Communication Technology Problems and Needs of Rural First Responders

Kerrianne Morrison
National Institute of Standards and Technology
kerrianne.morrison@nist.gov

Yee-Yin Choong
National Institute of Standards and Technology
yee-yin.choong@nist.gov

Shaneé Dawkins
National Institute of Standards and Technology
shanee.dawkins@nist.gov

Sandra Spickard Prettyman
Culture Catalyst, LLC
Sspretty50@icloud.com

ABSTRACT

Although new technology may benefit rural first responders to help them serve their communities, to date little is known about what communication technology problems rural first responders most need addressed and what future technology they desire. To explore the context of use and communication technology problems and needs of rural first responders, semi-structured interviews were conducted with 63 rural first responders across four disciplines: Communications (Comm) Center & 9-1-1 Services, Emergency Medical Services, Fire Service, and Law Enforcement. Using qualitative data analysis, interview data were sorted into problems and needs categories. Rural first responders' greatest problems were with reliable coverage/connectivity, interoperability, implementation/information technology (IT) infrastructure, and physical ergonomics. Rural first responders' greatest need for new technology was to address their current problems, but they were interested in new technology that leverages real-time technology and location tracking. Implications for researchers and developers of public safety communication technology are discussed.

Keywords

Communication technology, first responders, public safety, rural communities, usability.

INTRODUCTION

Rural Environments and Incident Response

First responders in public safety disciplines, namely Communications (Comm) Center & 9-1-1 Services (COMMS), Emergency Medical Services (EMS), Fire Service (FF), and Law Enforcement (LE) personnel, respond to emergency incidents to serve and protect their communities. Although these professions face many dangers and difficulties, first responders in rural communities encounter unique challenges by nature of the rural areas they serve. To better understand these challenges and how to mitigate them, rural areas in the United States (U.S.; e.g., Ricci et al., 2003; Tiesman et al., 2007) and in countries around the world (e.g., Aftyka et al., 2014; Birdsey et al., 2016; Hang et al., 2004; Jennings et al., 2006) have been a topic of research, with many studies focusing exclusively on rural emergency response (e.g., Gamache et al., 2007; O'Meara et al., 2002; Oliver and Meier, 2004; Ramsell et al., 2019; Reddy et al., 2009; Roberts et al., 2014).

A commonality in much of this work is finding that rural first responders are tasked to serve small communities that span wide landmasses. According to the U.S. Census Bureau's definition, rural areas comprise 97% of the U.S.'s landmass, but only 19.3% of the population (Ratcliffe et al., 2016; U.S. Census Bureau). Because rural first responders must often cover wide distances, some studies of rural areas have found longer ambulance response times in rural areas (Aftyka et al., 2014; Jennings et al., 2006).

Rural first responders also respond to incidents resulting from the unique terrain of the area. Some rural areas are

impacted by seasonal weather, experiencing high rates of sporting injuries (e.g., skiing) during certain seasons (e.g., winter) (Birdsey et al., 2016) and high rates of injuries during times of the year with more severe weather (e.g., monsoons, rain) (Hang et al., 2004). Although injury-hospitalization and death percentages are higher in rural than urban areas (Coben et al., 2009; Tiesman et al., 2007), rural areas are often served by rural first responders with small staffs that rely on volunteers or community workers who often have less experience and training (Gamache et al., 2007; Roberts et al., 2014).

Rural Barriers to Technology

Although these environmental features make incident response different for rural first responders relative to their urban and suburban counterparts, rural first responders face additional challenges in utilizing the proper equipment to respond to incidents. Communication technology such as radios, cell phones, and mobile data computers (MDC) are one of the most important tools first responders use in incident response, allowing them to obtain information about incidents and coordinate the appropriate response (Choong et al., 2018). Unfortunately, rural first responders face two primary barriers that prevent them from accessing and using communication technology.

First, rural areas tend to lack the infrastructure needed to implement the latest communication technology (Federal Communications Commission (FCC), 2020). This lack of infrastructure results in a lack of broadband access in many rural areas (FCC, 2020) and slow broadband speeds in some areas (Meinrath et al., 2019; Perrin, 2019) that may ultimately prevent rural first responders from accessing and using technology for incident response. Moreover, the costs for buying, installing, and maintaining broadband infrastructure are high in rural areas (Strover, 2001; Yankelevich et al., 2017), sometimes due to the impact of natural geographic barriers (e.g., mountains) and harsh weather conditions on equipment (Pötsch et al., 2016; Surana et al., 2008).

Second, some work suggests that people in rural areas are reticent to adopt new technology. Despite many rural areas gaining more access to broadband infrastructure, the urban-rural broadband adoption gap continues to persist (Dickes et al., 2010; Department of Commerce (DOC), 2010; Whitacre, 2008). Although demographic disparities between rural and urban areas are related to these lower adoption rates (Whitacre, 2008), LaRose et al. (2007) suggest that broadband adoption in rural areas is predicated on individuals' prior experience with, expected outcomes using, and self-efficacy for using the internet. Relatedly, work examining non-internet users found that their primary reason against adopting broadband in their homes was that they did not have any interest or need for broadband (DOC, 2010). Although this was the top reason for both rural and urban households, a larger share of rural households than urban endorsed this belief. These studies suggest that people in rural areas may not adopt technology because the benefits of adopting new technology are not made clear to them (Dickes et al., 2010; LaRose et al., 2007). Unfortunately, this may result in preventing rural first responders from utilizing tools that may help them during incident response.

Opportunities to Address Barriers

Fortunately, new legislation has created opportunities for mitigating these challenges by developing new technology specifically for first responders. The U.S. Middle Class Tax Relief and Job Creation Act of 2012 (Public Law 112-96, 2012) provided funding and dedicated broadband to establish the Nationwide Public Safety Broadband Network (NPSBN). While NPSBN development is in progress, this network will improve broadband access for first responders by supplementing land mobile radio (LMR) with Long-Term Evolution (LTE) solutions. Currently, the public safety research and development community has focused on developing new communication technology for first responders to operate with the new network. By improving broadband access and developing new communication technology, rural first responders can better share critical information during emergencies and disasters (Comfort et al., 2004) as well as use new capabilities such as those that improve location information (Weichelt et al., 2019) and assist with providing care to people in remote locations ahead of ambulance arrival (e.g., telehealth; Ricci et al., 2003).

Although the NPSBN is poised to help address rural first responders' need for broadband infrastructure, a solution is still needed to ensure that rural first responders will adopt new technology. Recent work has emphasized adoption as a critical piece of developing new technology for rural first responders and communities (Gasco-Hernandez et al., 2019; Weichelt et al., 2019). These studies and others (Choong et al., 2018) emphasize that although technology shows great promise to help first responders, unless technology is developed with the first responders' context and needs in mind, this technology may not be adopted by them. The concept of including users of technology in technology development is central to human factors research and user-centered design (International Organization for Standardization (ISO), 2019). By understanding the user, a developer can design technology with the users' needs in mind (Hackos and Redish, 1998). Ultimately, this improves the usability of a

product, increasing its efficiency, effectiveness, and satisfaction to the user (ISO, 2019). Therefore, in order to improve adoption of new technology, rural first responders must be directly included in research. This will ensure that technology is developed specifically for their context of use and that their current needs are accounted for when developing new technology.

