Towards Developing a Standardized Usability Evaluation Methodology for Public Safety Communications Technology: A User-Centered Approach

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Towards Developing a Standardized Usability Evaluation Methodology for Public Safety Communications Technology: A User-Centered Approach

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ABSTRACT

In public safety and homeland security, it is important to understand technology users' primary goals, the characteristics of the users, and the context in which they are operating. New and emerging technologies present opportunities and challenges for public safety standards. As part of the Public Safety Communications Research (PSCR) effort, the National Institute of Standards and Technology (NIST) usability team is currently researching the usability of communications technology for first responders. This is a large, multi-phase research project, with the ultimate goal of developing a standardized usability testing and evaluation methodology for public safety communications technology. In this document, we discuss our application of a user-centered research methodology to investigate first responders' technology and communication needs. We present the details of the initial phase of the project, including our methodological approach and results from working with subject matter experts (SMEs) in fire, emergency medical services (EMS), and law enforcement fields. We conducted in-depth interviews with 133 SMEs to understand their perceptions and attitudes towards communications technologies, and their

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Keywords

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Introduction

The forthcoming Nationwide Public Safety Broadband Network (NPSBN) is intended for public safety to take advantage of new technological innovations and enhance their communications and information sharing. The establishment of the NPSBN with the ability to run solutions over Long-Term Evolution (LTE), a high-speed mobile communication standard, provides a unique opportunity to advance public safety communications. As such, the public safety community is in the process of transitioning from the use of land mobile radios (LMR) to a technology ecosystem including a variety of broadband data sharing platforms. The NPSBN will enable law enforcement officers, firefighters and emergency medical services providers to send data, images, video, and location information in real-time. These new capabilities should help first responders perform their life-saving mission more safely, efficiently, and effectively.

This new NPSBN technology ecosystem has significant implications for public safety and homeland security standards development in the usability space. If advanced public safety communications technology is to be successful, first responders[8] must be able to achieve their goals and objectives with effectiveness, efficiency, and satisfaction in a variety of public safety contexts. In other words, the technology must be usable according to the International Organization for Standardization (ISO) 9241-210:2010 definition of *usability*: "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 [1]."

Research on usability and enhanced user interfaces (UIs) has been recognized as one of several major research priority areas necessary to support new public safety communications technology by NIST's Public Safety Communications Research (PSCR) effort. Well-designed and tested UIs are important components for successful deployment and adoption of new communication technology by first responders. In order for first responders to execute operations successfully, technology must support their ability to efficiently and effectively complete their tasks without interference – success requires a "sound understanding of the user, their requirements, and the inherent features that make a system usable [2]." The long-term goal of NIST's PSCR usability effort is the design of a standardized usability testing methodology and associated testing environment that is as realistic as possible and provides for repeatability and validity. Towards this end, our immediate work provides an in-depth look at the population of first responders, along with their work environment, their tasks, their technology usage, and their communication needs. The first phase, Phase 1, of the project is a qualitative component,

[8] For the purposes of this report, the use of first responders refers to personnel who are actively involved in day to day incident response and operations or in supporting roles.

focusing on interviews with first responders across the country. The second phase, Phase 2, will utilize the results of the qualitative interviews to inform a large-scale quantitative survey to be distributed nationally to first responders. The two phases of the project complement each other in order to provide a holistic view of first responders and their work, including their beliefs and needs related to communication technology. Here we report on initial analyses from Phase 1, the qualitative interviews, that have findings relevant to usability standards development for public safety and homeland security.

Background

Public safety has not typically benefited from the same widespread human factors attention that other domains such as the military and aviation have received. Despite this, the human factors research community has contributed public safety research in certain notable areas, such as radio interoperability and simulation-based training scenarios (e.g., [3][4]). Furthermore, the core theories of human factors methodology and key components of usability testing are domain-agnostic, meaning they apply to public safety in the same way that they apply to military, aviation, or any other domain. For example, successful usability testing depends on many factors including a well-defined methodology based on knowledge of users (here, first responders in the public safety domain), their tasks and contexts.

In order to better understand the variety of public safety contexts, we reviewed After Action Reports (AARs) across a variety of incident scenarios prior to developing our research questions and interview protocol [5]. Based on AARs and discussions with Subject Matter Experts (SMEs) in Fire, EMS, and Law Enforcement, we generated three initial research

questions that informed our Phase 1 study:

1. How do public safety personnel describe the context of their work, including their roles and responsibilities as well as process and flow?
2. How do public safety personnel describe their communication and technology needs related to work?
3. What do public safety personnel believe is working or not working in their current operational environment related to communication and technology?

These questions served as guides for the development of data collection tools, analysis of the data, and the presentation of results. It is important that input from first responders is collected and incorporated as the PSCR research community and the public safety and homeland security standards communities all move forward in developing technology for incident response. To do this, we must better understand the behavioral, procedural, and technical pieces that first responders believe are necessary to facilitate communication and best address their technology needs. Such data help define the problem space with respect to communication technology to allow designers, developers, researchers, and standards bodies to focus on translating and incorporating the user experience into new and existing technology for first responders. The ultimate goal is to enable the public safety community to better achieve their primary goals of protecting lives and property.

There are approximately 4 million first responders in the public safety community in the United States (U.S.), comprised of firefighters (FF), emergency medical services (EMS), law

enforcement (LE), public safety (PS)[9], communications (COMMS) personnel, including 911 call center workers, and others. These various types of first responders have different roles and functions, respond to different types of situations, operate on many different levels, and have varied communication needs. The public safety community also differs across organizations, jurisdictions, and geography. The diverse makeup of the public safety community translates into different first responder contexts of use and communication needs.

This document provides information about the contexts of first responders' work and how these contexts influence their communication and technology needs, as well as their beliefs and perceptions about their current technology, and what they would like technology to do. The information provided is supported by exemplar quotes representing first responders' variety of user needs and requirements to solve the technological problems they face in performing their work. Specific categories of technology development opportunities are identified. Finally, a set of user-centered design guidelines are described, serving as a data-driven foundation for future technology and usability R&D.

