIST's Public Safety Communications Research Program
R&D	Research and Development
RMS	Records Management System
SCBA	Self-Contained Breathing Apparatus
SSO	Single Sign-On

1. Introduction

In February 2012, the enactment of the United States Middle Class Tax Relief and Job Creation Act [1] marked an unparalleled push toward next-generation technologies for public safety. The legislation contained landmark provisions for the development and build out of the Nationwide Public Safety Broadband Network (NPSBN), a dedicated, interoperable wireless network for emergency responders. The goal of the NPSBN is to improve communication for first responders by providing an independent, interoperable communication platform during incident response including network priority and preemption. The public safety community is beginning to transition to more widespread, data-based communication technology and is in the process of supplementing the use of land mobile radios (LMR) with a technology ecosystem that will include a variety of new and improved communication tools, including a range of broadband data sharing platforms. The National Institute of Standards and Technology (NIST) Public Safety Communications Research (PSCR) program is dedicated to supporting the research and development (R&D) of NPSBN. Research within the PSCR program focuses on identifying and recommending ways to mitigate the issues faced in emerging public safety communication technology.

Within the larger PSCR program [2], the NIST PSCR usability project focuses on the human factors issues surrounding use of communication technology. The research within this project centers on the technology users—the first responders. This project seeks to better understand first responders' environments, tasks, and communication needs. The ultimate goal is to capture the requirements for the effectiveness, efficiency, and user satisfaction of first responders' use of communication technology, and to share their concerns and technology requirements with the wider public safety community.

The PSCR usability team took a multi-phase, mixed methods approach designed to provide an in-depth look at the population of first responders, along with their work environments, tasks, and communication needs. Phase 1, the qualitative component, data collection included 158 semi-structured interview sessions with 193 first responders from Comm Center & 9-1-1 Services (COMMS), Emergency Medical Services (EMS), Fire Service (FF), and Law Enforcement (LE) across the United States. Four volumes of Phase 1 reports have been published:

- Phase 1, Volume 1 presents findings from the initial phase of qualitative data collection [3].
- Phase 1, Volume 2 synthesizes and classifies the technology problems and needs identified by first responders from the full interview data set [4].
- Phase 1, Volume 3 focuses on rural first responders and how the rural environment influences their problems and needs regarding communication and technology [5].
- Phase 1, Volume 4 focuses on the contexts and challenges specifically facing COMMS personnel [6].

The second phase of the project, Phase 2, the quantitative component, utilized the results of the Phase 1 qualitative interviews to inform a large-scale, online, quantitative nationwide survey in order to provide a more comprehensive view of first responders and

communication technology. A total of 7 182 completed survey responses were received, with responses from all 50 states and the District of Columbia (D.C.). So far, two volumes of Phase 2 reports have been published:

- Phase 2, Volume 1 provides specifics about survey methodology (including survey development and dissemination) and summarizes nationwide participant demographics [7].
- Phase 2, Volume 2 focuses on survey data from three specific topics: mobile devices (i.e., smartphones and tablets) and applications/software used by first responders; futuristic technology for first responders, including the use of virtual reality (VR); and the types of technology first responders have, and think would be helpful in a major disaster or large planned event [8].

Based on the synthesized technology problems and requested functionality from the Phase 1 Volume 2 report [4], this report focuses on providing practical guidance and recommendations on how to apply Human Factors and Ergonomics (HFE) principles to improve the usability of public safety communication technology for the first responders. The objective of the current report is to offer succinct and concise recommendations, wherever applicable, to practitioners for developing usable communication technology for the first responders. The recommendations made in this report should be used in conjunction with the Phase 1, Volume 2 report that identifies the technology problems and requested functionality of first responders from the Phase 1 in-depth interview data as well as with the Phase 2 data from the large-scale nationwide survey when the results become available such as Phase 2, Volume 2 [8] and future volumes.

Authors' Note: The content, flow and timing of information communicated to, from and among first responders are not the mission of this report. Hence, they have been neither studied nor discussed in this document. What is being discussed in this report is the usability of communication technology for "as-is" content and information flow. However, in order to achieve an effective communication for the first responders, optimization of information content, flow and timing should also be considered while improving the usability of the communication technology.

2. Human Factors and Ergonomics Contributions to Usability

Ever since its inception more than 70 years ago, the field of Human Factors and Ergonomics (HFE) has developed and broadened substantially. While there are variations in defining HFE, we will adopt the definitions from two major HFE organizations:

Human Factors and Ergonomics Society (HFES) [9]:

> "*Ergonomics and human factors use knowledge of human abilities and limitations to design systems, organizations, jobs, machines, tools, and consumer products for safe, efficient, and comfortable human use.*"

And, International Ergonomics Association (IEA) [10]:

> "*Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance.*"

HFE deals with five major aspects of human interactions with systems [11]:

- **Perceptual**: such as visual, auditory, tactile, and kinesthetic sense
- **Cognitive**: such as attention, memory, mental workload, information processing, problem solving and decision making
- **Physical**: such as response selection, control of movement, physical capabilities, limitations and decrements
- **Environmental**: such as sound and noise, illumination, sun glare, moisture and temperatures, geography and topography
- **Social and Organizational**: such as group dynamics and composition, organizational structure and communication chain of command, trust and communication between first responders and the public.

The human element is a critical yet often overlooked component during technology development and integration. HFE professionals hold in-depth knowledge of human abilities and limitations with respect to those five major aspects and can apply the knowledge to the design of human-system interactions. Any product team responsible for the development and implementation of the communication technology for first responders should include a professional(s) with advanced degrees in HFE as an integral part of the team. The complete utilization of an HFE professional(s) in the entire product development lifecycle will result in greater efficiency through improved first responders' performance time, effectiveness by minimizing error rates (for example, inadvertent actuation), and first responder satisfaction of system operation. Thus, the inclusion of HFE professionals in product team can help ensure and improve product usability as defined by ISO 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*" [12][13].

A well-conducted and well-planned product development project will have several rounds of usability evaluation, at varying levels of fidelity. By incorporating first responder feedback throughout the design of a system, it is easier to identify major problems or flaws in a system at a much earlier stage. Usability evaluation is an iterative process which frequently results in needed product modifications before implementation to ensure first responders' requirements are met for performance excellence. Some of the widely used usability evaluation methods [14] include, but are not limited to the following: contextual inquiries/naturalistic observation, structured questionnaires (e.g., [15][16]), individual/group discussions on performance and usability issues, cognitive walkthrough (a usability inspection method), heuristic evaluation (a holistic view to catch usability problems), and user-based usability testing. Usability evaluations should be performed by trained professionals with deep knowledge and understanding of technology, HFE, and usability techniques. For each specific job or task performance situation, it is important to select the most appropriate evaluation approach. It is also imperative that there are adequate number of participants from representative user population in each usability evaluation in order to derive acceptable validity [17].

Thus, for any project developing communication technology intended for use by first responders, it should follow a two-stage human-centered process as outlined in Fig. 1. At the

first stage, when forming the project team, an HFE professional(s) needs to be assigned to the team to ensure that all good HFE principles are considered and applied from the beginning design stage throughout the entire product development lifecycle to completion. The team should conduct thorough requirements analysis to include requirements such as business and organizational requirements, environmental and physical requirements, functional and nonfunctional requirements, technical and system requirements, and most importantly user requirements which should be collected directly from target users (e.g., first responders).

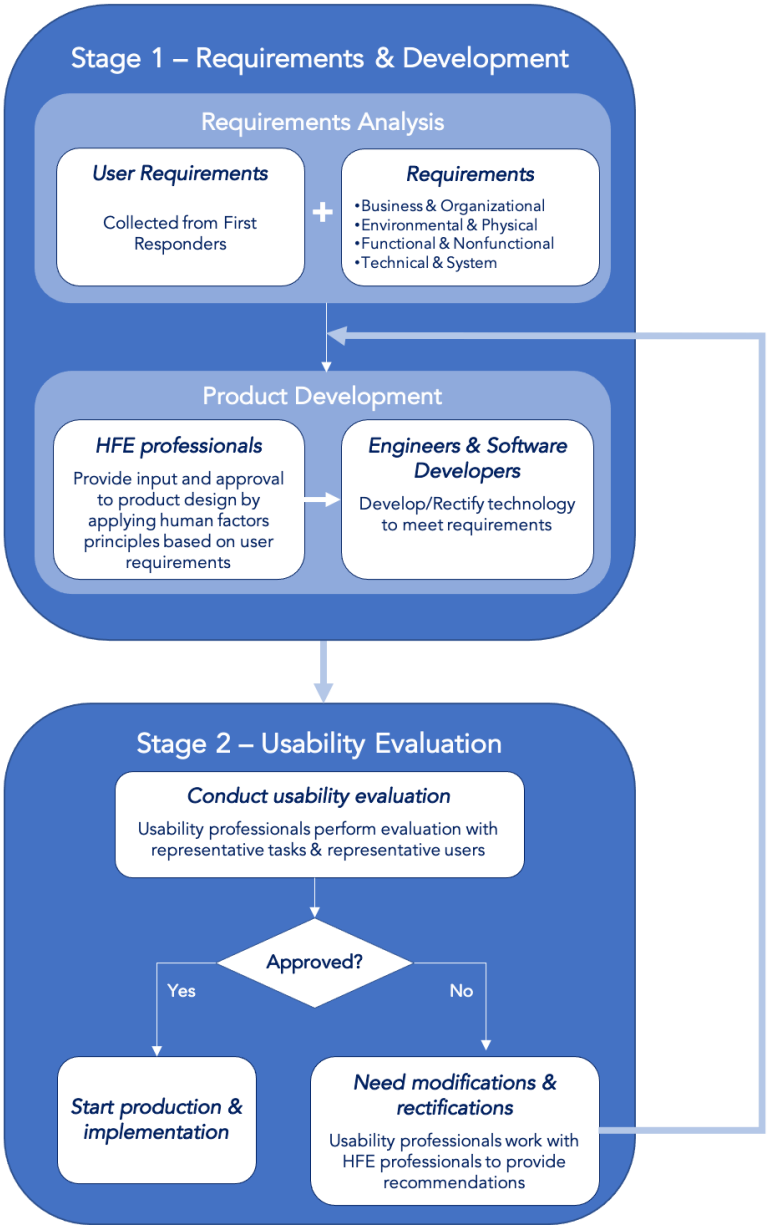

Fig. 1. Two-stage human-centered process – development and implementation of communication technology for first responders