Relevant Research on Rural First Responders

To date, most work examining rural first responders has examined their unique context of use. Studies examining the context for rural emergency and health care workers have found that rural emergency responders rely on community workers and volunteers (Greene et al., 2019; Roberts et al., 2014), feel overburdened (Iversen et al., 2002; Oliver and Meier, 2004), have fewer resources and equipment (Greene et al., 2019; Oliver and Meier, 2004; Pilemalm, 2018), and serve wide, remote, and geographically diverse areas (Greene et al., 2019; Iversen et al., 2002; Oliver and Meier, 2004). However, fewer studies have investigated how rural first responders perceive, interact with, and use communication technology.

The work that has assessed rural first responders' perceptions and use of communication technology has focused broadly on emergency and health care professionals, including nurses, emergency department workers, and EMS personnel (O'Meara et al., 2002; Reddy et al., 2009) as well as community citizens, volunteers, and organizations (Pilemalm et al., 2013; Ramsell et al., 2019). These studies find that emergency, health care, and volunteer personnel are hindered by their communication devices due to the lack of interoperability between the numerous devices they use (O'Meara et al., 2002; Reddy et al., 2009) and connectivity problems (Reddy et al., 2009) from a lack of infrastructure (O'Meara et al., 2002; Pilemalm et al., 2013). Recently Ramsell et al. (2019) found semi-professional emergency responders and community volunteers value smartphone application usability and interoperability to support communication during incident response.

Gaps in Past Work

Although these studies provide important insights, they have two important gaps. First, the studies that have assessed rural first responders' perceptions and use of communication technology are largely specific to healthcare professionals generally and EMS personnel. It is unclear if these same problems transfer to other types of rural first responder disciplines, or if other disciplines have different problems with communication technology. Second, many of these studies examined limited types of technology, focusing largely on network coverage and mobile devices (e.g., smartphones) rather than on other communication technology more broadly such as radios, MDC, and body cameras. More work is required to identify useful functionalities beyond networks and mobile phones and instead assess needs broadly across communication technology for rural first responders.

Current Study

In the current study we addressed these gaps in prior work by studying the communication technology problems and needs of rural first responders across four disciplines (i.e., COMMS, EMS, FF, and LE). We also built off prior work (Greene et al., 2019; Iversen et al., 2002; Oliver and Meier, 2004) to understand rural first responders' context of use. Focusing on hearing the voices of rural first responders is important as historically rural perspectives have been left out of research about rural environments (Chambers, 1994). Insights from this study can help developers to identify what shortcomings in current technology need to be addressed as well as where to invest future resources in developing technology for rural first responders. By ensuring solutions that are tailored to work within the unique environments in which rural first responders operate, rural first responders may be more eager to adopt and use new technology in incident response.

METHOD

We conducted an exploratory sequential mixed methods study with two phases. In Phase 1, qualitative interviews were conducted to comprehensively explore communication technology experiences of first responders. Findings from Phase 1 were then used to design the Phase 2 quantitative survey instrument. In this way, the exploratory nature of Phase 1 led to a broader representation of first responders in Phase 2. This paper only focuses on data and analysis from Phase 1 and details methods and results using qualitative analysis methods. There were many advantages to using a qualitative approach in this first phase of research. First, this approach allowed us to explore and probe the specific problems and needs experienced by first responders to provide deep insights into the experiences and perspectives of those first responders who participated. Although qualitative methods are exploratory in nature, these methods can be applied rigorously for analysis (see Saldaña, 2013) and achieve validity (see Shenton, 2004). Second, it allowed us flexibility to examine the nuances between different first

responder disciplines. Third, this approach emphasized engaging directly with participants through semi-structured interview techniques. This allowed for examination of first responders' top of mind priorities and dynamic perspectives and ensured that the voices of first responders were included in the research.

Recruitment and Sampling

Sixty-three rural first responders across four disciplines (COMMS (n=18), EMS (n=6), FF (n=19), and LE (n=20)) participated in the study. Purposeful and snowball sampling were used to recruit first responders. This sample was a subset of a larger effort to recruit a national sample of first responders (Choong et al., 2018; Dawkins et al., 2019; Greene et al., 2019). Five of the ten Federal Emergency Management Agency (FEMA) (2020) regions in the U.S. were represented in the sample.

Procedure

The research team scheduled 45-minute semi-structured one-on-one interview sessions at the first responders' place of work (e.g., fire station). However, in order to maximize the number of rural first responders interviewed, a subset of the interviews was conducted in small groups rather than one-on-one. This resulted in 48 interview sessions total with 63 total first responder participants. Participants were informed that they could withdraw at any time, skip any question as needed, and decline to be audio recorded. They completed demographic questions before the interview sessions. All data were collected anonymously. Recorded interviews were transcribed then de-identified and assigned an interview number. The National Institute of Standards and Technology (NIST) Research Protections Office reviewed the protocol for this project and determined it meets the criteria for "exempt human subjects research".

Instruments

Interview Instrument

An interview instrument was developed to guide the discussion during the semi-structured interviews. The interview instrument focused on two high-level areas: 1) understanding first responders' context of work, and 2) identifying first responders' perceptions of and experiences with technology. To understand context of work, the interview instrument included questions and follow-up probes related to job tasks and routines, relationships with people they work with or for, and characteristics of the environment they work in. Questions about technology focused on what technology they use, what problems they have encountered, and what technology they wish they had for their jobs. The interview instrument was developed iteratively through a process with a literature review, pilot interviews with first responders, and feedback from first responders and human factors subject matter experts (see Choong et al., 2018 for full methodological details for Phase 1).

Demographics Questions

Demographic characteristics (i.e., discipline, years of service, area, location, gender, and age) were collected to ensure interview data reflected the diversity of rural first responders. Additionally, we asked two questions related to technology experience and adoption (see Figure 1 and Figure 2) to better understand rural first responders' familiarity with technology. Participants could select as many options as were applicable to their own experiences.

Participant characteristics

The sample was made up of 18 COMMS participants, 19 FF participants, 20 LE participants, and 6 EMS participants. Table 1 displays the number of participants across rural first responder disciplines by gender, age, and total years of service. The sample was less representative of female first responders than male first responders, with female first responders comprising only 13 participants, though this is consistent with low proportions of female responders in FF and LE disciplines nationally (Crooke, 2013; Evarts and Stein, 2020). Relatedly, the larger number of females in our COMMS sample was consistent with gender demographics for the discipline nationally (U.S. Bureau of Labor Statistics, 2019). A majority of the sample was between 36 and 55 years old and had a wide range of total years of service.

