Flying SD Cards, Aerial Repeaters, & Homebrew Apps: Emergent Use of Technologies for Collaboration in Search and Rescue

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ABSTRACT

Search and rescue (SAR) teams are the first to respond to emergencies. This could include finding lost hikers, shoring buildings, or aiding people post-disaster. SAR combines orienteering, engineering, field medicine, and communication. Technology use in SAR has been changing with the proliferation of information communication technologies; so, we ask, how are established and emerging technologies used in SAR? Understanding how responders are adopting and adapting these technologies during SAR missions can inform future design and improve outcomes for SAR teams. We interviewed SAR volunteers to contextualize their experiences with technology and triangulated with additional questionnaire data. We discuss how technology use in SAR requires an intersection of expert knowledge and creative problem solving to overcome challenges in the field.

This research contributes an understanding of the constraints on and implications for future SAR technologies and SAR operators' creativity in emergent situations.

Keywords

Search and Rescue, Information Communication Technology, Creativity.

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INTRODUCTION

The integration of information communication technologies (ICTs) with emergency management has been a distant hurdle pushed ever backward by incompatible policy (Seeman et al. 2015; Hiltz et al. 2014), training not incorporating technology (Alharthi, LaLone, Khalaf, et al. 2018; Alharthi, LaLone, Sharma, et al. 2021; Lalone et al. 2023), and a non-existent information pipeline (Palen and Anderson 2016; Reuter et al. 2018). Yet, the everyday life of an average consumer has been more and more digitized to the point wherein society itself is becoming mediated by computation (Dix 2017). This has created an accelerated change that emergency management has not yet met (e.g. Palen et al. 2020; Lalone et al. 2023). By not integrating ICTs with the standard operating procedures of those responding to disaster, responders are unable to use these devices to their greatest effect. Consequently, ICT use is often improvised in the field.

It is now time to engage this technology integration hurdle and begin designing technologies that responders *need to use* (Palen and Anderson 2016; LaLone et al. 2019; Lalone et al. 2023). Yet, to do that, there is a need to understand what ways technology is being used in the field and how it differs from intended or designed use. Emergency management (EM) is a complex, inter-connected system of systems and, as such, requires significant labor to understand how to design for it. We begin this labor post-hazard-event with search and rescue (SAR) teams[1]. This group of EM workers are the first deployed to a devastated zone and are responsible for establishing a base camp while locating and triaging survivors.

To develop an understanding of current practices and the emerging needs and requirements of SAR workers we present a qualitative investigation of their work using both well-established and emerging technologies. This work is critical in surpassing the integration hurdle because understanding how to develop technologies that are eventually useful to them is a direct attack on the hurdle itself. Our aim is to better understand the applications of the these technologies, and, most importantly, how EM uses ICTs in the context of their work. To pursue that aim, we have constructed a research question that can serve as a guide for interpreting the data we have collected.

Research Question: How are established and emerging technologies used in SAR? Specifically, how can SAR teams in the USA be better served by technology development and design specifically for their needs.

Investigating our research question will allow us to better understand how technology is currently integrated with SAR teams and shed light on how best to design for further integration. We have gathered data from in-depth, semi-structured interviews with experienced SAR professionals in southwestern region of the USA. In addition to interviews, we further triangulate these data with results from an online questionnaire of a broader range of SAR responders. Most participants we interviewed were USAR and wilderness SAR response volunteers and professionals.

Through thematic analysis, we identify emergent themes including challenges and shortcomings of modern SAR technologies, collaborative practices involving the use of new technologies, and the creative development and application of new technologies in SAR. The paper's title reflects examples raised by our participants – the creative use of drones to move memory cards and radio repeaters to where they are effective and examples of new software developed in response to SAR needs. In the following sections, we review relevant background and prior work, describe our methodology, and present results. We discuss the constraints of technology use in SAR and implications for the design of future SAR technologies. We identify the creative application of emerging technologies such as drones and digital maps as an important lens for future SAR research. Further, we argue that a clear and modern understanding of the application of these technologies will inform developers designing new systems with clear and necessary use cases. We conclude with a discussion of the study's limitations and directions for future work.

BACKGROUND

The present research is situated in the USA, and so our understanding of SAR and of incident command is situated geographically. While other countries have similar approaches, disasters are local and so, most research on EM is not generalizable. We present a brief primer on EM generally and response processes in the USA more specifically but point the reader to Palen et al.'s living bibliography on crisis informatics (Palen et al. 2020) for more comprehensive references.

[1]Pronounced by our participants as a word, not sequence of letters.