Based on the requirements, engineers and software developers design and develop the product working in tandem with the HFE professional(s) to ensure product utility and

usability. The second stage starts when a prototype has been designed and developed, to go through a systematic, science-based, usability evaluation performed by trained usability professionals. The usability professionals may or may not be the same as the HFE professional(s) on the team, depending on the team structure. Comprehensive usability evaluations should involve target first responders with representative tasks in realistic operational environments.

The two stages can overlap and be iterative as modifications may be necessary based on the outcomes of the usability evaluations which will require the product to go back to stage one. When HFE professionals are proactively involved in the entire product development lifecycle, it significantly reduces the probability of reworks needed that may be discovered from usability evaluations. The HFE professional must approve that the product and technology meet the HFE and usability requirements to be ready for final implementation. This two-stage human-centered process is based on extensive industrial experience (e.g., chapter 2 and chapter 38 in [11]) to provide the most benefits in developing products for human use. It will reduce development cost and bring the product faster to market while providing good usability for first responders that are easy, quick, comfortable and safe to use with minimal errors.

In addition to the two-stage human-centered process, Fig. 2 illustrates the dimensions to be considered for a holistic and effective public safety communication design and operation.

Fig. 2. Dimensions for Holistic and Effective Public Safety Communication Design and Operation
(*Reproduced and modified by permission from [18]*)

3. Methodology

This document builds on findings reported in Phase 1, Volume 2 [4] which systematically analyzed first responder quotes related to technology based on the complete data collected in Phase 1 in-depth interviews. Full methodological details such as specifics related to study design, sampling strategy, data collection, and data analysis can be found in Phase 1, Volume 1 report [3]. Phase 1 data collection was based on in-depth, one-on-one, semi-structured interviews. The NIST Research Protections Office reviewed the protocol for this project and determined it meets the criteria for "exempt human subjects research" as defined in 15 CFR 27, the Common Rule for the Protection of Human Subjects.

Most interviews took place in the workplace, a police station or fire station, for example, in either a group gathering area or in a private office or conference room. Phase 1 data collection resulted in 193 participants interviewed in a total of 158 sessions–some interviews included multiple participants. Out of those 193 interviewed: 25 were personnel from Comm Center & 9-1-1 Services (COMMS), 25 from Emergency Medical Services (EMS), 71 from Fire Service (FF), and 72 from Law Enforcement (LE). A typical session lasted about 60 minutes. Participants were asked questions such as their context of work, daily routine, the community they serve, their experience with communication technology, and their wish list of communication technology.

Each interview session was audio-recorded and later professionally transcribed. After the interview recordings were transcribed, two *a priori* code lists were generated: one for EMS, FF and LE and the other for COMMS given the unique environment and primary tasks within that discipline. The transcripts were coded by the PSCR usability team researchers using the code lists to label sections or chunks of transcribed data capturing the essence of the statements to group, compare, and/or manipulate chunks. The data was then extracted by exporting the data associated with a code from each transcript into a separate document.

As stated earlier, this report aims at providing practical human factors guidance to address the problems and functionality requests identified in Phase 1, Volume 2 report [4]. There were three interview questions most relevant to first responders' experience with communication technology and what technology they wish to have:

- "List the different kinds of technology (devices, equipment) you use to do your job. How would you describe the technology/equipment you currently use? Are there apps that you use to do your job? Have there been times when technology has gotten in the way?"
- "What, if anything, do you think causes communication problems in your work? What, if anything, could help with these problems?"
- "Let's talk out of the box for a minute, describe your technology wish list: pie in the sky here, if technology could do whatever you wanted it to, what would you want?"

It has been established in behavioral science and HFE that when these types of questions are asked, people respond with the answers that are most critical to their own experience. So, it should be of higher priority of technology researchers and developers to address those

problems and needs expressed by the first responders. Relevant responses were coded as "problems: technology" or "wish list." Extracted data for both the technology problems and wish-list items were further analyzed systematically and classified into a total of 107 categories, including 50 categories of technology-based communication problems and 57 categories of requested functionality[1] as shown in Appendix A (adopted from Phase 1 Volume 2 report [4]).

This report aims at providing practical human factors guidance to address those technology problems and needs identified. With this goal in mind, we performed a systematic assessment of each of the 107 categories and further divided them into two groups–Groups A and B. Group A consists of 27 categories, each of which has specific HFE recommendations that can be applied to address the problems and/or needs in order to improve the usability. Subsequently, after careful reviews and evaluation, those 27 Group A categories were clustered and reduced into a total of 14 topics. Chunking was based on the joint characteristics of the problems/needs and the potential HFE solutions. Group B includes 80 categories where a unique HFE aspect was not identified, but rather the global human factors consideration was applicable. Those 80 categories in Group B were further clustered into 6 topics based on the practical characteristics shared by the categories in each topic. The two-stage human-centered process discussed in Section 2 (Fig. 1) is essential and applicable to both topics in Group A and Group B. Appendix A shows the original 107 categories of problems and needs from Phase 1 Volume 2 report [4], their new groupings (Groups A or B), and their new classification topics.

The overall methodology is summarized and depicted below in Fig.3.

[1] We will use the term "needs" in this report to reference the original term "functionality requested" in Phase 1, Volume 2 report.

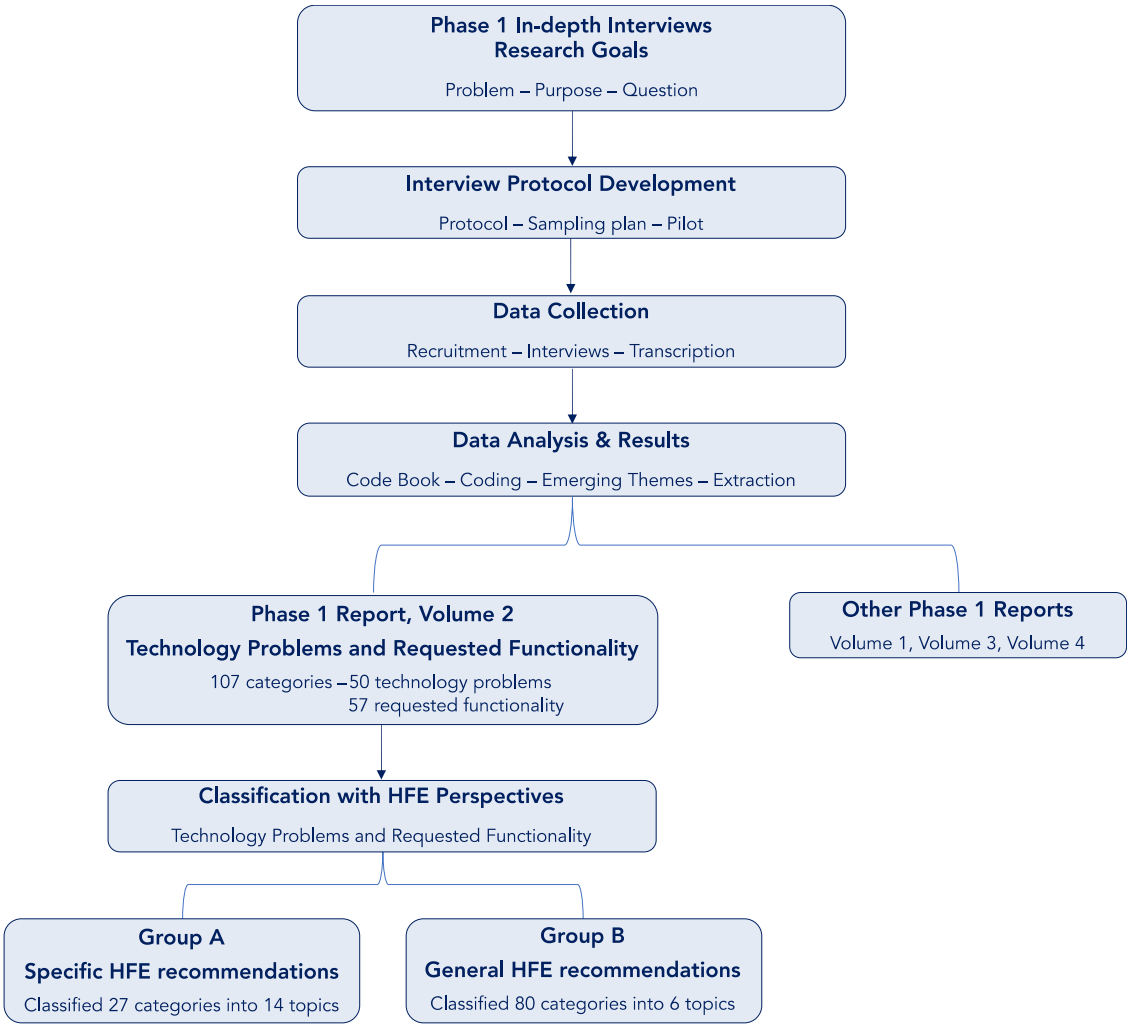

Fig. 3. Methodology – Classification with Human Factors and Ergonomics Perspectives of Technology Problems and Requested Functionality from Phase 1 Interview Data

4. Human Factors and Ergonomics Recommendations for Usable Communication Technology for First Responders

Section 4.1. provides detail and specific recommendations to address the 14 topics in Group A by applying best practices in the HFE fields. Section 4.2. lists Group B items organized in six related topics to be addressed and improved by the PSCR research and development (R&D) community.