Materials and Methods

The study can be described as a sequential, exploratory multi-method design. Qualitative research is iterative in nature and focuses on the importance of participants' voices and perspectives throughout the research process. The research process consistently returns to the research questions (as described in the Background section) to inform future elements of the

[9] Public safety personnel are cross-trained in all three first responder disciplines – FF, EMS, and LE.

process such as data collection and data analysis. Data collection and data analysis were conducted in tandem and occurred iteratively, each informing future iterations. This project is cross-sectional (see Sampling Strategy section), including input from participants from all public safety disciplines, from a variety of ranks and levels, and from a variety of geographical areas. A case study approach was used, which Yin [6] argues is appropriate when exploring "how" questions where contextual conditions are relevant to the phenomenon under study, and where the behavior of those involved in the study is only observed. For this project, the phenomenon of study consists of the experiences of first responder communication and technology, which cannot be understood outside of the first responder context.

Data collection was phased, with approximately 66 % (total of 133) of the interviews conducted in fiscal year (FY) 2017[10] and the remaining interviews conducted in FY 2018. The initial focus was on gathering data in urban and suburban areas from FF, EMS, and LE. In FY 2018, data collection expanded to include rural areas as well as interviewing tribal and COMMS personnel.

PARTICIPANTS AND SAMPLING STRATEGY

Since demographic factors such as age, years of service, and gender may play a role in participants' views related to public safety communication, purposive sampling[11] was applied in Phase 1. The sampling involved seeking participants who represented the full range of first

[10] FY'17 data collection ran from June to September of 2017, and FY'18 data collection ran from October 2017 to March 2018. Only FY'17 data are included in this document.
[11] Purposive sampling is a non-probability sampling technique where characteristics of a population and the objective of the study are used to choose members of population to participate in the study.

responder experiences. Multiple variables were considered during sampling strategy development in order to provide a representative sample of first responders in the U.S.; these variables are detailed in subsequent sections.

Role and Jurisdictional Diversity

There are a wide range of different types of first responders. They have different roles and responsibilities, as well as different communication and technology needs. The sampling strategy includes interviewing FF, EMS, LE, PS, and COMMS. Having input from each of these different types of first responders allows exploration of the similarities and differences among them, as well as the connections in their work.

The perspectives of first responders from a variety of positions within each of the public safety disciplines were also included since each level has differing needs related to communication and technology. Participants were currently in the field or had previous experience in the field, many having worked their way up the ranks into their current positions. Their responses represented not only their current positions and perceptions, but also those from when they were in the field as patrol officers, firefighters, or other first responders. Another important demographic variable is jurisdictional diversity. The jurisdictional relationships among various agencies including federal, state, county and local may impact first responder requirements. These inter-agency relationships will be considered in future iterations.

Geographic, Size, and Economic Diversity

Due to the varied public safety issues faced in different parts of the country, geographic

and cultural diversity were primary considerations. Areas for interviews were chosen that provide reasonable coverage of the depth and breadth of geographic and cultural diversity in the U.S. Also taken into consideration was coverage of the varied types of incidents that first responders face. These 8 areas align well with the 10 regions defined by the Federal Emergency Management Agency (FEMA) [7], as shown in Fig. 1. Due to time and resource constraints, we were unable to sample all 10 FEMA regions for the qualitative interviews. However, all 10 FEMA regions will be sampled for the future large-scale quantitative survey, envisioned for FY'19.

Across the U.S., urban (U), suburban (S), rural (R)[12], and tribal (T) districts are sampled to ensure that cities and districts of different sizes and different economic realities are represented (marked with the nearest airport codes in Fig. 1). These communities have different needs and experiences related to public safety and communication. This approach provides insight into the many different experiences of public safety communication across the U.S., ensuring coverage of both typical and unique experiences. The goal was to conduct five interviews each with police officers, firefighters, and EMS personnel in urban areas; three interviews with each discipline in suburban areas; and two interviews with each discipline in rural areas. We selected different target interview numbers for urban, suburban, and rural areas, since the number of first responders in an area is roughly proportional to the size and population of the community they serve.

[12] U – Territory inside an urbanized area or a principal city with a population of 500,000 or more. Urban areas represent densely developed territory that have a densely settled core with densely settled surrounding areas.
S – Territory outside a principal city and inside its own urbanized area with a population of at least 50,000. Suburban areas represent those in close proximity to densely developed urban areas.
R – Census-defined rural territory that is at least 5 miles or more from an urbanized area, as well as rural territory that is at least 2.5 miles from an urban cluster (territory with a population between 2,500 and 50,000).

Another variable related to size and economic diversity is the volunteer versus career status of first responders, which relates almost exclusively to firefighters. Of the approximately one million firefighters in the U.S., about 70 % are volunteer [8]. Of these, 95 % serve in areas with fewer than 25 000 people, thus generally in more rural areas.

Participant Demographics

Demographic statistics of the sample are presented in Fig. 2. These demographic statistics were collected using a demographic questionnaire at the start of each interview. Note that the demographics in Fig. 2 are from n=122 first responders, as some participants did not complete all questions on the demographic questionnaire. While there were very few women in the interview sample, 9.84 %, this is representative of the first responder community in general. Women make up approximately 13 % of LE [9] and less than 5 % of FF [10]. Most of the women interviewed were in LE, representing the higher percentage of women found in that discipline rather than in FF. First responders from a range of age groups were also interviewed, providing opportunities to explore if and how age might affect their perceptions and experiences. Finally, participants were interviewed with a wide range of years of service, from those with less than a year in the field to those with over 30 years of service. Generally, those with more years of service held different ranks and were often in positions of authority, having moved up during their career. This provided valuable insights into the ways in which rank and position might impact first responders' perspectives related to communication and technology.

Data Collection Instruments

A semi-structured interview protocol was developed for use during Phase 1. The interview protocol was based on the research questions, input from subject matter experts (SMEs), the literature, and background knowledge of the first responder community. The protocols included a short demographic form, and a variety of questions related to work tasks, relationships, and communication and technology tools.

An iterative approach to refining the data collection instruments ensured that language, questions, and concepts were appropriate and would elicit valuable responses that would allow the research questions for the project to be answered and addressed. To determine construct validity and to assess language appropriateness for the population, pilot interviews with two or three first responders in each discipline were conducted. Several SMEs also reviewed the instrument to assess content validity and to ensure all relevant and related concepts were addressed by the instrument. An alignment matrix was created to ensure each of the research questions was adequately addressed and the goals for this phase of the project were achieved by the interview protocol. This ongoing review and refinement of the protocol is consistent with the iterative nature of qualitative research.