Emergency Management & Technology

Broadly, emergency management (EM) is defined as, "a discipline that deals with risk and risk avoidance" (Haddow et al. 2021). Risks, in most cases, are a characteristic of a particular municipality is (e.g., a region prone to flooding, earthquakes, or fires) and planning around those risks is where EM often begins its practice. Planning and mitigation have been of growing interest broadly; it is estimated that the ratio is that each $1.00 spent on mitigation results in anywhere from $6.00 to $15.00 saved in responding to a large-scale incident (Multi-Hazard Mitigation Council 2019). Yet, regardless of planning, when an *incident* – a term used generally here but specifically defined and discussed in the EM context in the next section – occurs, the devastation and destruction cannot be fully accounted for. Cellular towers could fall or fail; electric plants could be disabled, disconnected, or destroyed; and other types of critical infrastructure end up destroyed, taken offline, or be experiencing other forms of hazards.

When an incident or hazard occurs, EM sends SAR teams to stabilize areas so that recovery can commence. As a result, when EM is in a response, personnel must regularly operate within conditions that do not include things like electricity, network connectivity, or mobile connectivity. Technology adoption in EM amongst SAR teams is difficult. Often costs are prohibitive, and standardization across teams can be challenging, especially in the U.S. where most teams are made up of volunteers (Bharosa et al. 2010; Kamel Boulos et al. 2011). Additionally training individuals on how newer technologies function can be challenging and, in the context of a intense SAR mission, any barriers to communication, locating or rescuing individuals in need, or devices that just generally make a mission harder are difficult to implement. If technology is not accessible for anyone and cannot be used to do much of anything, any amount of work done to solve that problem will increase not only the usefulness of technology, but its capacity to save lives.

EM has never fully stabilized as a discipline – it is always in a state of flux and leaders in the discipline are conflicted about what sorts of paths to professionalization and training are necessary (Lalone et al. 2023). Much of the current issue is situated around the pipeline of emergency medical services, fire fighting, law enforcement, and the armed forces. This has led EM to have a very specific version of a lack of diversity that leads to issues in one locale being manifest everywhere else simultaneously. In recent years, EM has been implicated in "technical deficiencies" relating to everything from communication to computer maintenance (Homeland Security Office of the Inspector General 2019; Chappellet-Lanier 2019). The present research is an attempt to unpack not only how these technical deficiencies manifest within a specific portion of EM, but to understand it in a way that can foster development. In the next section, we move from these general statements about EM to more specific description of how EM is structured.

We focus on SAR teams as these teams are often using technology in the most desolate conditions possible, directly after a crisis event. SAR involves locating persons in distress and rendering aid immediately after an event allows entry. Such activities happen at different scales and involve different activities, dependent upon scale: a lost hiker might require an on-foot search in the wilderness (Jones, Tang, Neustaedter, et al. 2020), seeking clues, while post-hurricane or post-earthquake urban SAR (USAR[2]) involves at-scale triage and on-the-fly engineering (Toups Dugas, Hamilton, et al. 2016; Alharthi, LaLone, Sharma, et al. 2021; Alharthi, LaLone, Khalaf, et al. 2018; Alharthi, Hamilton, et al. 2018).

Typically, SAR is a process that involves team members seeking survivors through an assemblage of skills and technologies reinforced by training. All SAR activities rely on collaboration around maps and an understanding of space as a core information technology (Toups Dugas, Hamilton, et al. 2016; Alharthi, LaLone, Sharma, et al. 2021; Alharthi, LaLone, Khalaf, et al. 2018; Alharthi, Hamilton, et al. 2018; Fischer et al. 2015; Kogan et al. 2016). This makes SAR an intensely socio-technical activity (Alharthi, LaLone, Sharma, et al. 2021). SAR team members triage the environment as they explore it, thus rendering it safe to access in order to extract and treat survivors (Toups Dugas, Hamilton, et al. 2016). Time is critical in SAR operations; using technology (e.g., drones) could decrease the time needed to find persons who are in distress (Waharte and Trigoni 2010). While much of SAR is carried out with a combination of non-electronic tools (e.g., paper, pens, compasses, maps) (Alharthi, LaLone, Sharma, et al. 2021), technology use has increased over the years due to improvements in GPS and mapping systems, the advent of smartphones (Stockton 2020), and consumer-grade drones.

Search & Rescue and Incident Response [in the United States]

In the USA, response to an *incident* – "An occurrence, natural or [human-]made, that necessitates a response to protect life or property....including planned events as well as emergencies and/or disasters of all kinds and sizes." (U.S. Department of Homeland Security 2017, p.65) – follows the Incident Command System (ICS), part of the

[2]Pronounced by our participants as "you-sar".