4.1. Group A Topics with Specific Human Factors and Usability Recommendations

The 14 Group A topics are summarized in Table 1, with the applicable discipline(s) marked with a blue dot. Topics are listed in descending order of number of blue dots and alphabetically if equal number of dots.

The specific human factors and usability recommendations for each topic are described in the associated sub-section. It is important to emphasize that the two-stage human-centered

process described in Section 2 should always be followed when developing and implementing the recommendations provided in this section.

Authors' Note: If there is no blue dot in a topic for a specific discipline, it only means that there was no corresponding data from the interviews for that discipline on that topic, based on the original categories identified in the Phase 1, Volume 2 report [4]. It doesn't mean that first responders in that discipline will not benefit from the recommended solutions for that topic. One should follow the two-stage human-centered process to identify requirements and discipline-applicability of the recommendations.

Table 1. 14 Topics in Group A with Specific Human Factors and Usability Recommendations.

Sub-section	Topics	911 [a]	[b]	[c]	[d]
4.1.1	Cybersecurity Authentication	•	•	•	•
4.1.2	Display Size and Control Design – Physical Issues	•	•	•	•
4.1.3	Mental Workload	•	•	•	•
4.1.4	Physical Ergonomics – Technology and Stress	•	•	•	•
4.1.5	Real-Time Technology	•	•	•	•
4.1.6	User Interface Design	•	•	•	•
4.1.7	Easy Communication Modality to Complete Task		•	•	•
4.1.8	Mobile Data Computer (MDC)		•	•	•
4.1.9	Radio Operation Design		•	•	•
4.1.10	User Interfaces – Auditory Warning Problems		•	•	
4.1.11	Communications Center – Information Handling	•			
4.1.12	Communications Center – User Interface for Call-taking and Dispatching	•			
4.1.13	Integrated System for Wearables			•	
4.1.14	Body Camera – Physical Issues				•

[a] COMMS; [b] EMS; [c] FF; [d] LE

The structure of each sub-section is designed to be consistent and self-contained with all relevant information in solving that topic. Each sub-section consists of the following elements:

- **Disciplines** – applicable disciplines based on the original categories identified in the Phase 1, Volume 2 report [4].
- **Problems/Needs** – brief summary of the problems and/or needs (requested functionality) from the original categories grouped into current topic.
- **Recommendations** – solutions and recommendations for the topic based on the best know-hows and practices in the HFE field.

- **Implementation Considerations** – factors to consider from an HFE perspective in the implementation process in order to alleviate or prevent potential negative impacts on human performance.
- **Related Topics** – related topic(s) to be considered together to obtain optimal usability benefits; or recommendations in the related topic(s) can have positive impacts on the current topic.
- **Topic Specific References** – specific HFE references applicable to the topic.

4.1.1. Cybersecurity Authentication

Disciplines

Problems/Needs

Problems with having separate authentications for each of the many systems used.

Recommendations

Provide single sign-on (SSO) that enables users to securely authenticate with multiple applications and systems by logging in only once.

Integrate the different functions which currently each need a separate authentication into one integrated system, similar to a smart phone, using SSO for accessing each and every function embedded in that single equipment.

When separate authentications must occur (for example, log in to the smart phone and the in-vehicle computer), allow the same set of credentials to be used, rather than require users to remember or carry different authenticators.

Provide easy to access and quick to resolve recovery mechanism when first responders encounter authentication failures. The impacts from authentication failures on first responders' access to mission-critical functionality should be minimized.

Implementation Considerations

When choosing the authentication methods to implement SSO (for example, memorized secret, out-of-band devices, or multi-factor cryptographic software/device), usability considerations should be given to:

- Memory limitation: for example, complex passwords.
- Physical considerations: for example, typing on small onscreen keyboards versus on a traditional full-size keyboard; typing with thick gloves.
- Environmental conditions: for example, in vehicles traveling at high speed; lighting issues with sun glare or extremely dark.

- Recovery mechanism: wherever possible, provide self-service capability to users to reduce reliance on IT support that may not always be available.
- Emphasis should be put on the security of the authentication and ease and reliable use of the system.

The benefits of SSO implementation include:

- Reducing response time: no need to log in for each system separately.
- Reducing memory load of first responders: no need to remember multiple log-in information.
- Increasing focus on primary tasks.

All these benefits should result in increased performance effectiveness, efficiency and job satisfaction of the first responders.

Related Topics

4.1.3 Mental Workload
4.1.6 User Interface Design

Topic Specific References

- Choong, Y-Y., Greene, K.K., and Franklin, J. (2015). *Usability and Security Considerations for Public Safety Mobile Authentication*. NISTIR 8080. [19]
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- Moallem, A. (2018). *Human-Computer Interaction and Cybersecurity Handbook*. CRC Press. [21]

4.1.2. Display Size and Control Design – Physical Issues

Disciplines

Problems/Needs

- Screen size too small
- Poor legibility of on-screen information or printed information such as driver license
- Inadvertent actuation of controls

Recommendations

Screen and Display size

- Before making decision whether to increase screen size, considerations should be given to variables that may cause these problems such as lighting, contrast, glare, small screen size, excessive information, and the visual capability of the user.

- Attention should be given to evaluate whether all the information displayed at once on the screen need to be displayed. Displaying too much information to the users (e.g., first responders) would increase mental workload, lengthen reaction time, increase error rate and make it hard for users to concentrate on the key vital information being assessed.
- If the screen size is to be increased, carefully perform research and assessment to identify the optimal screen size for the intended tasks and users such that the screen size is not too small causing viewing problems, nor too big causing problems to manipulate and operate.

Inadvertent Actuation of Controls

- In order to eliminate or reduce the possibility of inadvertent actuation, the controls should be of good size in different distinguishable shapes for different functions. Adding color to controls may further help to eliminate inadvertent actuation.

Implementation Considerations

Rectify the contributing factors as appropriate before proceeding with the decision to possible increase screen size.

Related Topics

4.1.3 Mental Workload
4.1.6 User Interface Design
4.1.8 Mobile Data Computer (MDC)

Topic Specific References

- Flach, J.M. , Bennett, K.B., Butler, J.W., and Heroux, M.A. (2021). Representation Design. Chapter 36 in Salvendy, G., and Karwowski, W. (Eds.). *Handbook of human factors and ergonomics (5th edition)*. John Wiley & Sons. [11]
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4.1.3. Mental Workload

Disciplines

Problems/Needs

Mental overload – problems with handling a lot of things concurrently while actively performing primary task.

Recommendations

First responders constantly work in situations that cause major mental overload. When in mental overload conditions, it will result in decreased work performance, increased stress and anxiety which impact the well-being of the first responders. The optimal mental

workload is reached when the user's performance is high, his/her well-being is good, and the error rate is low (Fig.4).

The adverse situation of mental overload can be significantly reduced or alleviated by implementing one or more of the following recommendations:

- Assess and identify the essential information needed at any given time and only present the primary information to first responders while still keeping secondary information available and accessible in an unobtrusive manner.
- Investigate the possibility and feasibility of adding artificial intelligence (AI) as decision aid (e.g., filter through information or pull out relevant information) to first responders' communications and operations.
- The operations of new/unfamiliar technology or infrequently used technology can increase first responders' mental workload impacting their decision making and performance, especially during incidents. It is important to make sure that the technology is intuitive, easy to learn, and usable to operate.

Implementation Considerations

The implementation of any of the above recommendations must be compatible and undisruptive with first responders' all other operations.