Table 1. Frequencies of Demographic Characteristics by Rural First Responder Disciplines

		COMMS	EMS	FF	LE	Grand Total
Gender	Female	10	1	0	2	13

	Male	8	5	19	18	50
Age (Years)	18-25	1	1	3	2	7
	26-35	2	1	3	5	11
	36-45	5	2	6	4	17
	46-55	8	1	5	8	22
	56-65	2	1	1	0	4
	over 65	0	0	1	1	2
Total Years of Service	1-5	2	3	3	3	11
	6-10	3	0	4	3	10
	11-15	4	1	2	2	9
	16-20	1	1	2	3	7
	21-25	1	0	5	7	13
	26-30	3	0	2	2	7
	Over 30	3	1	1	0	5
	No response	1	0	0	0	1
Total	Total Participants	18	6	19	20	63

Figure 1 and Figure 2[1] display rural first responders' experiences with using and adopting technology. Although nearly 83% indicated they could do most or all things with technology with some assistance, 19% indicated they had limited knowledge or needed help with technology. In looking at experience adopting new technology, nearly 40% mentioned they let others work out the kinks. Although 28.6% said they follow technology trends, nearly 21% either adopt new technology when theirs has died or it becomes required.

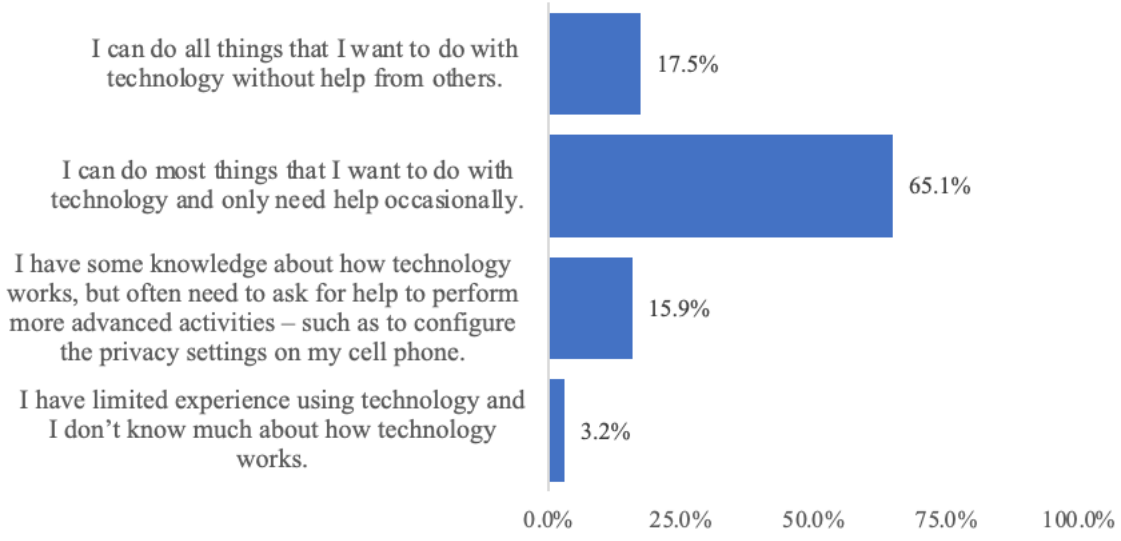

Figure 1. Experience with Technology.

[1] Because participants could select multiple responses and the total number of participants was used to compute percentages, responses sum to over 100%. One participant did not answer the questions.

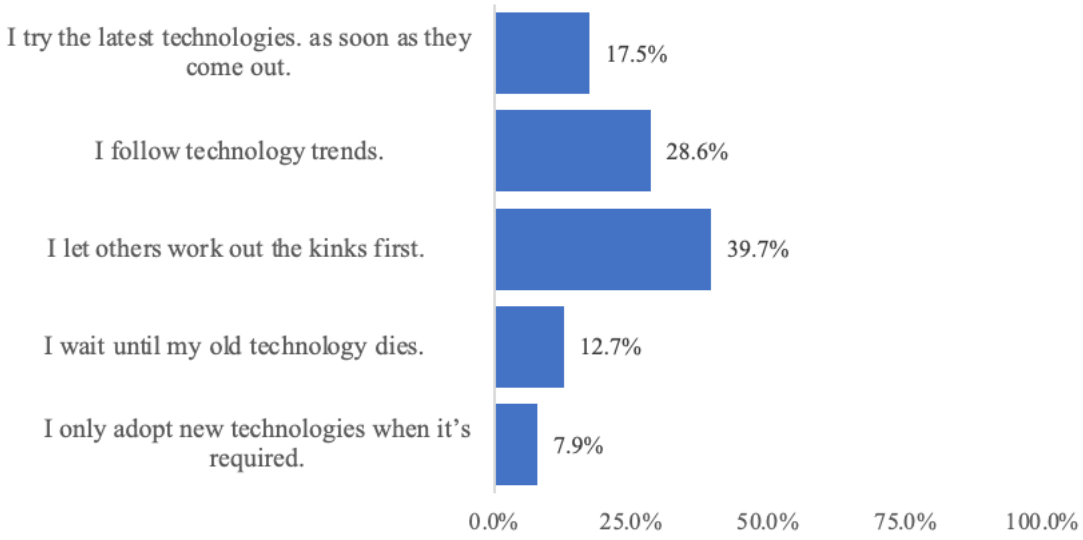

Figure 2. Experience Adopting Technology.

Qualitative Analysis

As part of the qualitative analysis process, transcripts were coded. Coding refers to assigning categories to participants' responses in order to reduce the data set so that it can be analyzed to find patterns and themes. The multidisciplinary research team first created an *a priori* coding list to be used for the initial coding of five randomly chosen transcripts from the entire project (see Choong et al., 2018). These five transcripts were independently coded by all team members, then the research team met to review their codes to determine if the codes were applied in consistent ways. This provided the opportunity to revise codes and operationalize how each should be applied, ultimately resulting in a finalized list of operationalized codes. The researchers coded all remaining transcripts using the final code list. The data associated with each code were extracted into separate files so that the relationships within and amongst the codes could be explored and themes identified.

The current study focused on the data from the transcripts of the 48 rural interviews with the 63 rural first responders, with codes related to: 1) communication technology problems and needs and 2) the context of use rural first responders operate within. First, to identify communication technology problems and needs, we reanalyzed responses initially coded into the "problem: technology" or "wish list" codes by further classifying responses into more specific categories and subcategories (see Dawkins et al., 2019). The "problems: technology" items were classified into the list of 18 technology problems displayed in Table 2. The same was done for the 15 "wish list" items displayed in Table 3. These categories and their corresponding subcategories were created for the larger research effort to identify the needs and requested functionalities that were most important to first responders (Dawkins et al., 2019). Here they were applied to the subset of the data with rural first responders. Two researchers independently identified the categories and subcategories for each response, with one researcher categorizing the problems and the other categorizing the needs. The research team then met to discuss, operationalize, and finalize the classifications. Second, to identify the rural context of use for problems and needs, we identified themes about the rural context from the extracted data (see Greene et al., 2019).

The qualitative results present themes using the direct quotes given by rural first responders. Quotes serve as exemplars and are representative of the data set as a whole. Each quote is followed by the reference to the participant in parentheses, including their discipline (i.e., COMMS, EMS, FF, or LE), area (R = Rural), and interview number (e.g., 001). Because participants were anonymous, identifiers are not tied back to a specific participant.