National Incident Management System (U.S. Department of Homeland Security 2017; Toups Dugas and Kerne 2007). As specified in ICS, every incident has either a single Incident Commander, which is typical of smaller-scale incidents, or a group of people that function as Unified Command, which is typical in larger scales or events that cross jurisdictional boundaries. ICS builds up complexity in response to the scale of the incident, and breaks down the complexity as it is no longer needed, with a key characteristic that each person only reports to one other above them in a chain of command. By default, all incidents include a Command branch (i.e., Incident Commander or Unified Command); the largest incidents will include branches to cover:

- Operations: making choices about response at the incident, physically enacting changes, and responding quickly;
- Planning: collecting information and making plans for subsequent operations;
- Logistics: moving personnel, equipment, and supplies to where they are needed; and
- Finance/Admin: handling purchases and other payments.

SAR may be the entirety of an incident response (e.g., post-hurricane, post-earthquake, lost persons) or a component of it (e.g., forest fires). SAR operations typically include one or more teams that move through an area to rescue survivors and render an area safe. The search component may include looking for signs of life and clues for the whereabouts of people, triaging locations for the likelihood that they contain survivors (or human remains), and collecting data about how a space has changed post-incident. The rescue component involves extracting survivors to safety and rendering aid (e.g., medical assistance, water, food).

SAR organization in the USA is complicated and many members of SAR groups are incident responders of various sorts from other organizations (e.g., firefighting, law enforcement). The Federal Emergency Management Agency (FEMA), an agency of the United States Department of Homeland Security (DHS), establishes policy and leads the coordination of the National Urban Search and Rescue System (FEMA 2003). Many SAR groups are small and volunteer-led, but the National Urban Search and Rescue System established one or more *Task Forces* associated with several states (e.g., Texas Task Force 1, California Task Forces 1–8).

Task forces have been distributed and established based on risks of particular regions of the country. It is worth noting that “task force” is a specific term, but gets used in two ways. In general, it refers to mixing multiple response units of different types (e.g., a team with a medic, technical search specialist, and canine handler) to accomplish a particular task (e.g., extracting and attending to victims); this is in opposition to a “strike team”, consisting of same-typed units (e.g., multiple firefighters). In EM, multiple teams – task forces and strike teams – will be deployed to an incident as the incident commander sees fit. In the context of SAR, “Task Force” as a proper noun refers to these federal response teams, which contain within their structure multiple types of (common noun) “task forces”, as outlined above (FEMA 2003; U.S. Department of Homeland Security 2017).

SAR groups may respond in various capacities, which structure their use of resources and who is in command; for example, Texas Task Force 1 might respond in its capacity as a state agency and be responsive to the state government, or it may be activated as part of a federal response (often in another state) and be responsive to FEMA. Members of larger SAR groups may also be simultaneous members of smaller groups, such as local wilderness search and rescue (and all of this in addition to their home organizations, which are typically firefighting). While all SAR groups have collections of specialized equipment, federal-level Task Forces typically have large equipment caches and are generally more well-resourced, at least when responding in official capacities (Force 2011).

Drones in Search & Rescue

While not a specific focus of the present research, drones were consistently brought up within our data and through interviews with our respondents. As such, we contextualize drones within EM and SAR in order to allow our respondent’s responses to be fully realized. The term *drone*, used for simplicity, refers to an aerial vehicle that can be controlled remotely rather than piloted directly (Austin 2010; Barin et al. 2017; Chang et al. 2017; Jones, Dillman, et al. 2016). While a variety of rescue robots have been developed for research (Murphy 2012), drones have the potential to offer a usable, lightweight, and somewhat immediate means of augmenting SAR practice (Khan and Neustaedter 2019b; Khan and Neustaedter 2019a).

In the context of SAR, drones have a variety of uses and have increased in popularity since they became commercially available. Most studies on drones for SAR work with simulation (Cacace et al. 2016; Cacace et al. 2017; Karaca et al. 2018), but a case study found that using a commercial drone to assist search for a missing climber near the peak of the Karakoram Mountains reduced the number of people needed to find the climber and reduced the risk of those SAR responders (McRae et al. 2019). Conditions like this are especially dangerous to people because of the vast area needed to search and dangerous altitude. Findings that drones could also decrease the time needed to find missing persons (Weldon and Hupy 2020) makes drones increasingly more viable in SAR.

Additionally, drones were used for SAR during Hurricane Harvey in summer 2017 (ABC News 2017; Hutson 2017) to create a map of the flooding and damage. In the midst of the hurricane rescue and relief process, drones allowed first responders to search for survivors more effectively, monitor the condition of the levies, and map clear pathways for responders to reach survivors via waterways. First responders also stated that since drones are exponentially cheaper than a helicopter they are more viable for volunteer based SAR teams (ABC News 2017).