Related Topics

All

Topic Specific References

- Endsley, M. R. (2021). Situation awareness. Chapter 17 in Salvendy, G., and Karwowski, W. (Eds.). *Handbook of human factors and ergonomics (5th edition)*. John Wiley & Sons. [11]
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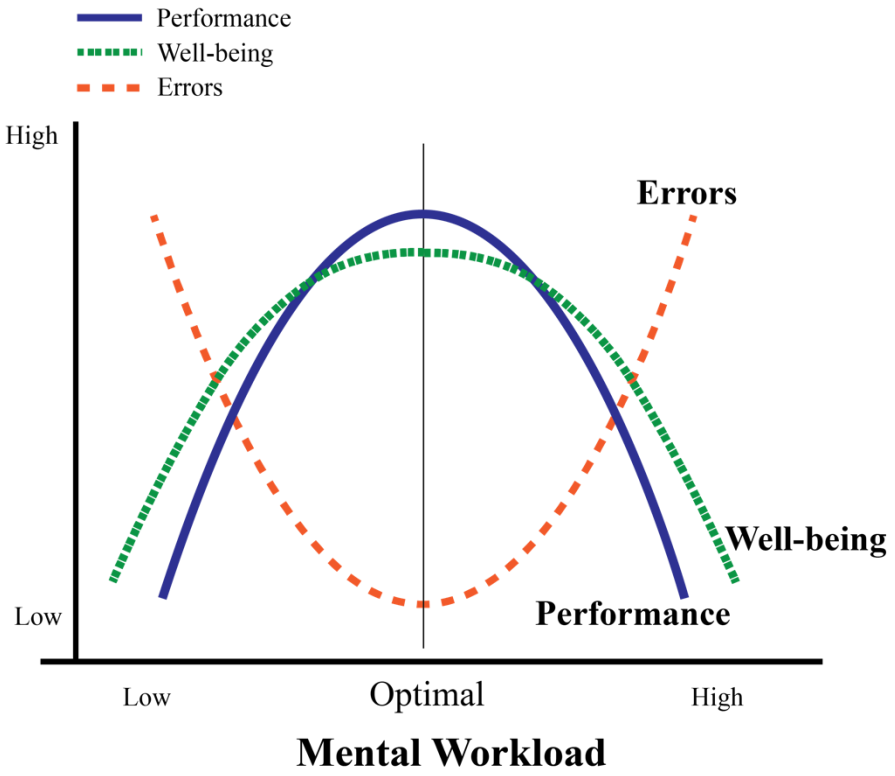

Fig. 4. Optimal mental workload condition with minimized error rates, maximized performance and close-to-maximized well-being of first responders

4.1.4. Physical Ergonomics – Technology and Stress

Disciplines

Problems/Needs

- Needs certain devices to be larger, especially for text entry: buttons, screens and in-vehicle keyboards.
- Technology causes discomfort – too many and too bulky and heavy.

Recommendations

Facilitating Text Entry

- In-vehicle computers (such as MDC or laptops) should be detachable and equipped with a physical and separatable, preferably standard-sized keyboard. The vehicles can be designed such that the steering wheels can telescope inward totally allowing first responders to write up reports with the detachable computer.
- In situations where it's safe and feasible to do so, in addition to typing notes or reports, provide options for first responders to choose using voice input to create the needed notes or reports.

Minimizing Number of Devices

- Adopting newer technologies to enable significant reduction in the size and weight of the individual items currently carried by the first responders.
- Newer technologies can provide the opportunity to integrate a number of items/functions into one integrated piece of equipment while at the same time having a good size screen, keyboard and button size.

Implementation Considerations

Rectifying the first responder's note taking and reporting tasks is time sensitive because over time, low-back and neck pain problems may develop and require medical intervention. The use of detachable in-vehicle computers and telescopic steering wheels will alleviate or significantly reduce postural discomfort currently experienced by many first responders from turning and leaning toward a fixed-mounted computer next to them.

The following needs to be taken into account while implementing the recommendations:

- When implementing the detachable computers, ensure smooth and easy operation for detaching and attaching the computer to its designated location. The computer mounting mechanism should be secured and won't become loose under any condition.
- When implementing the telescopic steering wheels, ensure smooth and easy operation. When needed (for example, an incident happens during report writing), the steering wheel has to be put back quickly to its previously configured position (for example, the first responder's personalized position).
- Avoid or minimize the use of on-screen soft keyboards requiring touch as the primary input method since it imposes challenges to first responders who are constantly in motion (e.g., riding in vehicles at high speed) and whose hands are often occupied (e.g., gloves, firefighting equipment, and patient care devices).
- Accommodate for operation at night or in low-light situations use by providing illumination mechanism to the keyboard to facilitate text entry.
- When implementing voice input solutions:
    - The operational range for voice-activated operation should be identified, tested and optimized for various environmental factors such as the effectiveness in high noise environment; or a voice input/command issued

can be confusing to other people nearby as a request to them.

- Voice input should be processed within the local system and not rely on internet connectivity for natural language processing on the cloud. The performance of locally processed voice-to-text should be evaluated with first responders to ensure the voice input solution is reliable, accurate, efficient, and effective for first responders.

Related Topics

4.1.3 Mental Workload
4.1.6 User Interface Design
4.1.8 Mobile Data Computer (MDC)

Topic Specific References

- Marras, W.S, and Karwowski, W.. (2021). Basic Biomechanics and Workstation Design. Chapter 12 in Salvendy, G., and Karwowski, W. (Eds.). *Handbook of human factors and ergonomics (5th edition)*. John Wiley & Sons. [11]

4.1.5. Real-Time Technology

Disciplines

Problems/Needs

Need technology to record and disseminate live videos and images to first responders and incident commanders (IC) during incident response – en route or on scene.

Recommendations

Option 1

Develop a new system (such as outlined in 4.1.9 Radio Operation Design) which integrates both verbal (e.g., phone or radio) and video communications with capabilities to send, receive and display video and images from those taken by drones or other camera sources.

Option 2

Develop a special wearable device: for example, a device similar to a watch that could be worn over gloves. The device could capture, display, and send videos and images, as well as receive and display videos and images from drones or other camera sources. If there is a heads-up display (HUD) integrated to first responders' personal protective equipment (PPE), the wearable device can project the videos/images to view on the HUD.

Implementation Considerations

Overall considerations

- Operation of videos and images should not interfere with first responders' verbal communications and their primary tasks.
- Dissemination (timing, content, and delivery mechanism) of videos/images needs to be very carefully considered. Visual information could be a major distraction attracting all of the user's attention, potentially causing an overall loss of situational awareness due to the exclusion of other information inputs.
- Table 2 below illustrates the nature of some human estimation biases in a variety of scenarios affecting perceptions that may impact the performance and outcome of first responders' operations. Knowing these biases may help first responders to more accurately assess and communicate the scenarios encountered and for the recipients to interpret.
- Metadata on any automatic or manual manipulation (such as contrast, lighting, colors) of the videos and images should be transmitted along with the videos and images and made available to the reviewer/receiver.
- Possibility of information overload to first responders receiving both video and audio information which would impact speed of response and quality of action.
- For both options, the new technology should be robust, durable, and withstand rough environmental factors such as high heat, moisture, dust, noise, glare and darkness.

Option 1

The following considerations need to be taken into account:

- Minimize the number of controls needed such as one control should be used for both taking and focusing videos.
- In order to minimize the probability of operation errors such as inadvertent activation, controls should be differentiated by size and shape, and be placed away from mission-critical controls such as the emergency button.

Option 2

The following considerations need to be taken into account:

- If there are touch screens, the operation should be active with or without gloves – considering alternate controls (such as voice-activation or physical push buttons) for use cases where touch screens might not work properly.

- Additional useful and intelligent functions could be added to the device – should gather user requirements from the first responders.

Related Topics

4.1.3 Mental Workload
4.1.6 User Interface Design
4.1.9 Radio Operation Design

Topic Specific References

❖ Proctor, R. W. and Vu, K-P. L. (2021). Selection and Control of Actions. Chapter 4 in Salvendy, G., and Karwowski, W. (Eds.). *Handbook of human factors and ergonomics (5th edition)*. John Wiley & Sons. [11]

Table 2. Human Estimation Biases

Quantity Estimation	Bias
Horizontal distance	Under-estimate
Height	Over-estimate when looking down Under-estimate when looking up
Speed	Over-estimate if object is accelerating Under-estimate if object is decelerating
Angle	Under-estimate acute angle Over-estimate obtuse angle
Temperature	Over-estimate heat Under-estimate cold
Weight	Over-estimate if bulky Under-estimate if compact
Occurrence	Over-estimate pleasant occurrence likelihood Under-estimate unpleasant occurrence likelihood

4.1.6. User Interface Design

Disciplines

Problems/Needs

Problems with the user interface of current communication technology:

- Is not intuitive, user-friendly, or consistent.
- Does not minimize steps for task completion.
- Does not have an integrated system.
- Does not incorporate the latest technology.

Recommendations

There are three solution options, ordered from the least desirable to the most desirable.

Option 1 *(least desirable)*

Keep the current technology but improve the user interfaces such as controls and communications that have caused problems for first responders.

Option 2

Integrate all of the current communication requirements into one device/system with improved usability.

Option 3 *(most desirable)*

Develop an intelligent human-centered single communication device/system. The unit should include all of the new communication modes (such as videos, pictures, text, and voice activation) with requirements gathered directly from first responders to facilitate their operation.

Implementation Considerations

Back-up solutions to all-in-one devices (such as option 2 and option 3) should always be readily available. When moving toward all-in-one solution, reliability and durability of the single device become more important since if that system breaks, the user will have no other resources available to manage the situation.