Table 2. Communication Technology Problems Categories and Subcategories

Category	Subcategories
9-1-1 Calls	Next Generation 9-1-1 (NG 911), caller location, nuisance calls
Audio Clarity	Hard to hear, audio feedback
Body Camera	Functional issues, physical issues
Connectivity	Reception, bandwidth issue
Disruption of Operations	Continuity of Operations (COOP), mobile operations
Implementation/Information Technology (IT) Infrastructure	Implementation/Installation issues, cost as a prohibitor, IT management, no user requirements collected/considered, public safety network reservations
Interoperability	External interoperability, internal interoperability
Microphone/Earpiece	Cord, earpiece, wireless microphones
Mobile Data Computer (MDC)/Mobile Data Terminal (MDT)	Navigation/mapping, functionality
Overwhelmed	Sensory overload, situational awareness
Physical Ergonomics	Robustness, battery problems, bulky and heavy, too many devices, physical discomfort, display size, safety concerns
Radio	Dead zones, traffic, channel switching, usability
Reliability	Unreliable technology, redundancy, unreliable transmissions
Security Constraints	Authentication, access control
Technology Outdated	Outdated, incomparable to personal technology
Technology Overrated	Problems with new technology, doesn't solve communication problems
User Interfaces	Ineffective and inefficient, alerting, modality
Video	Data issues, surveillance videos

Note. Categories and subcategories listed here are exhaustive but may not have been used across all disciplines. For example, "9-1-1 calls" only were coded for COMMS personnel.

Table 3. Communication Technology Wish List Categories and Subcategories

Category	Subcategories
All-In-One	Cell phones and/or radios, tablets, software and apps, general multifunctional devices, cameras
Communications Center Technology	Improved dispatch interface, multimedia data package, access to caller cell camera, large multi-view display
Functionality	Reliability, better coverage, clearer communication, improved functionality, longer battery life, faster devices
Futuristic	Media/Science-fiction influenced, smart buildings, face and object recognition software, self-driving vehicles, augmented reality (AR), emergency traffic light system
Integrated Gear/Wearables	Heads-up display (HUD), in-mask microphone/earpiece, responder vitals, personal protective equipment (PPE) technology
Interoperability	Software/hardware compatibility, interagency communication system, patient care report (PCR), body camera integration, interjurisdictional criminal data
Microphones/Earpieces	Wireless, specialized earpieces
Mobile Apps	Information references, discipline-specific apps
Physical Ergonomics	Smaller and lighter, fewer devices, robustness, larger devices
Radios	Channel switching, multiple talk groups, prevent accidental transmissions
Real-Time Technology	Live video and images - capture/live feed technology, traffic and navigation, drones, language translation, identification devices
Tracking	Responder location, caller location, search technology
Usable security	Single sign-on
User Interfaces	User friendly, hands free, non-verbal communication
Vehicles	Windshield HUD, built-in camera, automatic license plate reader, dashboard computer

Note. Categories and subcategories listed here are exhaustive but may not have been used across all disciplines. For example, the "body camera integration" subcategory in the "interoperability" category was only coded for law enforcement.

RESULTS

Technology Problems and Wish List Items Across Rural First Responder Disciplines

Technology problems are displayed in Figure 3 and wish list items in Figure 4. Across disciplines, rural first responders experienced the most problems with radios, reliability of devices, interoperability, implementation/IT infrastructure, and physical ergonomics. Their top wish list items were related to improving their current communication technology's functionality, specifically devices' reliability and coverage, as well as improving devices' interoperability and physical ergonomics. However, they also were interested in some futuristic technology, especially real-time technology and location tracking.

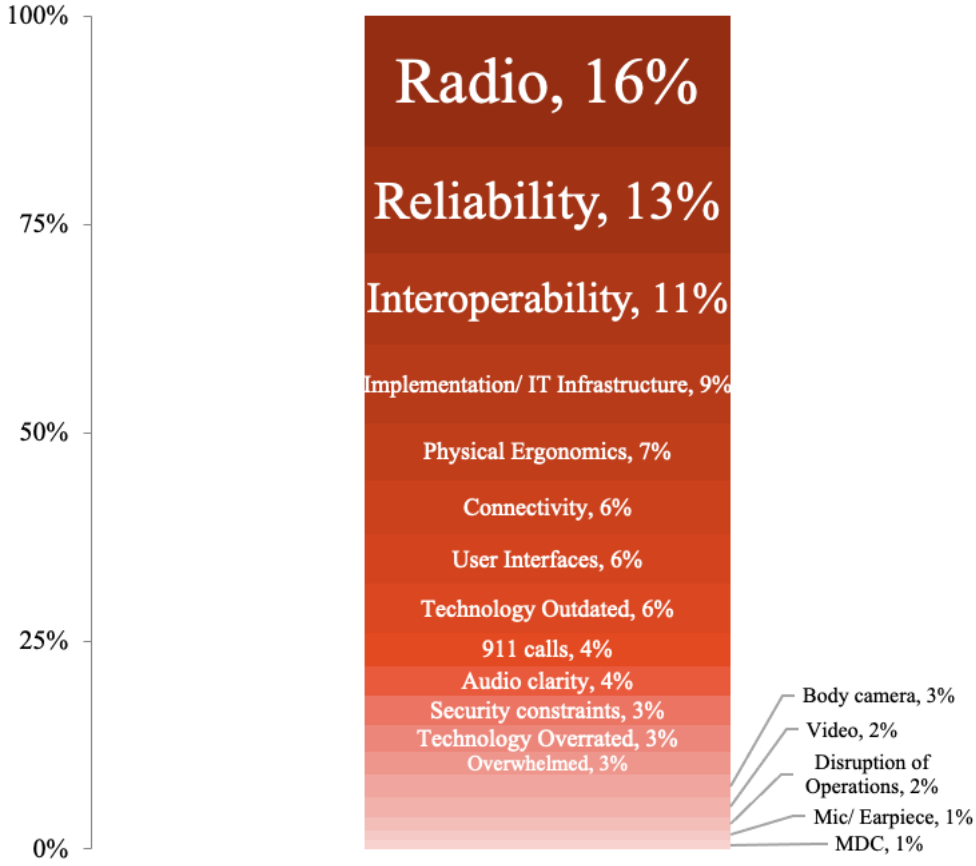

Figure 3. Technology problems across rural first responder disciplines.