As drone usage increases, we expect them to be of great value to the future of SAR (Jones, Tang, and Neustaedter 2019; Alharthi, LaLone, Khalaf, et al. 2018; Khalaf et al. 2018; McRae et al. 2019; Alharthi, LaLone, Sharma, et al. 2021) (and disaster response, in general (Khan and Neustaedter 2019b; Khan and Neustaedter 2019a)). Many SAR teams are developing drone units within an existing team. These units consist of several SAR members that specialize primarily on the use of drones in the context of a mission (Wynsberghe and Comes 2019; Fernandes et al. 2018).

METHOD

We recruited a variety of SAR and Task Force responders. Participants (n = 35, 3 self-identified as women, 30 self-identified as men, 2 declined identifying gender) between the age 36–77 (M = 52, SD = 12.83). Participants had varying roles and levels of experience within SAR. All participants were volunteer SAR team members from various teams across the Southwestern USA: New Mexico and Texas. Participant experience ranged from 3 years to 27 years ($M = 15$, $SD = 8$) . While most participants served as general SAR team members, three participants worked as a member of a drone team within their larger SAR organization. Two other participants were in team leadership positions that coordinated missions, allocated resources, and acted as points of contact between emergency dispatch services and their SAR teams. It should be noted that, at the onset of this study, our intentions were to differentiate experience, role, and team more clearly during data analysis. However, due to the rapid onset of the COVID-19 Pandemic and the emergency health orders that were in place, many of our recruited participants were unreachable. Thus, we reduced the categorical analysis of role and team and took a more holistic approach.

Table 1 shows the number of SAR responders we interviewed face-to-face and online, and also those that completed the online questionnaire. This range of expertise offers a diverse view of SAR practice and training relevant to our study. Most of the participants were local SAR responders, and we contacted them through email and by attending their monthly meetings prior to the onset of the COVID-19 Pandemic. After the onset of the COVID-19 Pandemic, our research team moved entirely to online recruitment, and we no longer attended SAR team meetings or attempted to go on site with SAR teams. Due to the digital research transition, our team decided to develop a long-form questionnaire to send to SAR team members in hopes of collecting a wider data set to use in analysis.

Interviews were performed between August 2019 and August 2020. Questionnaire data was collected in July of 2020. Because the project involved human subjects, the research protocol was evaluated by the New Mexico State University Institutional Review Board. It was approved under protocols #16098 and #19163.

Interview Component

We conducted in-depth face-to-face and online (Zoom/Skype) semi-structured interviews with five SAR responders. Each interview lasted 45–80 minutes; each participant was provided an information letter and signed a consent form online. The interview protocol involved a series of open-ended and follow-up questions focusing on responders' experience, technical background, factors affecting SAR planning success, and future vision for SAR work. Every participant was asked the same set of questions with variation in follow-up questions which was dependent on participant direction in the context of the interview. It should be noted that some participants had varying experience with the different technologies we asked about, primarily drones. We worked to probe each participant for information about each of these technologies. All interview participants are given a pseudonym of "P" followed by their interview number in chronological order.

Part of our study was to understand practice, but we were also interested in developing new technological interventions. We showed participants prototypes of technologies that are currently being developed or have not yet been fully adapted to SAR purposes, and explained about each wearable device in detail. However, in reflecting on the data collected in this portion of the interview, we determined that the focus was too narrow. Consequently, the component addressing technological intervention did not result in insightful data and is not discussed further in this paper. Interviews were audio-recorded and transcribed to support analysis.

Table 1. Breakdown of participants by research methodology.

Data source	No.	Details
Face-to-face Interviews	3	Face-to-face semi-structured interviews with professional SAR responders and instructors. The length of each interview was between 45 to 80 minutes.
Online Interviews	4	Online semi-structured interviews with professional SAR responders and instructors. The length of each interview was between 45 to 80 minutes.
Online Questionnaires	28	To reach skilled SAR professionals, an online questionnaire was sent to high-ranked SAR responders.

Questionnaire Component & Alterations Due to the COVID-19 Pandemic

In early 2020, our research team had coordinated meetings with local SAR groups to not only conduct in-person interviews, but also go in the field with their teams during training and, if safety and circumstance allowed, to be on a mission with them as observers. Additionally, our team intended to develop prototype technologies, which were based on previous research, and have SAR team members provide feedback on the efficacy of the design. However, as we were about to begin this process the COVID-19 pandemic began (World Health Organization 2020), and we were forced to reevaluate our methods to preserve the safety of the research team and participants.