Related Topics

All

Topic Specific References

- Hwang, W., and Salvendy, G. (2010). Number of people required for usability evaluation: the 10±2 rule. *Communications of ACM*, 53(5), 139-133. [17]
- ISO 9241-125:2017. Ergonomics of human-system interaction – Part 125: Guidance on visual presentation of information. [26]
- ISO 9241-161:2016. Ergonomics of human-system interaction – Part 161: Guidance on visual user-interface elements. [27]
- Lewis, J. R., and Sauro, J. (2021). Usability and User Experience: Design and Evaluation. Chapter 38 in Salvendy, G., and Karwowski, W. (Eds.). *Handbook of human factors and ergonomics (5th edition)*. John Wiley & Sons. [11]
- Theofanos, M., Choong, Y-Y., Dawkins, S., Greene, K., Stanton, B., and Winpigler, R. (2017). *Usability Handbook for Public Safety Communications – Ensuring Successful Systems for First Responders*. NIST Handbook 161. [14]

4.1.7. Easy Communication Modality to Complete Task

Disciplines

Problems/Needs

- Modality problems – inappropriate modality *(e.g., visual vs. auditory)*
- Need alternative methods to voice communications

Recommendations

- Whenever possible, simultaneously provide communications both verbally and with textual information to the first responders.
- For critical operations, provide a priority push button for communication.
- Provide visual presentation for the incident scenes while the first responders are responding to the incident.

Implementation Considerations

- Consider whether the first responders really need to have all the information available to them to effectively execute their task. Reducing non-essential information presented to first responders will improve first responders' operation and decrease their mental load and stress.
- Gather requirements directly from first responders to determine the best modality of communication and timing for different situations and disciplines by gathering requirements from first responders to facilitate their operation.

Related Topics

4.1.3 Mental Workload
4.1.5 Real-Time Technology
4.1.6 User Interface Design
4.1.8 Mobile Data Computer (MDC)
4.1.9 Radio Operation Design

Topic Specific References

See general references.

4.1.8. Mobile Data Computer (MDC)

Disciplines

Problems/Needs

Lack of functionality on MDC or functionality seldomly used.

Recommendations

Integrate all required functions (requirements gathered from first responders) such as Computer-Aided Dispatch (CAD) information, mapping, GPS, photos, notes and communication into the MDC that is detachable and portable, with appropriate screen size and weight.

From the HFE point of view, in order to maximize the usability and to provide effective and useful functionality to first responders, the

following should be considered in the design and development of the integrated MDC:

Physical Controls (such as buttons and knobs):
Utilize three techniques listed below (including differences in shape, size, and color of the controls) to ensure that first responders select the correct control for intended functionality which will help minimize errors and maximize speed of operation.

- The controls for critical functions should have the largest sizes and be closest to reach in order to minimize operation time according to *Fitts' Law* (i.e., the time to acquire a target as a function of the distance to and size of the target, see *Topic Specific References*).
- The interaction mode for each function should have a distinct shape and size different from all other functions.
- Provide distinct colors for different groups of functionalities.

Presenting CAD Information

- Presenting the information in a logical order that promotes situation awareness and facilitates decision making for first responders.
- Do not assume reverse chronological or chronological order without gathering requirements from first responders.
- Make key/critical incident information persistent and always visible without scrolling or taking extra steps to access. Collect first responder requirements and perform requirement analysis to identify most critical information such as what and where the incident is, and who is involved.

Screen/Display design: refer to 4.1.2 for recommendations.

Implementation Considerations

The development and implementation of the integrated MDC system will significantly improve first responders' communications, leading to improved efficiency and effectiveness of first responders' operations.

Related Topics

4.1.2 Display Size and Control Design – Physical Issues
4.1.3 Mental Workload
4.1.4 Physical Ergonomics – Technology and Stress
4.1.6 User Interface Design

Topic Specific References

- Fitts, P.M. (1954). The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement, Journal of Experimental Psychology, Vol 47, pp 381-391. [23]
- Proctor, R. W. and Vu, K-P. L. (2021). Selection and Control of Actions. Chapter 4 in Salvendy, G., and Karwowski, W. (Eds.).

Handbook of human factors and ergonomics (5th edition). John Wiley & Sons. [11]

4.1.9. Radio Operation Design

Disciplines

Problems/Needs

- Difficulty switching channels while en route riding in high-speed vehicles
- Difficulty in deciding and executing channel/zone switching
- Accidental button activation

Recommendations

Option 1 *(Doable Short-Term Solutions)*

- Provide appropriate training and re-training in the functional use of channel/zone switching
- Inadvertent actuation of the emergency button can cause stress and increase mental workload for the first responders, thus leading to increased error rate and decreased performance (Fig.4). The emergency button should be evaluated and redesigned/reengineered, if needed, so that it can't be inadvertently actuated but is still readily accessible at critical times. For example, one radio model that we have examined, the emergency button is next to the channel switching knob which makes it easy to accidentally activate the emergency button while switching channels. In this particular case, a solution is to increase the area around the emergency button and lower the position of the emergency button in the hole so that it can be pressed when needed but would not be inadvertently actuated.

Option 2 *(desirable long-term solution)*

The best solution is not to address the problems in piecemeal, such as the short-term solutions presented above. Instead, a holistic solution would use a completely integrated device, similar to a smart phone, with intelligent voice activation for communications, and channel switching instead of physical channel switching knobs. This device should also include a physical emergency push button (push-to-talk mission critical voice) as a backup to the voice-activated emergency call.

The benefits of developing and implementing an integrated voice-activated communication device include:

- It provides hands-free communications allowing first responders to communicate simultaneously while performing their primary tasks.
- It reduces first responders' mental workload which will result in faster and safer operations and reduce error rates. First responders will not have to decide which channel to switch or button to press when the intelligent voice recognition will direct the call to the appropriate channel.
- The all-in-one integrated device should be significantly smaller and lighter than the current radios used by first responders.

Additional useful and intelligent functions would be added to the device according to user and organizational requirements.

Implementation Considerations

The device should be robust, durable, and withstand rough environmental factors such as high heat, moisture, dust, noise, glare and darkness.

To implement an integrated voice-activated communication solution, the following considerations need to be taken into account:

- Make sure that the voice commands are designed to be compatible with first responders' expectation for activating the device to make it easy and intuitive to operate, minimizing cognitive processing required.
- The operational range for voice-activated operation should be identified, tested and optimized for various environmental factors such as the effectiveness in high noise environment; or a voice input/command issued can be confusing to other people nearby as a request to them.
- Voice-activated operation should not interfere with first responders' primary tasks.

Related Topics

4.1.3 Mental Workload
4.1.6 User Interface Design

Topic Specific References

❖ Lewis, J. R. (2016). *Practical speech user interface design*. CRC Press. [25]

4.1.10. User Interfaces – Auditory Warning Problems

Disciplines

Problems/Needs

Problems with the effectiveness of auditory warnings or alerts to first responders.

Recommendations

Provide at least one (or all) of the following solutions:

- Allow users to select, from a large set of possibilities, a warning sound unique to them.
- Provide warnings/alerts simultaneously with multiple cues such as sound, visual, and vibration.
- Provide the option to increase the sound level (Decibel) beyond the current levels.

Implementation Considerations

Before designing and implementing auditory warning, consider:

- The duration and volume of the auditory warnings should be balanced not to interfere with the user's ability to make verbal communications when needed.
- The available knowledge about noise and warnings as indicated in the topic-specific references should be considered in the design stage of the recommendations.

The benefits of implementing the solutions include:

- Allowing individually selected warning sound would help identify and distinguish which individual in the group is receiving the warning message.
- Providing multiple cues would increase the probability of the warning being detected by the recipient.
- Allowing higher volume would increase the probability of the warning sound being heard by the recipient, especially in a noisy environment.

Related Topics

4.1.3 Mental Workload
4.1.6 User Interface Design

Topic Specific References

- Casali, J. G. (2021). Sound and Noise: Measurement and Design Guidance. Chapter 18 in Salvendy, G., and Karwowski, W. (Eds.). *Handbook of human factors and ergonomics (5th edition)*. John Wiley & Sons. [11]
- Wogalter, M. S., Mayhorn, C. B., and Laughery, K. R. (2021). Warnings and Hazard Communications. Chapter 24 in Salvendy, G., and Karwowski, W. (Eds.). *Handbook of human factors and ergonomics (5th edition)*. John Wiley & Sons. [11]

4.1.11. Communications Center – Information Handling

Disciplines

Problems/Needs

- The need to be able to receive information in other modes, e.g., videos, images, and alphanumeric text information such as text-to-911.
- NG 911 concerns – in receiving text information, concern of losing the non-verbal information; in receiving visual information, concern of COMMS personnel getting excessive and potential disturbing visual information.

Recommendations

On the same user interface, allow call takers to access/monitor audio 911 calls and visual information such as text-to-911 messages.

Visual information such as videos and pictures received should be routed to human-centered AI COMMS system (as recommended in 4.1.12) for assessment. The AI system will determine the relevancy of the visual information and recommend whether (and to what extent) the visual information should be sent to agencies such as Law Enforcement, Fire, and EMS. The COMMS personnel may or may not see the visual information according to the internal organizational policy and process.

Implementation Considerations

Visual Information Aspect

- Visual information should be shared only with those whose actions will benefit from seeing it.
- Alphanumeric text information should only be sent when verbal communication is not possible.
- Privacy and security of the visual data.
- Fidelity of the visual data.

COMMS Personnel Aspect

- Psychological and emotional consequences of seeing the visual data.
- Possibility of information overload for COMMS personnel receiving both video and audio information which would impact speed of response and quality of action.

Related Topics

4.1.3 Mental Workload
4.1.5 Real-Time Technology
4.1.6 User Interface Design
4.1.12 Communications Center – User Interface for Call-taking and Dispatching

Topic Specific References

See general references.