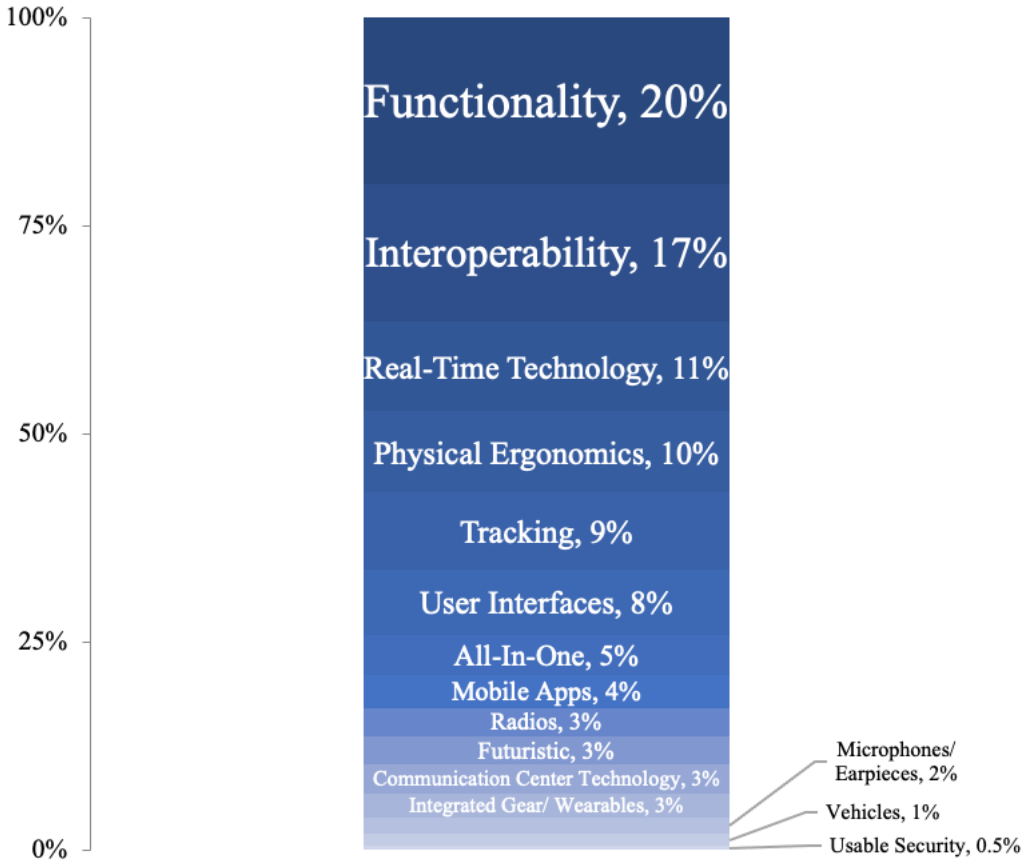

Figure 4. Wish list items across rural first responder disciplines.

Radio and Connectivity

Rural first responders experienced the most issues with dead zones preventing radio transmissions. Relatedly, rural first responders expressed problems with connectivity, especially in accessing bandwidth to gain reception for internet and cell phones. Some discussed dead zones in buildings or other structures, but many mentioned dead zones specific to rural terrain (e.g., mountains) that limit communication technology.

> Cell phones are great but again we're on a very rural county and if you get to the far ends of our county towards the east good luck. Radio traffic is null out there as well as cell phone is. (FF-R-049)

Rural first responders' most requested wish list item for improved functionality was improving radio and cell phone coverage in rural areas.

> ...You want your radios to work and you want your cell phones to work all over the county. I mean that's pretty much it…We did a missing person scenario down towards [county name redacted] in the national forest and nobody's radio worked...phone didn't work. (LE-R-048)

With access to wider coverage, rural first responders could improve the efficiency and effectiveness by which they communicate with their team members, transmit information to other responders and hospitals, and maintain a lifeline in dangerous situations.

Reliability

Many rural first responders felt their devices were unreliable, describing past experiences in which their communication technology did not work in the way intended.

> We have the [inaudible] MDTs [mobile data terminals], but I think we would call it a failed technology... We spend more time wasting time trying to keep that thing working than we do doing our job. So we've given up on it… (FF-R-019)

Finding a solution to reliability problems was also at the top of rural first responders' wish lists. They wanted to be able to trust the technology that they use, eliminating unnecessary distractions and stress.

Interoperability

Rural first responders described difficulties communicating among disciplines across rural areas and also during situations where they must work with other jurisdictions. The second most requested wish list item was improved interoperability, and many rural first responders were specifically interested in improved interagency communication. Improving communication interoperability for rural first responders with other disciplines, areas, and jurisdictions would help improve incident response, as well as increase information being shared with relevant parties.

> Speaker 2: I mean, I can't call [county name redacted], call on the cell phone. I can't call [another county name redacted]; we don't have their frequencies available, so it would all have to be relayed from us to here to County, to their dispatch to their officer and then back to the state again.
>
> Speaker 1: Which creates the delay you talked about earlier.
>
> Speaker 2: Right. And what is lost in translation. (LE-R-060)

Rural first responders also discussed that the numerous devices they use are not well integrated.

> I think my biggest gripes are that e-ticketing machine and just the fact that it's not well thought-out for the application. I don't think there's any reason why it couldn't be done on the phone that I already carry or the computer that's already in the car. (LE-R-018)

Rural first responders mentioned a need for more interoperability between software and hardware. Improving internal interoperability may decrease the amount of time to transmit information and may also reduce the burden, frustration, and confusion of using multiple devices.

Implementation/IT Infrastructure

Rural first responders described problems implementing and installing communication technology. One reason mentioned in the interviews was that many updates require access to the latest technology or use of broadband speeds to which many rural first responders do not yet have access. One COMMS worker described a situation where the communications center sought to use new technology but could not implement the new system because of the call center's outdated computer systems.

> So, you have to do an upgrade your phone system to make it compatible to go on NextGen…we are going to upgrade the phone switch, which we did. But then, our wall boards that tells us how many calls are waiting…they quit working. Well, we found out that the computers that are driving the wall boards are not powerful enough to drive the wall boards with the upgrade. (COMMS-R-019)

Many rural first responders discussed these issues with implementation as being related to a broader issue of funding.

> I mean funding is a huge issue…If a truck went down that truck's gone until we can save up the money or get a grant or figure out something to fix that truck. I mean we were living year to year as a department you know and that depended on the size of the department and the size of the town. (FF-R-048)

Because rural departments were often underfunded, cost may be a prohibitor for rural first responders in accessing, training for, updating, and replacing communication technology.

Physical Ergonomics

Physical ergonomics problems and needs captured a wide range of topics, with some related to rural first responders' number, size, and weight of devices, and others related to physical aspects of devices such as robustness, battery life, comfort, and safety concerns. Rural first responders discussed problems with devices' robustness in rural environments. Rural first responders must have robust equipment to meet the challenges of the incidents they respond to (e.g., extreme heat) and the environments they work within, as they often encounter difficult terrain such as mountains or rivers. For this reason, many rural first responders requested improved robustness as a wish list item.

> A lot of our computer sites are above 10,000, 11,000, 12,000 feet. You can't get to some of them unless it's summer. If one [of] them breaks down, well, just have to wait until the weather clears. I mean, we have ice loading on some of our tower sites such that it shuts them down… we wait until it warms up and it falls off…Sometimes we go up in a snow cab or the technician does. I mean, that's dangerous, expensive work… (EMS-R-008)

They also discussed having battery issues with their devices. Additionally, they requested having fewer devices to operate, as another problem was having too many devices. Although making devices more robust and integrated would be of interest to rural first responders across disciplines, some specific problems and needs differed depending on the discipline.