Further, due to the pandemic, many potential participants were unable to set aside time for an online interview. To reach more participants, we sent an online questionnaire to SAR responders. The questionnaire consisted of the same questions as the semi-structured interview, and participants were given an open format to respond at length to each section. The online questionnaire allowed us to reach out to 28 SAR responders. Questionnaire data is not used as quotations over the course of this paper, due to the limited responses we received in the context of open-ended questions. Questionnaire data was used to provide additional context and corroborate information given in the long form interviews such as team make-up, individual roles in the SAR team, and overall experience. See Appendix A for questionnaire questions. All questionnaire participants are given a pseudonym of "S" followed by their questionnaire number in chronological order; we use these pseudonyms whenever a particular questionnaire respondent's report supported reported results.

Analysis

In this work, we followed a thematic analysis approach (Braun and Clarke 2012), looking for similar themes among our data. After all data were collected, interviews were transcribed using an automated transcription service (Otter.AI 2021), and then corrected for grammar and syntax by hand. Interviews and questionnaire data sets were then imported in the qualitative data analysis software ATLASti.8 (ATLAS.ti Scientific Software Development GmbH 2018) for coding. Thematic analysis offers a broad scope to look for themes between heterogeneous data sources that relate to the same topic. While we would not expect to run any form of quantitative analysis across the interview and questionnaire data, this qualitative approach allows us to look at the questionnaires as a form of triangulation.

Emergent themes were categorized according to prevalence in the data sets and interview and questionnaire data were coded individually. Themes were gathered over several passes of the data. Ideas and topics that emerged from the data set, were then reviewed by the research team and then sub-codes were generated from the larger theme topics. Coding was completed by two graduate students and compared upon completion for agreement between coders. Three rounds of analysis were done in which coders compared individual coding of the interviews and revised codes. Interviews were then coded using the refined code book and analysis was done from the final set of coded interviews.

Topics within the interviews were coded by major themes and the organized into more specific sets of data for easy retrieval when writing about the data set. Major themes included: *challenges and shortcomings of modern SAR*, *the creation of custom digital maps and location tools*, and *drone use in the context of SAR*. Minor themes included topics such as: *communication technology failure and challenges*, *team planning and organization*, and *the challenges that come with being volunteer based SAR teams*. The results section is organized in a way that reflects the hierarchy of themes that were developed through the coding process.

RESULTS

Our participants state that there are clear technological and systemic challenges that come from being a part of a volunteer-based SAR team. These challenges include the shortcomings of technological design that is made for SAR teams and the lack of availability of these technologies. Additionally our participants spoke about the challenges that come with funding and organization of teams that are primarily based on volunteers and the difficulties this brings to coordinating missions. These challenges are detailed in the following sections with explicit quotes from our participants. We go over each of these topics in detail providing further data given by our participants that responded to the questionnaire inquiries.

Challenges and Shortcomings of Modern SAR Technologies

SAR practice has continued to evolve as technologies and systems have changed over time. Technical search equipment (e.g., high-sensitivity microphones, thermal imagers) is invaluable to SAR teams, and SAR teams have begun to adopt newer technologies as they are financially able to do so. However, each of these new technologies comes with its own set of challenges due to faults with the technology itself and access to these technologies due to barriers (e.g., cost, availability). The following sections document challenges as expressed by our participants.

Coordinating with Unreliable Communication

Participants reported various shortcomings and technical challenges that are unique to using equipment in remote areas and under the conditions that many SAR teams face. These shortcomings diminish effective communication and hinder successful rescues.

It is important to note that the word "communication" happens on different levels in the context of SAR. In SAR, communication refers to the successful transfer of information – instructions, reports, questions, suggestions – without delay or misunderstanding so that all who need that information acquire it rapidly and understand it fully (Jones, Tang, and Neustaedter 2020; National Incident Management System 2014). Team members require a great deal of information during a mission, and it is of vital importance that it should flow efficiently and quickly. During SAR operations, it is essential to use standardized communication procedures and language (National Incident Management System 2014). The primary means of communication is the radio carried by the responders. These radios are typically half-duplex, i.e., only able to only transmit *or* receive at any time.

Participants mentioned transmission is more problematic in the mountains because of the valleys [S3, S5]. Large amounts of rock block or reflect radio signals. There is mostly weak cell phone and radio coverage in the rural areas of the southwest USA and reception repeaters or boosters do not work. A radio repeater is a device that receives radio signals and transmits those signals at a higher power so it can travel greater distances (Coperich and Turner 1982).

> When you're operating in the mountains or especially in a gorge, there's [another gorge] that is anywhere from 600 to 900 feet to the bottom of the river and it goes around corners and it's 50 miles long, and it can be a communication nightmare....it's very difficult to even hit some repeaters[3] [P2]

Many factors impair transmission or reception of radio signals, such as: weather, geographical location, frequency spectrum / interference, and battery life [S6, S13]. Overall, participants discussed issues with communication (cell phone / radio reception), limits in available technology (due to funding or access).