4.1.12. Communications Center – User Interface for Call-taking and Dispatching

Disciplines

Problems/Needs

- Problems with different computers and software systems require multiple keyboards and multiple mice operated by a single user.
- Need one large integrated display for showing information currently displayed on multiple screens.

Recommendations

To address the current challenge of having different systems for different tasks, a holistic approach is needed. It is recommended to develop a human-centered AI COMMS system to operate as a decision-support agent for both call-taking and dispatching. When a 9-1-1 call comes in, this call will be simultaneously routed to both a call taker and to the AI system. Since the AI system, when designed properly, can process information and make decisions faster than human users, it will provide suggestions on the course of actions to call takers and dispatchers before they make the final decisions.

The system's user interface should utilize one large computer screen with one device for alphanumeric input (e.g., a keyboard) and one device for interaction input (e.g., a mouse) to operate all needed information and actions.

The implementation of this complete system would reduce error rate (e.g., inadvertent operations) and increase efficiency of operations. It will also help reduce COMMS personnel's mental workload and stress, and increase their job satisfaction.

Implementation Considerations

When implementing this human-centered AI decision-support system, consider that:

- Its fidelity with human-decision makers should be first validated before implementation.
- The time duration and cost may be required to develop the system.
- It may change the selection criteria as well as training and operations for COMMS personnel.

Related Topics

4.1.3 Mental Workload
4.1.5 Real-Time Technology
4.1.6 User Interface Design
4.1.11 Communications Center – Information Handling

Topic Specific References

See general references.

4.1.13. Integrated System for Wearables

Disciplines

Problems/Needs

- While wearing the self-contained breathing apparatus (SCBA) mask, first responders need easy access to specific information, e.g., air tank levels, carbon monoxide levels, thermal imaging, or incident information.
- Need for various types of technology built into first responders' personal protection equipment (PPE).

Recommendations

Information display on SCBA mask

- Develop a heads-up-display (HUD) integrated to the SCBA mask with the capability of displaying only critical information such as: air tank levels, carbon monoxide levels, thermal imaging, or incident information.
- Attention should be given to the organization and layout of the information on the HUD so that it gives first responders' the best situational awareness and does not cause distractions with unnecessary information. Displaying too much information to the users (e.g., first responders) would lengthen reaction time and increase error rate and make it hard for users to concentrate on the key vital information being assessed.

PPE technology

- Any development of new wearable technology needs to be fully integrated into existing first responders' gear without external wiring or cables. Batteries should be intelligently integrated to facilitate charging, replacement, operating time, and life cycle; ideally not requiring separate batteries for each wearable device.
- The placement of wearable devices and accessories should avoid high impact areas such as around hands and where heavy PPE is worn (e.g., straps from SCBA pack).

Implementation Considerations

Before developing the HUD user interface and the integrated PPE technology, a comprehensive collection and assessment of user requirements with first responders should be conducted.

The new technology should be robust, durable, and withstand rough environmental factors such as high heat, moisture, dust, noise, glare and darkness.

Related Topics

4.1.3 Mental Workload
4.1.6 User Interface Design

Topic Specific References

- Bartkowiak, G., *et al*. (2021). Use of Personal Protective Equipment. Chapter 25 in Salvendy, G., and Karwowski, W. (Eds.). *Handbook of human factors and ergonomics (5th edition)*. John Wiley & Sons. [11][8]
- National Fire Protection Association. *NFPA 1971 Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*. National Fire Protection Association, 1997. [22]

  (check https://catalog.nfpa.org for NFPA standards on protective ensembles for other types of fire fighting)

4.1.14. Body Camera – Physical Issues

Disciplines

Problems/Needs

Problems with size and placement of the body camera and securing it.

Recommendations

First responders are concerned with where to place the body camera and the uncertainty that the camera will not fall off. This problem can increase stress and anxiety leading to first responders' less effective operation.

Option 1 *(Doable Short-Term Solutions)*
In order to alleviate these problems, the body cameras need to be made smaller and lighter with secure fastening capability such as more powerful clipping mechanism.

Option 2 *(desirable long-term solution)*
Keep body camera in mind when designing new uniforms for police officers so that the camera is built into the clothing without extra wiring or cables (as stated in section 4.1.13 for integrated wearables). Batteries should be intelligently integrated to facilitate charging, replacement, operating time, and life cycle.

Implementation Considerations

- The required placement of the body camera should not cause video occlusion when first responders are performing an important activity, for example, when first responders are in a shooting stance.
- When determining the optimal size and weight of the camera, the desired longer battery life should also be considered and not be compromised.
- It is important to consider the unintended consequences of including certain camera functionality such as orientation or lighting self-adjustments. If the video doesn't show the perspective from the officer's point of view, then it can change the way people think about the outcome of an event.

Related Topics

4.1.3 Mental Workload
4.1.6 User Interface Design
4.1.13 Integrated System for Wearables

Topic Specific References

- Sharit, J. and Salvendy, G. (1982). Occupational Stress: Review and Reappraisal, *Human Factors*, 24(2), pp 129-162. [24]

4.2. Group B Topics with General Recommendations

The six Group B topics along with their original categories (in Phase 1 Volume 2 report [4]) are summarized in Table 3, listing in alphabetical order, with the applicable discipline(s) marked with a blue dot.

While there are no specific HFE recommendations for each of the six topics, they should be addressed by following the two-stage human-centered process described in Section 2.

Table 3. Six Topics for the 80 Problems/Needs Categories in Group B

Topics	Original Categories (in NISTIR 8245 Phase 1, Volume 2)	911			
Audio communication – clarity, reception and availability	*Audio Clarity* Hard to hear Audio feedback	•	•	•	•
	Connectivity Reception; Bandwidth	•	•	•	•
	Disruption of Operations Continuity of operations (COOP) Mobile operations	•			
	Functionality Reliability Better coverage Clearer communications Faster devices	•	•	•	•
	Radio Dead zones; traffic Multiple talk groups	•	•	•	•
	Reliability Unreliable transmissions	•	•	•	•
Develop and implement technology to achieve new objectives	*Functionality* Improved functionality	•	•	•	•
	Futuristic Smart buildings Self-driving vehicles Emergency traffic light system		•	•	•
	Implementation/IT Infrastructure Implementation/installation issues Cost a prohibitor IT management No user requirements collected or considered Public safety network reservations	•	•	•	•

	Interoperability External interoperability Interagency communication system Interjurisdictional criminal data Patient care reporting (PCR)	•	•	•	•
	Mobile Apps Discipline-specific apps Information references		•	•	•
	Overwhelmed Situational awareness			•	•
	Real-Time Technology Identification device Language translation Traffic & navigation	•	•	•	•
	Security Constraints Access control		•	•	•
	Technology Outdated Outdated Incomparable to personal technology	•	•	•	•
	Technology Overrated Problems with new technology Doesn't solve communication problems	•	•	•	•
	Tracking Caller location Responder location Search technology	•	•	•	•
	Video Data issues				•
Integrated Systems	*All-In-One* Cameras Cell phones and/or radios General multifunctional devices Software & apps Tablets	•	•	•	•
	Integrated Gear/Wearables Responder vitals			•	
	Interoperability Internal interoperability Software/Hardware compatibility	•	•	•	•
	Vehicles Automatic license plate reader				•
Microphone and earpieces	*Integrated Gear/Wearables* In-mask microphone/earpiece			•	
	Microphone/Earpiece Cord Wireless microphones Earpiece Specialized earpieces		•	•	•
New hardware and software devices added to current products for visualization	*Body Camera* Functional issues				•
	Communications Center Technology Access to caller cell camera	•			
	Futuristic Augmented reality (AR) Face and object recognition software Media/Science-fiction influenced	•		•	•
	Interoperability Body camera integration				•
	Mobile Data Computer (MDC) Navigation/ Mapping		•	•	•

	User Interfaces Hands free		•	•	•
	Vehicles Built-in camera Dashboard computer Windshield HUD		•		•
	Video Surveillance videos				•
Physical size/weight and reliability	*911 Calls* Nuisance calls	•			
	Functionality Longer battery life	•		•	•
	Physical Ergonomics Battery problems Bulky and heavy Robustness Safety concerns Smaller and lighter		•	•	•
	Reliability Unreliable technology Redundancy	•	•	•	•

5. Conclusion

This report focuses on providing practical guidance and recommendations on improving the usability of communication technology for first responders by applying human factors and ergonomics knowledge and principles in usability evaluation methodology. The current report is a companion document and should be used in conjunction with the Phase 1, Volume 2 report that identifies the technology problems and needs of first responders from the in-depth interview data.

Based on the interviews with 193 first responders regarding their views and experiences with communication technology, problems were identified, and needs were requested for improvement. In this report, two main groups of problem and needs areas were identified with usability and HFE perspectives. One group consists of 14 specific topics–to each of which specific HFE recommendations were made in order to ensure the usability of communication technology. In the other group, there are six topics clustering 80 communication technology problems and needs which generic HFE considerations are applicable. To ensure the usability of communication technology for first responders, both groups require the two-stage human-centered process to be followed for technology development and implementation. The two-stage process includes: (1) HFE professional(s) is integrated with the product team from the initiation and throughout the product development lifecycle; (2) at various stages, the product needs to go through usability evaluations before the final implementation. The HFE professional must approve that the product and technology meet the HFE and usability requirements to be ready for final implementation.