Based on results from the pilot interviews, a short demographic questionnaire was finalized focusing on gender, age and years of service since these three variables might influence participants' perceptions of and experiences with technology. Two additional questions related to participants' ease and comfort with technology were also included. The demographic questionnaire was short to allow maximum time for the interviews. Since usability focuses on users, their tasks, and the context of use [11], interview questions fell into two main categories:

context of work; and perceptions of and experiences with communication and technology. Questions about context of work included descriptions of: their overall job, tasks, and daily routine; relationships with other people (their direct colleagues, other first responders, dispatch, the community, and the media, for example); and what work is like—both in and out of the station or specific work environment.

The protocol and all relevant documents were approved by the NIST Human Subjects Protection Office (HSPO) and the Office of Management and Budget (OMB) Paperwork Reduction Act (PRA). The finalized interview questions are listed in Appendix A and the demographic questionnaire is in Appendix B.

Procedure

Phase 1 is based on the collection of in-depth, one-on-one, semi-structured interviews. 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. Each participant was provided with a copy of the Information Sheet about the study, and was informed verbally that:

- their participation was voluntary,
- they could stop at any time without penalty,
- they could decline to answer any question(s),
- all data would be de-identified,
- the interview would take approximately 45 minutes, and
- the study had been approved by the HSPO.

Participants were asked for permission to audio record the session. Only one participant declined, in that case the research observers took notes about the interview and participant responses. Participants were sometimes called away during an interview for an incident response.

Fiscal Year 2017 (FY'17) data collection ran from June through September, with 133 participants interviewed in a total of 105 sessions (some interviews included multiple participants). The breakdown of interviews is shown below in Table 1. There was a total of 5 627 minutes in the recordings and a total of 1 807 pages in the transcripts (Table 2).

TABLE 1. Number of Participants Interviewed in FY'17: (a) By Discipline, and (b) By sites visited.

(a) By discipline

	FF	**EMS**	**LE**	**COMMS**[a]	**PS**	***Total***
Urban	35	11	26	1		*73*
Suburban	25	6	12	1	2	*46*
Rural	5	3	5	1		*14*
Total	*65*	*20*	*43*	*3*	*2*	*133*

(b) By sites visited (using airport codes to represent general locations)

	FF	**EMS**	**LE**	**COMMS**[a]	**PS**	***Total***
AUS	9	4	7			*20*
DCA	8	3	8			*19*
DEN	11	8	10	2		*31*
NYC	10		2			*12*
ORD	5	5	4			*14*
SEA	15		7			*22*
SFO	7		5	1	2	*15*

[a] Although they were not planned for Year 1, there were 3 COMMS interviews due to convenience sampling, since they were present at the interview locations and expressed great interest in participating.

TABLE 2. Interview Length and Transcript Numbers.

	Count*	Total Length	Average	Max	Min	SD
Interview Recordings	105	5 627 (minutes)	53.59	121	13	18.58
Transcripts	105	1 807 (pages)	17.21	42	5	5.90

* There were only 105 interview recordings/transcripts because some interviews included multiple participants.

Qualitative Data Analysis

This section describes the qualitative data analysis process and procedures used to analyze the interview data. The data consist of interview transcripts, demographics, field notes, and analytic memos. The interviews and field notes provide an in-depth and yet overarching look at first responders and their work in their own words. All interview recordings were transcribed by an external transcription service. The transcripts form the major dataset for analysis. In addition, research team members wrote field notes related to interviews they conducted, which served as additional data for analysis. Data analysis for Phase 1 involved both individual and research team coding and analysis sessions.

In contrast to coding in the computer science and software engineering domains, qualitative coding is a process of labeling sections or chunks of narrative data capturing the essence and/or salient features to group, compare, and/or manipulate similar chunks. Coding is a process for reducing and/or reconfiguring data in an organized and meaningful way.

Coding is the beginning of the analysis process. The coding process began with an *a priori* code list. The a priori codes are a set of labels based on the research questions, relevant literature, and an understanding of the communication and technology space in the first

responder community. Each research team member used the a priori codes and coded (labeled) the same subset of five randomly chosen transcripts to ensure that the codes were being used by the team in similar ways and to identify needs for additional codes. The goal of this step was to recognize where there was convergence and divergence among the researchers' coding and to use these points of intersection/difference to explore the data more fully. The code book was revised and the codes were operationalized based on ongoing discussions, ensuring that multiple points of view were captured. Operationalizing each code consisted of providing the definition of the code, when to use it, when not to use it, and examples for each code.

The second step of coding is data extraction. Data extraction refers to pulling all the data associated with a code from each transcript into a separate document. This process of breaking apart the data is a technique to study the data in different ways, used to provide access to the "whole" and to the "parts" to determine if and where relationships exist or what themes might be developing across codes.

Qualitative analysis is the process of exploring the relationships of the data and the codes to identify themes. Analysis includes thematic, negative case, values, and descriptive exploration of the data and the codes [12]. Analytic memoing is used to document the relationships of the data and the codes. The iterative process of going back and forth between data and codes, between the full data set and extracted files facilitates the identification of themes, trends, outliers and provides an overall impression and understanding of the data.

Results

This section reports on important findings from data analysis to-date, focusing on those themes of greatest relevance to development of future usability testing standards. These technology problems and needs were largely described by first responders when answering interview questions related to technology and information (Appendix A, Q2-7). During data coding, "problems" were operationalized as issues identified by participants related to doing their jobs. "Needs" were operationalized as things that would facilitate first responders' jobs. Although these problems and needs could be related to concepts other than technology (people, information, policies/procedures, funding, etc.), here we focus solely on those problems and needs directly related to technology, and usability issues in particular. After data coding and extraction were completed for technology problems and user needs, those extractions were then thoroughly analyzed and categorized; problems and needs from the usability categories form the bulk of results discussed here.

Tabular data with extraction counts by code and discipline are included in this section, followed by an in-depth look at qualitative findings by using the words of first responders who participated. The conventions for referencing data are as follows: all direct participant responses are verbatim in blue text and come directly from participant transcripts. The participant responses are followed by a notation that is comprised of three parts: discipline (FF; EMS; LE; COMMS; PS); city type (Urban=U; Suburban=S; Rural=R; Tribal=T); and interview number. Thus (FF-R-009) refers to an FF interview, from a rural location, who is fire interviewee number 009. This convention provides assurances to the reader of the data's provenance and that the data can quickly and easily be located within the larger dataset when necessary.