> We had serious communication issues because we were in the wilderness in an area where we didn't have good cell phone coverage, we didn't have good radio coverage and we were trying to work off one of the permanent repeaters in the area but when we were down real low....we were often completely out of touch. [P1]

These shortcomings create barriers to effective and consistent communication. While weather and geographical location are out of the control of SAR team members during a mission, technological improvements are something participants believe to be both possible and necessary:

> You know you need to be able to depend on your equipment as much as possible, but it's impossible to depend one-hundred percent on your equipment. You have to be ready for anything and everything. [P2]

[3] "Hitting repeaters" refers to individual radios being able to access a stationary radio repeater device to rebroadcast the signal.

Equipment Reliability

One of the central concerns for participants is the effectiveness of portable and interchangeable batteries for equipment that they carry with them on a mission. The participant above mentioned their desire to depend on equipment as much as possible but knowing its limits to avoid risky situations for the team or the individual(s) they are searching for:

> ...battery life is definitely of interest especially if we're working in super cold environments and water stability [water-proofing] for equipment is a huge concern... [P1]

This is expanded upon by another participant:

> On a mission, I make sure when I buy a new cell phone, I get the one with the biggest amp hours, as far as a battery goes, so I can keep doing a lot of things a lot longer than most people do. But that's always been the limitation: getting the phone that does what I want to do and have that extended battery. So, because you just can't charge it out in the field. Goal Zero[4] makes the solar panels, the power packs. And that's where we've had to go. You need to bring those extra power packs, especially if you're going to use it. One of the things, when they started coming up with the GPS apps for your phones, a lot of our people on our team started using that when they found out real quick that drains your phone really quick, especially if you don't have the extended battery. [P7]

Here the participant mentions the importance of battery life but also field equipment's water exposure rating. When SAR team members are in the field, having equipment that can be submerged, rained on, or exposed to high amounts of sweat due to physical exertion is important [S9, S11, S15].

Volunteers, Limited Funding, & Distributed Organization

The SAR teams in our study face many challenges resulting from their organizational and volunteer nature. Participants indicated that there is a general lack of organizational cohesion nationally. Many SAR teams are created as branches of the local sheriff's office and informally coordinate with state agencies. However, team structure and policies are self-determined, and equipment is generally financed by individual members. This results in varied access to and use of technologies between teams. Certain equipment is standardized across teams simply due to similar requirements of SAR teams. For example, tools such as radio, cell-phones, various GPS systems, and, increasingly, drones, are ubiquitous. There are a wide variety of commercial drone models, cell phones, and mapping systems, and as in any commercial market some tools are better than others [S4].

The variation between SAR teams is further reflected by their organization and being primarily volunteer-based, which can impact team dynamic and mission execution:

> We are completely 100% volunteer. All of our money is through our own fundraising efforts. We don't receive any money from the sheriff's department. However, we do work for the sheriff's department, we have Sheriff's Department IDs.... And when a mission requires more resources a team can call the state SAR organization [edited for anonymity] and since the state organization is appointed and all volunteers. All the volunteers from the county teams make up the state organization as well. We do double duty. [P7]

Here this participant further elaborates on the nature of volunteer team organization. While SAR teams are organized as a part of the sheriff's department, they are individually led and organized. In this participant's case there is also a state organization that can help coordinate SAR teams across counties, but again this organization includes volunteers from the local teams. The participant describes this as doing "double-duty", meaning that the overall function and performance of these teams completely relies on people who have constraints on availability outside of SAR:

> We have other jobs, we have lives, we have families, so you can't always put 100% into running the team efficiently and organized. And people come and go throughout the team. So what someone developed...somehow it didn't get passed on to the new person who's doing it. So you do you have this loss of continuity, or they may want to do something totally different, in which case, the standards

[4]Goal Zero is a company that manufactures equipment to power mobile devices (Goal Zero 2021).

> may not be there. They may want to do it their way, but their way is not necessarily the way it should be done... So there's a personnel problem. And that's mainly because we're volunteer, we only have so much time... I think that's, you know, the only way to really work around that is the team with their process and procedures and with computers and everything that's helped with keeping documents updated and keeping track of it all... but it still takes people their time and effort to keep those things updated and moving forward. That's always going to be an issue. [P7]

As this participant explains, having a volunteer team does not only affect the technological and equipment that those teams can use. It also affects training, continuity between team members as people cycle out, and core team function. The participant talks about a loss of continuity and a change in procedural understanding that can be lost from person-to-person as training standards are developed mainly by the team itself, there is not a formalized curriculum for all team members to pass and understand [S5]. This participant goes on to describe their team's process for training new people, but this is not formalized [P7]. While technological gaps between teams and individuals and their impact on performance or efficiency can be easy to qualify and understand, team organization and the volunteer structure of SAR teams may play an even more important role in the success of SAR teams. As P7 mentioned above there are certain things that get in the way of team function and organization that are intrinsic to being a volunteer organization. Other participants echoed these same concerns, that training new team members and setting protocol for the team is difficult because team members have other lives, needs and goals outside of SAR.