The objective of this report is to provide concise and actionable HFE guidance and recommendations to the PSCR R&D community without extensive discussions on the theoretical background information. Practitioners interested in addressing a specific topic can

take the recommendations, design and develop the technology following the two-stage human-centered process throughout the entire product development lifecycle to deliver the desirable and usable communication technology to first responders.

References

[1] Middle Class Tax Relief and Job Creation Act of 2012, Public Law 112–96, 126 Stat. 156, February 22, 2012. http://www.gpo.gov/fdsys/pkg/PLAW-112publ96/pdf/PLAW-112publ96.pdf (accessed on April 02, 2020)

[2] Public Safety Communications Research, "Research portfolios," https://www.nist.gov/ctl/pscr/research-portfolios (accessed April 02, 2020)

[3] Choong, Y-Y., Dawkins, S., Furman, S., Greene, K.K., Prettyman, S.S., and Theofanos, M.F. (2018). *Voices of First Responders – Identifying Public Safety Communication Problems: Findings from User-Centered Interviews, Phase 1, Volume 1*. NISTIR 8216, July 2018. https://doi.org/10.6028/NIST.IR.8216

[4] Dawkins, S., Choong, Y-Y., Theofanos, M.F., Greene, K.K., Furman, S., Steves, M., and Prettyman, S.S. (2019). *Voices of First Responders – Examining Public Safety Communication Problems and Requested Functionality: Findings from User-Centered Interviews, Phase 1, Volume 2.1.* NISTIR 8245, May, 2019. https://doi.org/10.6028/NIST.IR.8245

[5] Greene, K.K., Dawkins, S., Theofanos, M.F., Steves, M., Furman, S., Choong, Y-Y., and Prettyman, S.S. (2019). *Voices of First Responders – Examining Public Safety Communication from the Rural Perspective: Findings from User-Centered Interviews, Phase 1, Volume 3*. NISTIR 8277, November, 2019. https://doi.org/10.6028/NIST.IR.8277

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Appendix A: New Classifications of 107 Categories of Public Safety Communication Technology Problems and Requested Functionality

The original 107 categories of problems and requested functionality by discipline were classified into Group A or Group B, shown below in Table 4 and Table 5, adopted from NISTIR 8245–Phase 1 Volume 2 report [4]. Group A items were further clustered into 14 topics and Group B items were clustered into 6 topics.

Table 4. New Classifications of Original Problems Categories by Discipline (adopted from NISTIR 8245–Phase 1 Volume 2 report)

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topics	Problems Experienced	911			
		Radio				
B	Audio communication: clarity, reception and availability	Dead zones *Areas where radio coverage is poor or nonexistent*	●	●	●	●
B	Audio communication: clarity, reception and availability	Traffic *Problems with jammed radio channels due to reasons such as only one person can talk at a time; people communicating too much*		●	●	●
A	Radio Operation Design	Channel switching *Problems finding and/or switching to the appropriate radio channel, or radio channels becoming out of sync*		●	●	●
A	Radio Operation Design	Usability *Problems with physical aspects of the radio, e.g., accidental button activation*		●	●	●
		Reliability				
B	Physical size/weight and reliability	Unreliable technology *Problems with unreliable technology*	●	●	●	●
B	Physical size/weight and reliability	Redundancy *Backup plans needed due to unreliable technology*	●	●	●	●
B	Audio communication: clarity, reception and availability	Unreliable transmissions *Uncertainty about whether messages have been properly sent/received*	●	●	●	○

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topics	Problems Experienced	911	+	🔥	🛡
		Interoperability				
B	Develop and implement technology to achieve new objectives	External interoperability *Interoperability issues communicating with other disciplines, jurisdictions and agencies*	●	●	●	●
B	Integrated Systems	Internal interoperability *Issues with technology and data not being integrated, not communicating with each other, and often times from different vendors*	●	●	●	●
		Physical Ergonomics				
B	Physical size/weight and reliability	Robustness *Problems with technology not being durable enough*		○	●	●
B	Physical size/weight and reliability	Battery problems *Problems with battery – e.g., doesn't last long enough, compatibility, charging issues*		●	●	●
B	Physical size/weight and reliability	Bulky and heavy *Problems with device's big size and/or heavy weight*		●	●	●
A	Physical Ergonomics – Technology and Stress	Too many devices *Problems with carrying too many devices*			○	●
A	Physical Ergonomics – Technology and Stress	Physical discomfort *Technology causes physical stress on body*	○	●		●
A	Display Size and Control Design – Physical Issues	Display size *Problems with legibility if screen is too small*			●	●
B	Physical size/weight and reliability	Safety concerns *Technology putting officers at risk*				●
		User Interfaces				
A	User Interface Design	Ineffective and inefficient *User interface not designed to be intuitive, user-friendly, or consistent; not supporting users' needs*	●	●	●	●

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topics	Problems Experienced	911	+	Fire	Police
A	User Interfaces - warning problems	Alerting *Problems with user interface that provides warnings or alerts to users*		●	●	
A	Easy Communication Modality to Complete Task	Modality *Inappropriate modality (e.g., visual vs. auditory)*		●	○	●
		Implementation/IT Infrastructure				
B	Develop and implement technology to achieve new objectives	Implementation/Installation issues *Problems with implementation and/or installation of technology*	●	●	●	●
B	Develop and implement technology to achieve new objectives	Cost a prohibitor *Expensive technology preventing adoption*	○	●	●	●
B	Develop and implement technology to achieve new objectives	IT management *Problems with having adequate IT management*	○	●	●	●
B	Develop and implement technology to achieve new objectives	No user requirements collected/considered *Technology implemented without users' input*	○	●	●	●
B	Develop and implement technology to achieve new objectives	Public safety network reservations *Concerns with the implementation and/or operation of a large-scale public safety communication network (e.g., service provider, coverage, quality, bandwidth)*	●			○
		Security Constraints				
A	Cybersecurity Authentication	Authentication *Problems with the authentication process, multiple system logins, or passwords during incident response*	○	○	●	●
B	Develop and implement technology to achieve new objectives	Access control *Responders not able to use all technology/functions*		●	●	●

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topics	Problems Experienced	911			
		Technology Outdated				
B	Develop and implement technology to achieve new objectives	Outdated *Problems with aging, outdated technology*	●	●	●	●
B	Develop and implement technology to achieve new objectives	Incomparable to personal technology *Problems with technology being incomparable with personal technology available commercially*	●		●	●
		Connectivity				
B	Audio communication: clarity, reception and availability	Reception *Dead-spots within cellular reception or connection not always stable*	○	●	●	●
B	Audio communication: clarity, reception and availability	Bandwidth issue *Bandwidth issues with wireless connection*		●	●	●
		Audio Clarity				
B	Audio communication: clarity, reception and availability	Hard to hear *Difficult to hear due to technology, background noise, sensitivity of worn microphone/radio position, or SCBA mask*	●	○	●	○
B	Audio communication: clarity, reception and availability	Audio feedback *Audio feedback causing static or noise on channel*	○	○	●	○
		Microphone/Earpiece				
B	Microphone and earpieces	Cord *Microphone/earpiece cord susceptibility to melting, entanglement, becoming disconnected, or problems integrating into uniform*		○	●	●
B	Microphone and earpieces	Earpiece *Problems with earpieces or earbuds (e.g., hearing loss concerns, fit)*		○	●	●

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topics	Problems Experienced	911	+	Fire	Police
B	Microphone and earpieces	Wireless microphones *Problems with pairing wireless microphones*		○	●	○
		Overwhelmed				
A	Mental Workload	Sensory overload *Problems with handling a lot of things concurrently while actively performing primary task*	○	○	●	●
B	Develop and implement technology to achieve new objectives	Situational awareness *Technology can be distracting, requiring responders' attention*			○	●
		Body Camera				
B	New hardware and software devices added to current products for visualization	Functional issues *Problems with video quality, data transfer, accuracy of scene capture, additional operational tasks, etc.*				●
A	Body Camera	Physical issues *Problems with placement (e.g., video occlusion) and placement mechanism*				●
		Technology Overrated				
B	Develop and implement technology to achieve new objectives	Problems with new technology *New technology functionality doesn't meet expectations (e.g., disappointing, time consuming)*	●	○	○	○
B	Develop and implement technology to achieve new objectives	Doesn't solve communication problems *Technology can enable communication, but is not necessarily the answer to communication problems*	●			
		Mobile Data Computer (MDC)				
B	New hardware and software devices added to current products for visualization	Navigation/ Mapping *Navigation/Mapping inaccurate and/or not available*		●	●	○

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topics	Problems Experienced	911			
A	Mobile Data Computer (MDC)	Functionality *Lack of functionality or functionality seldomly used*		●	○	○
		911 Calls				
A	Communications Centers Information Handling	NG 911 *Concerns about excessive contextual information via visual input to 911, lack of contextual information via text to 911, or information transfer interference with callers' 911 apps*	●			
B	Develop and implement technology to achieve new objectives	Caller location *Problems with identifying caller location especially with cell phones*	●			
B	Physical size/weight and reliability	Nuisance calls *Accidental non-emergency calls, e.g., pocket dials with cell phones, smart watches and medic alert buttons*	●			
		Disruption of Operations				
B	Audio communication: clarity, reception and availability	Continuity of Operations (COOP) *Problems with separate communications centers, lack of redundancies (e.g., trunk lines, cell towers), etc.*	●			
B	Audio communication: clarity, reception and availability	Mobile operations *Problems with functionality available (e.g., mobile truck unit, VPN)*	●			
		Video				
B	Develop and implement technology to achieve new objectives	Data issues *Problems with storage, quality, or interoperability among systems*				●
B	New hardware and software devices added to current products for visualization	Surveillance videos *Problems with using surveillance videos*				●