Technology Problems and Wish List Items for Each Rural First Responder Discipline

Although many of these problems and needs were common across all disciplines, each rural first responder discipline experienced unique problems specific to their job requirements and context of use. Each also identified specific wish list items that would be beneficial to their needs. The discipline-specific data presented below were emphasized within a discipline but were not unique to that discipline.

COMMS Responders

Rural COMMS personnel experienced unique problems by nature of the environment they work within. COMMS personnel do not respond on-scene; they instead take emergency calls and dispatch first responders to the scene. COMMS personnel discussed the difficulty in locating callers during 9-1-1 calls, as some rural areas do not have addresses. Unique terrains (e.g., mountains, rivers) also bring in seasonal tourists, causing an increase in visitors unfamiliar with the area who have difficulty identifying their location when calling 9-1-1. For these reasons, COMMS personnel saw benefits to using technology to improve caller tracking.

> I would want to have the ability to see where my callers are…And I wish I could have the technology to see like a straight path to guide my officers to my callers…There are times when we've had calls where people were in domestic situations and they couldn't really tell us everything so that would help a lot. (COMMS-R-014)

They were also interested in improving communications center technology, such as having improved dispatch interfaces, better multimedia data packages to receive information, and access to callers' cell phone cameras. Although they saw benefits to technology, COMMS personnel were wary of new technology. They could foresee negative impacts and new challenges that may come with new technology, especially Next-Generation 9-1-1, a digitally-based 9-1-1 system (see National 911 Program). COMMS personnel expressed concerns over both seeing graphic or inappropriate images in texts and needing to slow down their response time to communicate via text with callers.

EMS Responders

EMS personnel mentioned problems writing and sending patient reports to hospitals. They discussed their MDCs were often unreliable and would crash or otherwise fail to save a patient report. In addition to crashing, EMS personnel also discussed that sometimes when their computers were working, computers could still fail to send patient information due to disrupted connectivity.

EMS personnel discussed that reliable and usable technology was expensive, causing some departments to opt for outdated solutions. In some cases, EMS personnel discussed using pencil and paper for report writing rather than computers. When EMS personnel did have technology for writing and recording patient information, they were

often frustrated by how difficult their systems were to use. In fact, EMS personnel sometimes spent more time writing a report than they needed to, and in some cases had to rewrite their reports. Moreover, some mentioned that because they did not have dedicated IT staff, they often wasted valuable time fixing their systems or finding alternate solutions.

> What happens when it doesn't work? What happens when we have trouble with it? Who fixes it? Because I can't just call downstairs to IT, okay? I've got a contractor that does our IT because we don't have an IT department. They're budgeted two days a week, maybe. (EMS-R-008)

For these reasons, EMS personnel expressed interest in reliable technology, as this improvement may save them time and frustration, allowing them to focus on their jobs.

FF Responders

FF personnel had difficulty with mics and radios during incident response. They had problems hearing their radios when there was external sound caused by the fire and alarms, and their mics picked up breathing and other sounds that made communications hard to hear. They also had physical ergonomics issues, ranging from problems with batteries to having devices that were not robust to rural incident response. Many also expressed that their technology was outdated.

> …When a fire is paged out here they may page out the appropriate response it may or may not go out over the radio. We have somewhat of an outdated underfunded antiquated communications here in our county. (FF-R-049)

Although improved functionality for current devices was the top requested wish list item, FF personnel also saw benefits to new technology that could provide them with live real-time information about rural fires. They also requested improved software/hardware compatibility that could link multiple devices to send information to a single source.

LE Responders

Use of body cameras is specific to LE personnel in their day-to-day work. Some expressed physical challenges securely attaching their body cameras to their uniform, as well as mentioned that they spend significant time and effort storing and uploading the cameras' information.

> [Regarding body camera videos] It can add quite a bit of time because for the most part the upload time is the real time…I think the longest recording I have was probably about 3 hours which it breaks it up into thirty minute intervals but it took almost 2 ½ or 3 hours for that one video to upload then I had 10 other ones that I had to upload so the upload speed is absolutely horrible. (LE-R-045)

LE personnel often mentioned challenges using devices that were bulky, too numerous, and not reliable due to battery problems. These ergonomics challenges were often specific to the equipment they use, such as e-ticketing devices and utility belt equipment.

Futuristic Functionalities

Beyond desiring technology to address their current problems, rural first responders most discussed wanting new technology that can provide real-time and location tracking information.

Real-Time Information

Rural first responders discussed that the ability to send and receive live video and images would be useful.

> Or that there's the ability that that camera would be tied to the MDC so that I could push a button, take a picture, and transmit that without sitting here and opening an email, figure out who's working today, who's going to get this email…(FF-R-008)

Accessing rich and detailed information in real-time would assist rural first responders with planning for and

responding to incidents.

Access To Location Information

Many discussed that having tracking information would be useful for locating both 9-1-1 callers and first responders during incident response.

> And I think the mapping is a little -- like if we could somehow manage to afford, like live mapping or whatever…(COMMS-R-019)

Some rural first responders discussed that having information collected from previous incidents and locations as well as global positioning system (GPS) tracking of nearby responders and vehicles would improve preparing for and responding to incidents.

DISCUSSION

Rural first responders' primary communication technology problems were the lack of reliable coverage and connectivity, interoperability, implementation/IT infrastructure, and physical ergonomics of communication technology. This is consistent with work examining both rural (Greene et al., 2019; O'Meara et al., 2002; Pilemalm et al., 2013; Reddy et al., 2009) and urban and suburban public safety personnel (Dawkins et al., 2019). This suggests that research and development addressing these problems are likely to benefit all first responders. However, our findings suggest that the rural context of use must be considered in order to improve communication technology specifically for rural first responders.

Although urban and suburban first responders also experience dead zones and connectivity issues (Dawkins et al., 2019), the lack of broadband infrastructure and geographic dead zones are largely unique to rural areas. Most rural first responders in this study relied on using radios and cell phones to communicate, and when these devices were unable to connect, rural first responders had no way to coordinate with other responders in the area or acquire new information. Although broadband coverage has been improving (FCC, 2020), some areas that have coverage have slow speeds (Meinrath et al., 2019; Perrin, 2019). Developers should carefully consider the communication technology they develop for use in rural areas; until broadband access and speed is improved, some devices may not work as intended or at all. Therefore, researchers and designers should continue to consider how to increase coverage and connectivity of communication technology in rural areas.

Researchers and designers would also benefit rural first responders by developing devices that are robust to extreme weather and terrains and are developed with appropriate physical ergonomics requirements in mind for each first responder discipline. While FF personnel may need robust radios and mics adaptable to hot temperatures and loud scenes, LE personnel need body cameras and equipment for their belts that allow them to move easily. Moreover, rural first responders in this study had limited budgets that may preclude them from replacing technology often. Therefore, technology should also endure for a long period of time.