Creating Custom Digital Maps & Location Tools for SAR

Participants generally believe that even though there are limitations on the efficacy of certain modern technologies, systems like satellite radios and GPS equipment have improved:

> I remember in early days sometimes we would just be out there kind of lost without a signal and now that doesn't happen that often. [P1]

Although there are gradual improvements to the technology, there are some situations where SAR team members are out-of-touch with other teammates and the base of operations [S1–3]. One essential safety measure in specific scenarios is knowing one's location and making a plan of action based on their location [S1–20].

Another participant talked about the lack of effective mapping systems designed for SAR teams specifically [P7]. Consequently, a member of their team developed a homebrew mobile application that allows users to communicate directly with one another, send dispatch alerts, and, most importantly, identify a precise GPS location of someone through interaction with a link sent to a cell phone number. This participant explained that if someone is missing but still has cell service, their software can send a link directly to their cell phone and provide the team with an exact latitude and longitude. This participant stated that their team felt inclined to develop this system because there was a lack of similar software:

> There were other apps out there we used to use but those seem to fade away. And I'm not sure why. I don't know if it was reliability, or maintainability...So what our guy did, who is pretty smart he's an IT guy by trade... He's got it all set up in his basement. So he runs the system, and we told him you can never leave! ... He's a single point of failure. We've been looking at that as like, how do we mitigate that risk.? But he basically took all these different apps or whatever, that were out there. Took the best things from each one of those and came up with his own app for our system...I could do it with you right now...and it would give me your latitude longitude. If I were to text it to you, then it would return back and give me your latitude and longitude, as long as your GPS was enabled in on your phone. [P7]

This participant explains how their own team developed a complex tool to accurately find lost persons because similar tools did not exist or were not well-maintained.

P7 goes on to describe attending a west coast SAR conference in 2012 and meeting another attendee who created an interactive geographic information system (GIS) software that is made specifically for SAR teams. This participant reported using a topographical mapping software developed by a private company, CalTopo, which is specifically designed with SAR teams and first responders in mind (CalTopo 2021). While this software is licensed to various industries, SAR teams get a discount (a limited free version is also available). The limiting factor in the case of this mapping software seems to be industry knowledge of its existence. This participant describes their interaction with this developer and the software's benefit to SAR teams as follows:

> (Developer) is creating a GIS system that the lay search rescue person could use with little to no training, but yet still have almost the same power as a GIS, you know, full blown GIS. So he gave me a free account. I used it for years on the team, trying to get people to buy into it. And eventually, his company took off....then he created search and rescue accounts where it was reduced price and more users.... I talked our team into getting one of the team accounts, it's only 500 [USD] a year for a search and rescue team, and every person on the team can have access to it... If you have the subscription, like we do, you can create a map, you can share it, you can distribute it, there's QR codes you can use. I mean, it's pretty powerful. [P7]

Mapping systems within SAR communities are slowly advancing and becoming more readily available. In the instance of this software however, its creation was seemingly contingent upon the developer previously being involved within the SAR community according to our participant (CalTopo 2021). Given that SAR generally takes place in remote and hard-to-access areas, having accurate and accessible maps is important. While CalTopo works well for the teams it is being used by, the central challenge here is this software being used by more teams. Only one of our participants mentioned the use of this software, even though it seems to support a feature set that would be helpful to many SAR teams. Tools like CalTopo or other advanced mapping systems could be more integrated into SAR training and practice. It is clear based on on P7's experience with CalTopo it has been a massive boon to their mission planning and coordination in the field. It is likely there are many other tools and technologies out there that would help address some of the challenges faced by SAR teams, but there appears to be a lack of awareness and adoption.

Drones in SAR

While drone use in SAR was not a focus of our investigation, it became apparent that drones increasingly provide utility to SAR teams. They can be used to search for missing persons, move supplies between team members, and even support communications and guidance in the field [S4, S7]. In the following sections, we report the experiences of our participants with drones in SAR practice. This includes practical application of drone technologies, specific features of drones that our participants found the most beneficial, and creative drone use in the field.

Drones in Practice

Participants noted that drone use can and has dramatically changed SAR. In general, drones are being used to provide better operational intelligence during rescue missions and can cover more ground in less time than responders in the process of a mission. Drone use in SAR is complex and requires a different skill set than those used on the ground [S5].