The direct participant responses used to illustrate the findings in the following sub-sections are exemplars from the coded transcriptions. Each was chosen as an example representing the set of extracted quotes to describe the concept. For the majority of the presented findings an exemplar from multiple disciplines (designated in the notation for each quote) is presented, demonstrating the cross-cutting nature of the finding.

TECHNOLOGY PROBLEMS AND NEEDS

Table 3 provides a view of the data by those codes particularly relevant to this report, sorted by first responder disciplines. Table 3 presents the number of coded extractions from all transcripts for FY' 17 cities: Austin, Washington, D.C., Denver, New York City, Chicago, Seattle, and San Francisco[13]. The final code book listing all codes, sub-codes, and their operationalizations is presented in Appendix C.

TABLE 3. Extraction Counts by Code and Discipline

CODE	FF	EMS	LE	PS	*Total*
Context of Work	510	252	532	9	*1303*
Context of Work - Stress/Overload	85	27	95	8	*215*
Context of Work - Risk/Safety	106	36	109	14	*265*
Context of Work - Relationships	212	93	279	5	*589*
Frustration	155	53	198	6	*412*
Information	143	70	93	2	*308*
Information - Control	71	30	92	2	*195*
Operational Environment	439	282	368	13	*1102*
Problems	63	36	32	3	*134*
Problems - Technology	611	211	631	33	*1486*
Problems - People	142	32	95	2	*271*
Problems – Information	136	46	105	2	*289*
Problems – Policies/Procedures	116	49	112	2	*279*
Reliance on Technology	37	21	29	1	*88*
Rules & Politics	2	2	1	0	*5*
Rules & Politics – Priority/Influence	40	8	28	7	*83*

[13] Note that additional cities were included in FY'18 data collection.

User Characteristics	52	26	93	2	*173*
User Characteristics – Knowledge/Experience/Skills	153	88	161	5	*407*
Wish List - Needs	388	121	356	18	*883*
Total	***3460***	***1483***	***3409***	***134***	***8486***

As is shown in Table 3, there were numerous technology problems and needs identified by first responders in our interviews. While there some key differences among FF, LE, and EMS domains in terms of specific technological problems and needs they described (for example, LE experienced more body camera problems than did FF or EMS), there was fairly extensive overlap in the majority of problems and needs expressed across domains. This overlap is indicative of cross-cutting technological issues experienced by first responders; such cross-cutting themes offer important opportunities for usability researchers and standards bodies to contribute meaningful solutions in the public safety and homeland security communities. As we are moving towards a standardized usability testing methodology, we focus the remaining Results and Discussion sections on those technology problems and user needs of greatest significance to usability.

Usability: Physical Aspects

First responders across all domains experienced problems with physical aspects of usability, often referring to the size, weight, bulkiness, and durability of technology. It is important to note that this theme of physical usability emerged in both the problems and needs data across domains, despite the fact that we did not specifically ask first responders about usability in our interviews (see Appendix A for interview questions). When describing physical usability issues, first responders gave a variety of examples referring to different technologies:

…the shoulder mic, I wrap my earpiece around it to try to hold it in place. Then I've got cables that go back and attach to my vest to hold onto this. And then I've got the cable that comes around to my radio and then it locks on. So it's kind of cumbersome because you only have so much space to put so much technology and we're running out of room. (LE-S-021)

I think the self-contained breathing apparatus, the bottles that we use, right? The cylinders. As they're adding technology they're adding weight. The Scott pack that we used to have with no bells and whistles, just air, that was it. It was 18 pounds. The thing we have now is like 27 pounds. Now, it has technology built in. It lets you know when your bottle is low. It has all these things. And if you go down, it has a computer chip and someone can use a homing device to find you. And that's all amazing, except it's 50 % more on your back. And the minute you put that on, you're not thinking about the fact that the microchip might help somebody find you, you're thinking about the fact that, "I'm slamming this thing against my back 12 times a day. I'd really rather not slam 27 pounds. If I had to slam something against my back, I wish it was 18," right? (FF-U-012)

So I have a hard time trying to fit everything on my belt as required in policy. Especially if you're some of the smaller officers, male or female just depending on your waist size, it's like you don't have enough real estate to fit all this stuff that's required. So a lot of people have dropped tasers or that kind of stuff. Now

> they're adding the body camera's right here. And you have a radio right here. You have the mic. This is just here. And then you're like-- and then you've got your notepad. You've got your pens and then everything around your waist and your gloves. (LE-U-007)

The idea that first responders are "running out of room" for technology points to the fact that usability evaluation must take a holistic view of technology; while individual pieces of technology may work well in isolation, when they are combined, problems with weight and space constraints often arise. First responders often commented on the need for technology that is small, lightweight, and portable:

> In a perfect world, I would like technology that's small, that I can talk to and would get rid of all the stuff I have to carry… my gun, taser, that kind of stuff. That all makes sense. But some of the other stuff, if we could just kind of work it into one thing that was small and light possibly, that'd be ideal. (LE-U-007)

> So I would like to be able to do everything that I can do in my car away from my car via a cell phone, or a tablet, or something portable I can put in my pocket, or put in a backpack, or magnetic somewhere, or something like that. (LE-U-003)

> I would say probably a small PDA[14] would be really cool to have in the back ambulance, and maybe just a remote-- I guess just be able to enter some basic demographic information in a really easy kind of format instead of having to grab

[14] PDA stands for Personal Digital Assistant.

the laptop sometime. (EMS-U-004)

First responders, especially in the fire domain, often discussed issues with durability and ruggedization of technology, other aspects of physical usability that must be considered.