Table 5. New Classifications of Original Requested Functionality Categories by Discipline (adopted from NISTIR 8245–Phase 1 Volume 2 report)

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topic	Functionality Requested	911	Medical	Fire	Police
		Real-Time Technology				
A	Real-Time Technology	Live video & images - capture/live feed technology *Technology to record and disseminate videos and images live to responders and incident commanders (IC) en route and on scene*	●	●	●	●
B	Develop and implement technology to achieve new objectives	Traffic & Navigation *The need for real-time traffic information and/or GPS navigation en route to an incident*		●	●	●
A	Real-Time Technology	Drones *Technology to assist first responders during incident response, en route or on scene*		●	●	●
B	Develop and implement technology to achieve new objectives	Language translation *Technology used to communicate effectively with the public without going through a third party*	●	○		●
B	Develop and implement technology to achieve new objectives	Identification device *Technology used to efficiently and effectively identify a victim or person of interest on scene (e.g., mobile fingerprint reader, iris scanner)*				●
		Functionality				
B	Audio communication: clarity, reception and availability	Reliability *The need for technology to work when necessary and how expected*	●	●	●	●
B	Audio communication: clarity, reception and availability	Better coverage *The need for improved connections to radio or cell towers from any location*	●	●	●	●
B	Audio communication: clarity, reception and availability	Clearer communications *The ability to hear and be heard more clearly via technology*	○		●	○

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topic	Functionality Requested	911			
B	Develop and implement technology to achieve new objectives	Improved functionality *Instead of new technology, improve functionality of current technology to be more effective in assisting first responders in completing their tasks*	○	○	●	●
B	Physical size/weight and reliability	Longer battery life *The need for device batteries to last the duration of an incident*	○		●	●
B	Audio communication: clarity, reception and availability	Faster devices *The need for faster technology*	●		○	●
		User Interfaces				
A	User Interface Design	User friendly *The need for technology that assists responders in completing their tasks by designing device operations to be efficiently and effectively completed in one simple step, not a series of complex steps*	●	●	●	●
B	New hardware and software devices added to current products for visualization	Hands free *Technology that can be operated without the use of first responders' hands*		○	●	●
A	Easy Communication Modality to Complete Task	Non- verbal communication *The transmission of information using methods alternative to voice communication*		●	●	○
		Tracking				
B	Develop and implement technology to achieve new objectives	Responder location *Technology that provides the accurate location of responders and responding resources both inside and outside of structures (e.g., number, discipline, location, direction)*	●	●	●	●
B	Develop and implement technology to achieve new objectives	Caller location *Technology that allows responders to pinpoint from where a 9-1-1 call originated*	●	●	●	

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topic	Functionality Requested	911	+	🔥	🛡
B	Develop and implement technology to achieve new objectives	Search technology *Technology that assists responders in search and rescue for victims (e.g., sonar, drones) or finding persons of interest (e.g., cell phone pinging)*	○		●	●
		Interoperability				
B	Integrated Systems	Software/Hardware compatibility *The need to operate a variety of hardware devices and software systems seamlessly (e.g., RMS and CAD)*	●	●	●	●
B	Develop and implement technology to achieve new objectives	Interagency communication system *Technology that makes it possible for responders to communicate between public safety disciplines, jurisdictions, and agencies, either locally or statewide*	●	●	●	●
B	Develop and implement technology to achieve new objectives	Patient care reporting (PCR) *Technology that has the ability to send patient information to the hospital and other entities that provide emergency medical services during incident response*		●		
B	New hardware and software devices added to current products for visualization	Body camera integration *The need for body camera technology to be integrated with other technology used for incident response, e.g., facial recognition systems and other camera systems*				●
B	Develop and implement technology to achieve new objectives	Interjurisdictional criminal data *Technology that allows information sharing about criminals between jurisdictions*				●
		Physical Ergonomics				
B	Physical size/weight and reliability	Smaller and lighter *The need for technology to be smaller and lighter, enabling easier portability*		●	●	●
A	Physical Ergonomics – Technology and Stress	Fewer devices *Minimizing the need to have too many devices*	●	○	●	●
B	Physical size/weight and reliability	Robustness *The need for technology to be more durable*		○	●	●

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topic	Functionality Requested	911			
A	Display Size and Control Design – Physical Issues	Larger devices *The need for certain devices to be larger (e.g., buttons, keyboards, screens)*	○	○	●	●
		Integrated Gear/Wearables				
A	Integrated System for Wearable	HUD *The need for a heads-up display built into the SCBA mask, and for it to display specific information, e.g., air tank levels, CO levels, thermal imaging, responder location*			●	
B	Microphone and earpieces	In-mask microphone/earpiece *The need for a microphone inside the turnout gear instead of having to speak into the radio via mask amplifier*			●	
B	Integrated Systems	Responder vitals *Sensors and other technology built into the turnout gear that monitors health and safety status of responders*			●	
A	Integrated System for Wearable	PPE technology *The need for various types of technology built into responders' gear*			●	
		All-In-One				
B	Integrated Systems	Cell phones and/or radios *The need for hardware and software applications to be built into smartphones, or for multi-functional radios (e.g., phone-radio combination device)*	●	●	○	●
B	Integrated Systems	Tablets *The need for tablet computers to be used as all-purpose devices, incorporating various software applications*	○	●	●	
B	Integrated Systems	Software & Apps *The need for various software applications or mobile apps to be combined into one for improved efficiency and to reduce duplication of effort*			●	○
B	Integrated Systems	General multifunctional devices *The need for devices to serve a variety of purposes, combining multiple software applications into one device*	●		○	●

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topic	Functionality Requested	911			
B	Integrated Systems	Cameras *The need for hardware and software applications to be built into photo and video cameras*	●			●
		Futuristic				
B	New hardware and software devices added to current products for visualization	Media/Science-fiction influenced *Advanced technology that replicates or repurposes what is used in mainstream media, e.g., Minority Report movie, Iron Man movie*	●		○	●
B	Develop and implement technology to achieve new objectives	Smart buildings *Buildings with sensors and other technology built-in to provide more information to responders during an incident*			●	○
B	New hardware and software devices added to current products for visualization	Face and object recognition software *Technology that has the ability to identify people and specific vehicles based on their appearance*	○			●
B	Develop and implement technology to achieve new objectives	Self-driving vehicles *Automated vehicles that do not require a driver*		●		●
B	New hardware and software devices added to current products for visualization	Augmented reality (AR) *Technology that can be used to enhance responders' environmental information during incident response*				●
B	Develop and implement technology to achieve new objectives	Emergency traffic light system *Traffic lights that adapt to emergency vehicles, changing traffic signals to allow vehicles responding emergent to pass through intersections*		●		
		Microphones/Earpieces				
B	Microphone and earpieces	Wireless *The need for cordless microphones and/or earpieces*		●	●	●

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topic	Functionality Requested	911			
B	Microphone and earpieces	Specialized earpieces *Custom earpieces that permit non-radio sound to be heard while the earpiece is in use*			●	●
		Radios				
A	Radio Operation Design	Channel switching *Non-manual radio channel switching capabilities, either automatically by location or remotely by dispatch*			●	○
B	Audio communication: clarity, reception and availability	Multiple talk groups *The need for a variety of different avenues for communicating on the radio*		○	●	○
A	Radio Operation Design	Prevent accidental transmissions *The need for devices to guard against unintentional radio use*		○	●	
		Mobile Apps				
B	Develop and implement technology to achieve new objectives	Information references *Mobile apps that provide access to the internet for databases of searchable, downloadable, or printable information*		○	●	●
B	Develop and implement technology to achieve new objectives	Discipline-specific apps *The need for specific apps (e.g., e-ticketer or license scanner for LE, asset tracking for FF)*			●	●
		Vehicles				
B	New hardware and software devices added to current products for visualization	Windshield HUD *Technology built into the windshield of police vehicles that displays relevant incident information*				●
B	New hardware and software devices added to current products for visualization	Built-in camera *The need for a camera to be mounted on the dashboard or in rear of vehicle*		○		●

New Classifications in This Report		Original Categories in NISTIR 8245, Phase 1 Volume 2	Disciplines			
Group A or B	Topic	Functionality Requested	911			
B	Integrated Systems	Automatic license plate reader *The need for technology that automatically scans and flags license plates from the vehicle without officer actions*				●
B	New hardware and software devices added to current products for visualization	Dashboard computer *The need for CAD technology to be built into the vehicle's dashboard*				●
		Usable Security				
A	Cybersecurity Authentication	SSO *The need for single sign-on capabilities to simplify authentication across apps*	○		○	●
		Communications Center Technology				
A	Communication Center – User Interface for Call-taking and Dispatching	Improved dispatch interface *The need for dispatch-specific interfaces to be more useful and intuitive*	●			
A	Communications Centers Information Handling	Multimedia data packages *The need for call takers to be able to receive information in other methods, e.g., video*	●			
B	New hardware and software devices added to current products for visualization	Access to caller cell camera *Technology that would allow COMMS to activate and view the caller's camera to see the caller's environment*	●			
A	Communications Centers Information Handling	Large multi-view display *The need for multiple computer monitors setup in the control room*	●			