An important theme in the interviews was the additional burdens placed on rural first responders. Not only did they serve a wide area, but because of funding and resource allocations, they were often asked to do their jobs without proper equipment and personnel. Although technology has the potential to decrease these burdens by increasing the amount of information they have and decreasing time spent on tasks performed, we saw obstacles to this goal in our data. In many cases technology was an added burden, both mentally and physically to the day-to-day tasks of rural first responders. Some were distracted by managing and carrying many devices, and some spent extra time fixing technological problems and coordinating communication efforts between and across agencies. Therefore, designers should develop technology that will be easy to use and maintain, cost effective, lightweight, and integrated into technology they already possess. Additionally, in responding to the technology experience and adoption questions, approximately 61% of rural first responders indicated they would be hesitant to proactively adopt new technology. Developers must therefore ensure the benefits of new communication technology are made clear. By alleviating burdens caused by technology, rural first responders may more readily adopt new communication technology that will reduce their frustration and save them time. Such changes may help rural responders perform their jobs more efficiently, thereby decreasing the amount of time needed to respond to incidents. Because past research has found a relationship between response times and patient outcomes and satisfaction (Jennings et al., 2006; Persse et al., 2004; Rogers et al., 1999), improved efficiency may have benefits to rural first responders and their communities.

Taken together, it is unsurprising that when rural first responders were asked what new technology would benefit them, they wanted their current problems fixed rather than entirely new communication technology. However,

this does not mean that rural first responders were uninterested in new or futuristic devices. Rather than seeing future technology as a way to improve communication, rural first responders saw more utility for technology to improve access to real-time information. These findings are consistent with prior work with urban and suburban first responders (Choong et al., 2018) and underscore the need for developers to address problems but also anticipate first responders' need for information.

It is important to note that these results were a part of the Phase 1 study, which was only the first phase of a larger sequential mixed methods study. Therefore, while the Phase 1 results were meant to explore the experiences of first responders and their context of work, the results were also intended for use in developing the Phase 2 survey. The qualitative results presented in this study were meant to deeply investigate a phenomenon by providing access into the world of those interviewed, in their own voices. Although the sample sizes for each discipline in this paper were small (e.g., n=6 for EMS), the data were rich and highly contextualized to the rural environment. Thus, the goal was not to generalize to the broader rural population, but to provide in-depth insights into the phenomenon from the perspective of those interviewed. Phase 2 was designed to expand upon the Phase 1 results with a larger sample. Phase 2 results can provide a broader representation of first responders and comprehensively capture communication technology usage, problems, and needs. Therefore, the ultimate aim of our research will be to use both exploratory findings from Phase 1 and broader representative findings from Phase 2 to inform the development and design of new technology for first responders. We encourage additional studies to continue to expand upon the communication technology experiences of first responders, especially those who work within rural environments. Specifically, work is needed to analyze differences in problems and needs depending on demographic subgroups (e.g., gender, age, volunteer status) as well as ensure findings can generalize to the broader rural population. Future work may also benefit from moving beyond self-report to using scenario-based assessments (see Pilemalm, 2018) to elucidate problems experienced during incident response, as well as testing new technology (e.g., real-time technology) with this population.

These limitations non-withstanding, results from this study highlight many ways communication technology can be designed and improved for rural first responders:

1. Better coverage and connectivity for cell phones and radios
2. Improved interoperability both for communicating across agencies and for integrating devices
3. Strong and long-lasting devices that work in extreme physical environments
4. Affordable devices that are easy to fix and inexpensive to train on

By continuing to study human factors in rural first responder populations, technology can be developed and improved for rural first responders. This could shift how rural first responders view, adopt, and use communication technology. Rural first responders may transition away from viewing communication technology as a problem and burden, and instead view communication technology as a trusted tool for more effectively and efficiently protecting and serving their communities.

REFERENCES

Aftyka, A., Rybojad, B., and Rudnicka-Drozak, E. (2014) Are there any differences in medical emergency team interventions between rural and urban areas? A single-centre cohort study, *Australian Journal of Rural Health,* 22, 5, 223-228.

Birdsey, M., Islam, M. R., and Barmare, A. (2016) Sporting injuries, seasonal trend and impact on rural Australian hospitals: Implications and recommendations, *Australian Journal of Rural Health,* 24, 6, 402-408.

Chambers, R. (1994) The origins and practice of participatory rural appraisal, *World Development,* 22, 7, 953-969.

Choong, 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. National Institute of Standards and Technology Interagency or Internal Report (NISTIR) 8216. doi: 10.6028/nist.Ir.8216

Coben, J. H., Tiesman, H. M., Bossarte, R. M., and Furbee, P. M. (2009) Rural–Urban Differences in Injury Hospitalizations in the U.S., 2004, *American Journal of Preventive Medicine,* 36, 1, 49-55.

Comfort, L. K., Ko, K., and Zagorecki, A. (2004) Coordination in Rapidly Evolving Disaster Response Systems: The Role of Information, *American Behavioral Scientist,* 48, 3, 295-313.

Crooke, C. (2013, July) Women in Law Enforcement, *Community Policing Dispatch*, Retrieved from https://cops.usdoj.gov/html/dispatch/07-2013/women_in_law_enforcement.asp

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, Phase 1 Volume 2.1. National Institute of Standards and Technology Interagency or Internal Report (NISTIR) 8245. doi: 10.6028/nist.Ir.8245

Dickes, L., A. , Lamie, D. R., and Whitacre, B. E. (2010) The Struggle for Broadband in Rural America, *Choices,* 25, 4.

Evarts, B., and Stein, G. P. (2020). National Fire Protection Association's (NFPA) US Fire Department Profile 2018. Retrieved from https://www.nfpa.org/News-and-Research/Data-research-and-tools/Emergency-Responders/US-fire-department-profile

Federal Communications Commission. (2020). 2020 Broadband Deployment Report. Retrieved from https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2020-broadband-deployment-report

Federal Emergency Management Agency (FEMA). (2020, September 15, 2020) Regions, Retrieved from https://www.fema.gov/about/organization/regions

Gamache, S., Hall, J. R., Ahrens, M., Penney, G., and Kirtley, E. (2007). Mitigation of the Rural Fire Problem: Strategies Based on Original Research and Adaptation of Existing Best Practices. Final Report of Cooperative Agreement EME-2004-CA-0187. Retrieved from https://www.semanticscholar.org/paper/Mitigation-of-the-Rural-Fire-Problem%3A-Strategies-on-Ahrens-Gamache/0199797c922c6d98ef5e7467c36ab24135800247?p2df

Gasco-Hernandez, M., Zheleva, M., Bogdanov, P., and Gil-Garcia, J. R. (2019) Towards a Socio-Technical Framework for Bridging the Digital Divide in Rural Emergency Preparedness and Response: Integrating User Adoption, Heterogeneous Wide-Area Networks, and Advanced Data Science*, Proceedings of the 20th Annual International Conference on Digital Government Research*, Dubai, United Arab Emirates.

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 Phase 1, Volume 3. National Institute of Standards and Technology Interagency or Internal Report (NISTIR) 8277. doi: 10.6028/nist.Ir.8277

Hackos, J. T., and Redish, J. (1998) Chapter 2: Thinking about Users, In *User and task analysis for interface design* (pp. 23-50), Wiley, New York.

Hang, H. M., Byass, P., and Svanström, L. (2004) Incidence and seasonal variation of injury in rural Vietnam: a community-based survey, *Safety Science,* 42, 8, 691-701.