I think the tablets may have its benefits as long as they're durable…We're not delicate. We're just not delicate people. So when you put something on there that is a level of technology that is where we are today but is not durable, that's a concern for us as firemen. (FF-U-025)

It's got to be bacteria resistant. It's got to be waterproof…It's got to go through high temps, got to go through low temp. It can't have thin wires…We use it in the water. We use it in the cold. We use it in the hot. (FF-R-019)

I think the radios need to be hardier so that if they are exposed to chemicals, or if they are exposed to fire, if they are exposed to these things they keep working. Radios have become the lifeline of this industry--that is how they get help, need help, whatever, that's where they live. (FF-S-023)

That's one of the things I think would help out a lot of firefighters but I understand that a lot of our [EMS] stuff needs to be durable as well. Coming up with durability and smaller objects is harder to do… Small is good. But coming up with-- I understand having a durable product too is-- having a durable product

> is more important than having a small product. But if we are able to figure out both, that would be a great thing to have. (EMS-S-014)

Usability: User Interfaces and Information Display

As with physical aspects of usability, we did not ask specifically about problems and needs related to user interfaces (UIs) and information display, yet the importance of UIs and their associated functionality emerged as a consistent theme across public safety domains. Information presentation is critical for public safety incident response, and first responders are keenly aware when there are issues with the manner in which information is displayed to them:

> But there's a level of art and science to how information is displayed. And I don't think that those who are creating the applications for us now either understand that or have the capacity to invest in the infrastructure necessary to display it cleanly in a way that works. (FF-S-032)

> The push is important, how [information] gets to the officer. Flying, bing, and you just see a big picture, "This is the car we're looking for." That's awesome…It needs to be boom, "Wanted vehicle for this," boom, and just the picture of it. Simple, bold writing. That's the key…Give it to me so I can digest it. (LE-U-023)

> You're getting all these 10 incidents. They're getting thrown on us. Now you're trying to read the comments in that one while they combine another one into it, so it scrolls that down to the bottom. So technology-wise, yeah, the way that a lot of

> these CADs[15] and the way they interact with tablets, their setup is they're not for actually relaying the information or reading the information. It just runs it like a running log, like you're looking at a phone bill, basically, whereas they should be set up more where it's more filtered information. It shouldn't just have all the generic information displaying. And that's across the board…that's here, that's everywhere that it just…it just dumps whatever information is in the CAD remarks all into one rather than actually having it more of a filtered stuff. I don't care what the contact log information is. It should be in the background. I just want the actual remarks. (FF-U-042)

The idea of wanting and needing simplicity in technology was articulated by numerous first responders in our interviews. First responders referred to the idea of simple, easy-to-use, "Fisher-Price®" technology:

> You need relatively simple what I call "Fisher-Price® technology." Big shapes, big buttons, colors, things like that so that I don't have to scroll down menus and things like that. I need it very simple because I don't have the time or the mental capability or the bandwidth to be looking at a lot of different things. When you're under stress, you want something that will do simple things quickly. And a radio is very good for that, but when you're in trouble, that's where you need that the most. (FF-S-035)

> You have so many tasks that you're trying to achieve… Simple shape, one button,

[15] CAD stands for Computer Aided Dispatch.

boom…It is super beneficial to be able to just hit one button, find that one thing. It's in the same spot on your gear every single time." (FF-S-035)

I think there's room for [new technology] as long as it's durable and it's user-friendly. That's huge. Because when we need the technology, we need it to be simple. We don't need it to be complex because we don't have the time to work through complexities in anything technology because our decisions are instant…And so technology is great, but if it's complex, it kind of is counterproductive. (FF-R-025)

So instead of doing all these commands to do one function, just make it one button, make it simple. If you want to talk to someone, hit talk, and then go from there or make it more of a push button, easier. (LE-S-034)

With everything across the board, if you don't make it simple, they're not going to do it. They're just going to move on to the-- or stay where they are, in the past. (LE-S-021)

It's over-complicated…just make it simple. Cops are smart, but we're smart in a different way, but adult learning is different. When you're older, you don't want to learn new things. You don't want to learn how to utilize this iPad for work. You don't want to learn how to utilize this new MDT[16] system. (LE-U-013)

[16] MDT stands for Mobile Data Terminal.

First responders require technology solutions that are simple to use, simple to learn, and simple to integrate into their environments; they need usable technology.

Usability: Communication Needs

A core tenet of usability is "know thy user." Part of this knowledge is understanding how user characteristics, such as position or years of experience in the field, can impact technology usage. In our data, very distinct differences were observed in communication and information needs and practices across first responders, depending in large part on their discipline, their position, and especially their role in the chain of command. Participant responses clearly show that not all first responders need access to all types of communication technology, nor to the same communication tools—everyone does not need everything. There are some important similarities across disciplines; for instance, FF, EMS, and LE all need to know the location and nature of incidents, and traffic patterns while in route to a location. However, it is important that technology developers and data providers know that even within a single discipline, technology and information needs differ based on both individual first responder roles, and the scale and nature of the incident to which they are responding. In the public safety realm, communication is a hierarchical act in that people at different levels need different tools to communicate and have different reasons for communicating and potentially different types of information to communicate.

In FF, information and communication needs differ drastically between incident commanders (IC) and the firefighters under their command. The ICs need a much more holistic view of the incident to monitor and direct all teams involved, whereas the individual firefighters

are often completing very specific tasks and communicating only with their immediate crew. Likewise, information and communication needs for a single-family home structure fire differ from a high-rise fire or a large-scale hazmat incident.

For EMS, information and communication needs of an EMS squad supervisor responsible for directing multiple crews are different from those needs of an individual paramedic and his/her partner. Coordinating and providing patient care for a mass casualty incident (MCI) is different than dealing with a single cardiac arrest patient.

In LE, information and communication needs for a single patrol officer during a routine traffic stop are very different than those of an incident commander in charge of coordinating police response to an ongoing active shooter incident. The needs of shorter duration incidents versus more extended ones, such as public protests and demonstrations require different information and communication.

During incidents, another communication need is accountability and location tracking. Those who monitor and direct personnel expressed the need to have the capabilities for accountability and location tracking of the crew, units, and building occupants.

> So I think that my number one thing would be that, either through the use of our radios or some device, that we can get accurate physical accountability on the fire ground. So it's not just the X, Y coordinate. I want the X, Y, Z coordinate. (FF-U-014) (Urban Assistant Fire Chief)

I can tell you that for large-scale events, from the command side of things, I would like to see or have some type of a booklet saying, "Okay, you know what? These ambulances are coming from this direction and these ambulances are coming from this direction. Where can I place them so that they don't running[*sic*] into each other or direct them in a way…?" (EMS-U-010) (Urban District EMS Chief)

There's a lot of rescue stuff for downed firefighters. It would be great to have location devices on firefighters' hats so that I can see, "I have two in the basement right now and there's supposed to be only two. Good. I have three on the second floor, and there's supposed to be five. Where are your other two people? Hey, there's a mayday in the basement." And, "Okay. It looks like I have this engine in the basement, and they must be calling the mayday." It'd be great to have a-- and again, that's that screen. It'd be good to have just a regular house layout. (FF-S-041) (Suburban Battalion Chief)

You can actually pull up locations, you can pull up overheads of locations, you can touch screen. So like if I respond and someone's barricaded inside their house, I can pull up the location on [service name redacted]. I can touch screen and go, "Officer Jones is there, Officer Smith is over there." You can actually map out your tactical situation so you can have awareness…. Everybody on the call, you can track people by their GPS locator on the radio so you know where officers are

> at, at these critical incidents. If you have, whether it's a barricade or a bad car accident or something, it gives the commander the ability to know what's going on at the entire thing. Right now we actually end up using paper and pencil to do that. (LE-U-029) (Urban Assistant Patrol Chief)

As is evident in this section, communication needs vary dramatically according to the chain of command, the type and size of the incident, and responsibility for accountability and location tracking.

TECHNOLOGY OPPORTUNITIES

Based on the user identified problems and needs in our data, five cross-disciplinary opportunities emerged for the technology R&D community. These are common needs and key characteristics that cut across public safety domains, and can benefit FF, LE, EMS, PS, and COMMS domains.

- **Interoperability** – The ability of a system or a product to exchange and make use of information with other systems or products without special effort on the part of the users—data integration and sharing from radios to radios, systems to systems, devices to devices, and departments to departments.
- **Reliability and connectivity** – 100 % reliability and connectivity for radio, cellular, and wireless networks in spite of geography and topography—urban canyons, subways, basements, or other dead zones.
- **Accountability and location** – Technology that provides for accountability and location

tracking of the crew, units, 911 callers, and building occupants.

- **Maintenance, technical support and training** – Minimization of the burden and costs of the associated maintenance, technical support and training of technology imposed on users and departments.
- **Organizational Policies and administration** – Facilitation and promotion of technology adoption by first responders through policies (e.g., a BYOD, or Bring Your Own Device policy), procedures, and administration to minimize barriers and hindrances to use while supporting first responders' primary tasks.

USER-CENTERED DESIGN GUIDELINES

The number and severity of issues first responders experience with current technology permeated the interviews and resulting data. First responders feel strongly that improvements to existing technology to address user needs cannot and should not be ignored by the R&D community. Indeed, proving to first responders that their input is heard by effecting meaningful improvements in their current technology would increase their interest in future technology. To encourage adoption, new technology must be developed with and for first responders; the development process must consider and address first responder needs and concerns.

The cross-disciplinary technology opportunities discussed in the previous section provide developers with what first responders need in relationship to communication technology. Additionally, there are six user-centered design principles that first responders believe are requirements for developers when addressing the cross-disciplinary technology opportunities identified [13].

- **Improve current technology**
  - Improve the functionality and usability of technology that first responders currently have. Make their existing technology more affordable, and more reliable. For example, improve radios for better coverage, durability, and clarity, and improve associated microphones and cords. It is not necessarily new technology that first responders want, but the improvement of current technology that they believe is most important.

    Let's slow our horses a little bit, and let's back up and… Instead of introducing all this extra new stuff let's, one, make sure what we have actually works better. And then, two, let's not rely on it so much. (FF-U-042)

- **Reduce unintended consequences**
  - Develop technology that does not interfere with first responders' attention to their primary tasks. Technology interference can cause distraction, loss of situational awareness, and cognitive overload for first responders. A more subtle unintended consequence of technology is long-term, as over-reliance on technology can develop over time.

    The promise of technology is always overshadowed by its faults or its unintended consequences. (EMS-R-008)

- **Recognize 'one size does not fit all'**
  - Standardization is undeniably important for consistency, compatibility,

interoperability, and quality. However, technology must accommodate a wide variety of public safety user needs, which can vary across disciplines, personnel, departments, districts, and contexts of use. While there are similarities across first responder disciplines, given their notable differences, technology must be easily adaptable and configurable.

So that's the challenge [for developers]. Whatever you come out with, it's not going to be one size fits all. (EMS-U-001)

- **Minimize 'technology for technology's sake'**
  - Minimize 'technology for technology's sake, and instead develop technology with and for first responders. Technology development should be driven by first responders' characteristics, needs, requirements, and contexts of use.

    In my opinion, technology should make life easier, not harder. Right? And if the radio doesn't do anything other than just add more weight to your belt—with these new radios, I'm not accessing any new channels that I didn't have privilege for. (LE-U-003)

- **Lower product/service costs**
  - Develop technology at price points that departments can afford, lowering costs for technology. For example, consider the '*One Laptop per Child*' approach where various entities collaborated to make and widely distribute rugged, low-cost, low-power, connected technology in areas that could not otherwise afford such devices [14]. The goal was not only to design the tool, but to design it at a price-point that

made it feasible and scalable for widespread distribution. This is especially important given public safety budget constraints, which are often more pronounced in rural areas.

> [Technology] has to be affordable, and that's the challenge…We'll never be able to spend $10 000 on a radio. We have a hard enough time spending--right now, I mean, our radios are costing almost 4 grand for radio. And that's why we have older radios because we can't afford the new stuff. (FF-R-019)

- **Require usable technology**
  - To help ensure usable technology, know thy user and develop 'Fisher-Price®' solutions for public safety. Technology should be simple, easy to use, light, fast, and not disruptive. Technology should make it easy for the user to do the right thing, hard to do the wrong thing, and easy to recover when the wrong thing happens.

> It needs to be built by Fisher-Price®…It's got to have big buttons because I'm wearing gloves. It's got to be built for a three-year old. (FF-R-019)

> In the police world, if you want somebody to use something, it has to be simple. The more complicated it is, it's very seldom getting used. (LE-R-001)

Adherence to these user-centered design guidelines can promote first responders' openness to adopting new technology. Participants in our interviews were not opposed to technology, but they want and need technology that makes their work easier to accomplish, not

harder.