International Organization for Standardization. (2019). Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems. In (Vol. ISO 9241-210).

Iversen, L., Farmer, J. C., and Hannaford, P. C. (2002) Workload pressures in rural general practice: a qualitative investigation, *Scandinavian Journal of Primary Health Care,* 20, 3, 139-144.

Jennings, P. A., Cameron, P., Walker, T., Bernard, S., and Smith, K. (2006) Out-of-hospital cardiac arrest in Victoria: rural and urban outcomes, *Medical Journal of Australia,* 185, 3, 135-139.

LaRose, R., Gregg, J. L., Strover, S., Straubhaar, J., and Carpenter, S. (2007) Closing the rural broadband gap: Promoting adoption of the Internet in rural America, *Telecommunications Policy,* 31, 6-7, 359-373.

Meinrath, S. D., Bonestroo, H., Bullen, G., Jansen, A., Mansour, S., Mitchell, C., . . . Thieme, N. (2019). Broadband Availability and Access in Rural Pennsylvania. Retrieved from https://www.rural.palegislature.us/broadband/Broadband_Availability_and_Access_in_Rural_Pennsylvania_2019_Report.pdf

Middle Class Tax Relief and Job Creation Act of 2012, Public Law 112–96, 126 Stat. 156. (2012, February 22, 2012) Retrieved from http://www.gpo.gov/fdsys/pkg/PLAW-112publ96/pdf/PLAW-112publ96.pdf

National Highway Traffic Safety Administration's Office of Emergency Medical Services National 911 Program. Next Generation 911, Retrieved from https://www.911.gov/issue_nextgeneration911.html

O'Meara, P., Burley, M., and Kelly, H. (2002) RURAL URGENT CARE MODELS: WHAT ARE THEY MADE OF?, *Australian Journal of Rural Health,* 10, 1, 45-50.

Oliver, W. M., and Meier, C. A. (2004) Stress in small town and rural law enforcement: Testing the assumptions, *American Journal of Criminal Justice,* 29, 1, 37-56.

Perrin, A. (2019, 8/18/2020) Digital gap between rural and nonrural America persists, *FactTank: News in the Numbers,* Retrieved from https://www.pewresearch.org/fact-tank/2019/05/31/digital-gap-between-rural-and-nonrural-america-persists/

Persse, D. E., Jarvis, J. L., Corpening, J., and Harris, B. (2004) Customer Satisfaction in a Large Urban Fire Department Emergency Medical Services System, *Academic Emergency Medicine,* 11, 1, 106-110.

Pilemalm, S. (2018) Participatory Design in Emerging Civic Engagement Initiatives in the New Public Sector: Applying PD Concepts in Resource-Scarce Organizations, *Association for Computing Machinery (ACM) Transactions on Computer-Human Interaction,* 25, 1, Article 5.

Pilemalm, S., Stenberg, R., and Andersson Granberg, T. (2013) Emergency Response in Rural Areas, *International Journal of Information Systems for Crisis Response and Management,* 5, 2, 19-31.

Pötsch, T., Schmitt, P., Chen, J., and Raghavan, B. (2016) Helping the Lone Operator in the Vast Frontier, *Proceedings of the 15th ACM Workshop on Hot Topics in Networks*, Atlanta, GA.

Ramsell, E., Granberg, T. A., and Pilemalm, S. (2019) Identifying functions for smartphone based applications in volunteer emergency response, *Proceedings of the 16th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2019)*, Valencia, Spain.

Ratcliffe, M., Burd, C., Holder, K., and Fields, A. (2016). Defining Rural at the U.S. Census Bureau. Retrieved from https://www.census.gov/library/publications/2016/acs/acsgeo-1.html

Reddy, M. C., Paul, S. A., Abraham, J., McNeese, M., DeFlitch, C., and Yen, J. (2009) Challenges to effective crisis management: using information and communication technologies to coordinate emergency medical services and emergency department teams, *International Journal of Medical Informatics,* 78, 4, 259-269.

Ricci, M. A., Caputo, M., Amour, J., Rogers, F. B., Sartorelli, K., Callas, P. W., and Malone, P. T. (2003) Telemedicine reduces discrepancies in rural trauma care, *Telemed J E Health,* 9, 1, 3-11.

Roberts, A., Nimegeer, A., Farmer, J., and Heaney, D. J. (2014) The experience of community first responders in co-producing rural health care: in the liminal gap between citizen and professional, *BMC Health Services Research,* 14, 1, 460.

Rogers, F. B., Shackford, S. R., Osler, T. M., Vane, D. W., and Davis, J. H. (1999) Rural trauma: the challenge for the next decade, *J Trauma,* 47, 4, 802-821.

Saldaña, J. (2013) *The coding manual for qualitative researchers* (2nd ed.), SAGE, Thousand Oaks, CA.

Shenton, A. K. (2004) Strategies for ensuring trustworthiness in qualitative research projects, *Education for Information,* 22, 63-75.

Strover, S. (2001) Rural internet connectivity, *Telecommunications Policy,* 25, 5, 331-347.

Surana, S., Patra, R., Nedevschi, S., Ramos, M., Subramanian, L., Ben-David, Y., and Brewer, E. (2008) Beyond pilots: keeping rural wireless networks alive, *Proceedings of the 5th USENIX Symposium on Networked Systems Design and Implementation*, San Francisco, California.

Tiesman, H., Zwerling, C., Peek-Asa, C., Sprince, N., and Cavanaugh, J. E. (2007) Non-fatal injuries among urban and rural residents: the National Health Interview Survey, 1997-2001, *Injury prevention : journal of the International Society for Child and Adolescent Injury Prevention,* 13, 2, 115-119.

U.S. Bureau of Labor Statistics. (2019). HOUSEHOLD DATA ANNUAL AVERAGES 11: Employed persons by detailed occupation, sex, race, and Hispanic or Latino ethnicity. Retrieved from https://www.bls.gov/cps/cpsaat11.htm

U.S. Census Bureau. Rural America, Retrieved from https://gis-portal.data.census.gov/arcgis/apps/MapSeries/index.html?appid=7a41374f6b03456e9d138cb014711e01

U.S. Department of Commerce Economics and Statistics Administration and the National Telecommunications and Information Administration. (2010). EXPLORING THE DIGITAL NATION: Home Broadband Internet Adoption in the United States. Retrieved from https://www.ntia.doc.gov/report/2010/exploring-digital-nation-home-broadband-internet-adoption-united-states

Weichelt, B., Heimonen, T., Pilz, M., Yoder, A., and Bendixsen, C. (2019) An Argument Against Cross-Platform Development: Lessons From an Augmented Reality App Prototype for Rural Emergency Responders, *JMIR Mhealth Uhealth,* 7, 3, e12207.

Whitacre, B. E. (2008) Factors influencing the temporal diffusion of broadband adoption: evidence from Oklahoma, *The Annals of Regional Science,* 42, 3, 661-679.

Yankelevich, A., Shapiro, M., and Dutton William, H. (2017) Reaching beyond the wire: challenges facing wireless for the last mile, *Digital Policy, Regulation and Governance,* 19, 3, 210-224.