Discussion and Conclusions

According to participant responses collected in our interviews, researchers and developers should focus on technology that facilitates first responders' primary tasks and improves the user experience. In public safety incident response, a primary task often hinges on decision-making under significant time pressure, stress, and in hazardous environments. In order for first responders to achieve their goals and objectives and support good decisions, it is vital that they receive the right information at the right time, delivered in the right way. Thus, understanding their contexts of use and what first responders believe about communication technology is imperative for public safety R&D. Technology should not be developed in a vacuum. Before designing and developing technology first responder input must be collected — their voices should drive what technology is developed. With this user-centered research, we contribute data and findings based on the voices of first responders, a necessary first step in a larger project aimed at developing a standardized usability testing and evaluation methodology for public safety communications technology.

To design a usability testing methodology for public safety, one must first understand the components of usability. As described in the Introduction, the ISO 9241-210:2010 definition of *usability* is: "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." This definition of usability provides a guide of what to test and how to measure it. It identifies who (specific users) participates in the testing, what is tested (user's tasks), where the test takes place

(context of use) and metrics to evaluate the test. Metrics are especially important in usability testing. Effectiveness measures how well a user can perform a task, for example, if users can successfully accomplish a task or goal and how accurately users accomplish the goal. Efficiency measures the time required for a user to accomplish the task. Finally, satisfaction measures user attitudes, perceptions, and opinions with respect to the product or system. Effectiveness and efficiency are generally quantitative measures, while satisfaction is a qualitative measure. For the public safety space, consider the following to tailor usability metrics for first responders:

- *Effectiveness* – how the technology will be useful in first responders' primary task of protecting lives and property while preserving or enhancing situational awareness,
- *Efficiency* – how the technology will be easy to use and save first responders time,
- *Satisfaction* – how the technology will promote first responders' comfort and confidence in use.

Accurate collection and reporting of usability metrics are central to any usability testing methodology; usability test reporting is addressed in the ISO Common Industry Format (CIF) for Usability Test Reports, per ISO/IEC 25062:2006 [15] and ISO/IEC TR 25060: 2010 [16]. We envision customization of the CIF for public safety, akin to the way in which the CIF was tailored for domains such healthcare, for usability testing of electronic health records [17]. The public safety space will benefit from following well-established human factors and usability testing guidelines from other safety-critical domains—such as aviation and healthcare. As in other domains, usability testing throughout the technology development lifecycle will facilitate successful deployment and adoption of new public safety communication technology.

DISCLAIMER

Any mention of commercial products or reference to commercial organizations is for information only; it does not imply recommendation or endorsement by the National Institute of Standards and Technology nor does it imply that the products mentioned are necessarily the best available for the purpose.

Appendix A: Interview Questions

Context and Beliefs of Work

1. What is your job title?
    a. If you were describing your job to someone who knew nothing about it (like to a kid, or someone from another planet), how would you describe it?
    b. Tell me about your daily routine. How does your day begin?
        i. If there isn't one, list the different kinds of things you do during the day.
        ii. What's typical communication like for you during your work day?
    c. What is it like when you are at the station?
        i. Describe your relationships with other folks you work with.
        ii. Tell me about the community you serve.
    d. What is it like when you are at work but outside of the station?

Communication and Technology

2. List the different kinds of technology (devices, equipment) you use to do your job.
    a. How would you describe the technology/equipment you currently use?
    b. Are there apps that you use to do your job?
    c. Have there been times when technology has gotten in the way?
3. How (if at all) have things changed in terms of communication since you became a first responder?
    a. Do these changes make communication better or worse for you?
4. In a typical day on your job, what kinds of information do you need?
    a. Are there other kinds of information you need for situations that aren't so typical—and if so, what is it?
5. If you think about the incidents you've responded to over the last few weeks or months, is there information that could have helped you understand the scene before you got there? Tell me about it.
    a. What kind of information would be the most helpful, either for typical or for more complicated calls?
    b. How would you want to get that information?
6. What, if anything, do you think causes communication problems in your work?
    a. What, if anything, could help with these problems?

7. 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?
    a. Are there new or different apps you can think of that could be useful?
8. Is there anything else you'd like to share about your job that you think is important for us to know?
9. Do you have any questions for me/us?

Appendix B: Demographic Questionnaire

Your area(s): ☐ Fire ☐ EMS ☐ Law Enforcement ☐ Dispatch
☐ Other Public Safety: _____

Total years of service: _____

Location: ☐ Urban ☐ Suburban ☐ Rural ☐ Tribal ☐ Other: _____

City, State: _____

Gender: ☐ Female ☐ Male ☐ Prefer not to answer

Age: ☐ 18-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 56-65 ☐ Over 65

Experience with different kinds of technology:
(including desktop or laptop computers, tablets, smartphones, and the Internet).

- ☐ I have limited experience using technology and I don't know much about how technology works.
- ☐ I have some knowledge about how technology works, but often need to ask for help to perform more advanced activities – such as to configure the privacy settings on my cell phone.
- ☐ I can do most things that I want to do with technology and only need help occasionally.
- ☐ I can do all things that I want to do with technology without help from others.

In general, when do you adopt new technologies?

- ☐ I try the latest technologies as soon as they come out.
- ☐ I follow technology trends.
- ☐ I let others work out the kinks first.
- ☐ I wait until my old technology dies.
- ☐ I only adopt new technologies when it's required.

Appendix C: Final Code Book

Codes and Sub-codes	Code Operationalization
Change	This can be about technology, about policy/procedures, rules for behavior, laws, tasks; anything that refers to if/how things have shifted or not over the course of a participant's career
Communication	This refers to examples of when information is passed from one entity to another, or when a flow of information is needed but not necessarily there; For example, "I need to talk to my partner"; this is not a specific identification of information or technology
Context of Work	Tasks related to what is done as part of the job
Stress/Overload	*Physical, cognitive, or emotional expressions of anxiety, tension, or feeling overwhelmed*
Risk/Safety	*Situation involving exposure to danger; harm or loss*
Relationships	*The sense of community developed among individuals or groups of people, a connection, association, or involvement, including relationships present within a discipline, between disciplines, or with the public*
Frustration	An expression of annoyance, because of inability to change or achieve something
Information	Data, evidence, or intelligence related to an incident or to work environment/situation
Control	*Entity who has the ability/responsibility to act or pass on information*
Delivery mechanism	*Physical (paper, evidence, objects, or other artifacts) or Face to Face*
Operational environment	This can refer to the station, the department, the leadership, the city/state; anything that's larger than just the user (we)
Problems	Identification of issues identified by participants related to doing their jobs
Technology	*Issues with technology*
People	*Issues with people*
Information	*Issues with information (in getting, receiving, or producing information; situations where there was too little or too much information)*
Policies/Procedures	*Issues with formal or informal rules and operating processes and procedures for how things should be, have been, or are being done*
Rules/Politics	Formal or informal guidelines that directly or indirectly govern the work, expectations, and/or environments of first responders
Budget/purchasing	*Considerations related to funding and/or procurement*
Priority/Influence	*Related to priorities of the administration (e.g., station, local government)*
Policies/Procedures	*Formal rules and operating processes for how things operate*
Unspoken rules for behavior	*Informal understandings of how things should be done (for example: radio discipline)*
Technology	Devices utilized by first responders to do their jobs or as part of their daily tasks
Reliance on technology	*Situations when responders don't know what to do without the technology or when it's not available (either when it breaks or is not appropriate to use)*
Positives about/with technology	*Benefits and affirmative views of using technology*
Training	Initial and/or ongoing preparation and practice of job-relevant skills
User characteristics	Participant related demographics, or identification of demographic pieces related to other work colleagues
Pride	*Feelings of dignity about their work, work environment, and/or work organization*
Job commitment/satisfaction	*Expressions of how participants love what they do or dedication to their work*
Generation gap	*Real or perceived differences due to age*
Knowledge/experience/skills	*Discipline relevant understandings and abilities related to their work*
Wish List	Things (funding, information, processes, technology, devices, or equipment) that would facilitate first responders' job.

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List of Figure Captions

FIG. 1 Geographic Regions for FY'17 Interviews.

FIG. 2 Demographic Data.

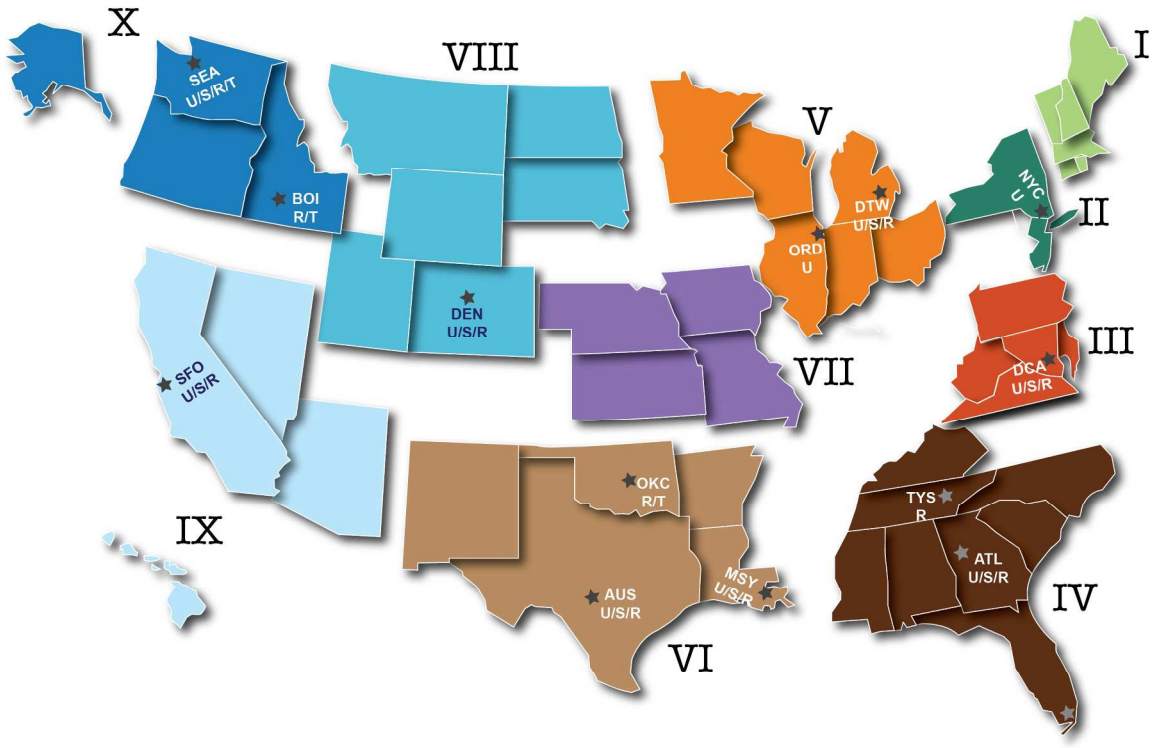

Fig. 1. Geographic Regions for FY'17 Interviews.

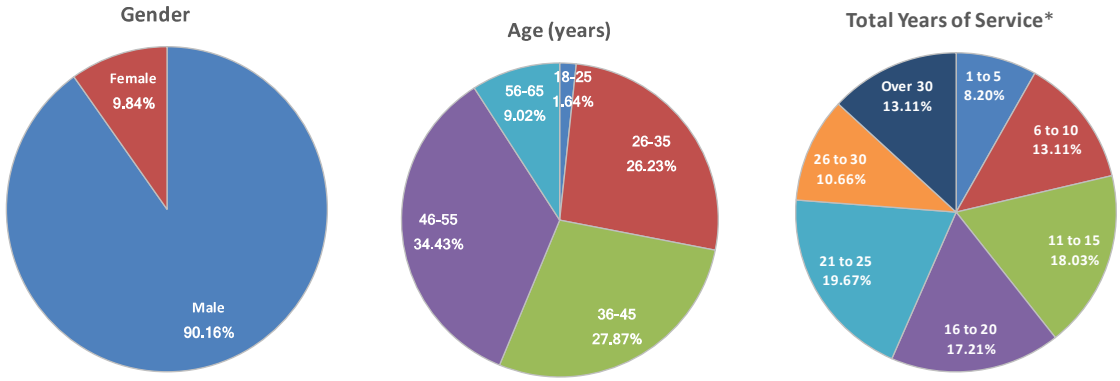

Fig. 2. Demographic Data (n=122).
* Total Years of Service: Average=18.89, Range= (1,40), SD=9.38