> What we're trying to do is clear areas that would take us hours or days to search that a drone can search very quickly or inaccessible areas, we've sent them great distances to see if they can get a glimpse into a cave or the top of a cliff, to see if they get into a crevice where it would take us hours to check if there was anybody there so they've been extraordinary...In terms of support for the mission and we always like to have our drones with us. [P2]

Participants feel that the utility drones provide while on a mission is immense. They allow teams to see and do things that would normally take many hours to do on foot.

> Yes our drones are very valuable, they have limitations depending on a mission....recently on a mission we were able to fly a drone down into the gorge and determine obstacles in our pathway to the recovery and so we were able to better understand what equipment we needed to carry down in order to traverse those obstacles more safely. It helped us to become much more aware of safety issues and the environment and be able to be a little more prepared for them. [P1]

Drone use in the context of SAR can vary. Sometimes drone pilots are tasked with flying a patterned aerial grid – a "screen" – over a designated area that is too hard to reach with all-terrain vehicles or human searchers, or they are required to search areas that might take other searchers hours to reach. Drones in SAR missions can quickly and efficiently provide detailed data, impacting the decision-making process of the search. With a drone in the air, SAR team members can be alerted of any geographical challenges within the area that will require special equipment or skill to navigate. This is important because it prevents sending a team out blind and risking them facing an obstacle unprepared that may delay the find [S10–12]. Participants explained that the use of drones improves the chances of a successful find for the team:

> You make the drone do work legs can't.... If we were not using the drone, they had no chance of making the find. The whole mountain range was too big. [P2]

In some cases, when a lost individual is found, but the area is not easily accessible by rescuers, drones can lower food and supplies to the subject until the team can safely evacuate them from the site. One participant [P6] mentioned the challenges of using drones in the southwest. Special licenses must be acquired before drones can legally be used in SAR, and there are no-fly zones across the southwest, such as over military bases. Participants stated that further training and certification processes for drone use would make them stronger assets of the team [P6]. State certification of drone use varies by state, and some participants reported that the certification process is lengthy and a barrier to use and access for smaller SAR teams. Participants also mentioned challenges in training and teamwork with drone pilots and other SAR members given that drone team training can be different and more involved than usual SAR training practices. Drone teams usually must have the same skills and training as regular SAR team members and know how to operate a drone in the context of a mission. Additionally, drone teams do not always train with other SAR members which can make coordination in the context of a mission difficult.

> We want the potential pilots to have a year on specifically the drone team helping out with kind of some of those other tasks before they are set up to be the the pilot and command...you're looking up and down with the camera itself, because that can move kind of independently of the drone, you have a lot of like settings buttons for maybe stopping and recording or switching from pictures to video. So there's a lot of stuff going on there and we want everyone to get a sufficient amount of practice before actually working a mission. [P6]

Typically drone pilots are specialized members of a SAR team that operate outside of usual mission control, and they have become increasingly important. Drone pilots undergo differential training procedures to work with a SAR team and focus on different aspects of the mission during a rescue. Training for drone pilots involves getting the necessary certifications required to pilot the drone for emergency response, but also learning to fly the drone in ways that are important in SAR usually meaning finding small details and patterns while in the air that can lead to a find. This can mean working in tandem with other team members, where someone flies the drone and another person monitors the drone's video feed and relays that information to the team. Some participants mentioned that drone pilots notice details that other responders might not see as they have a different perspective (aerial view), and can see patterns or tracks in a geographical area that might be missed by team members on the ground:

> ....we utilize the drones to sight specific things on the ground...we go out [to the field] and see how easily our drone operators can spot them, how easily and quickly they fly grids over the area, how quickly can they spot something [by] using the drone and from what height is best and what size of things can they spot at certain heights... [P2]

It is clear based on participants' responses that drone use is an integral part of modern SAR, especially in remote areas, and are critical to the success of some missions.

Application of Specific Drone Features in SAR

Specific drone models are required for the increased demand placed on the hardware in the context of SAR. However, for many small or volunteer-based teams, cost remains the central issue. Viable SAR drones are usually over a thousand dollars, and for volunteer-based teams, this is often difficult to reconcile considering the cost of the unit, the training required, and the certification process that is needed before they can legally be used. It is clear that the ability to attach devices to drones are helpful, but they still need improvement:

> The drone has those three separate attachments, you can put on: the speaker, the spotlight, and then the the strobe light. So really, the only reason you'd be using the spotlight that you're going to be pointing at the ground is for searching when it's dark or at night. Which is also when you would be using that strobe light at the same time. So it's kind of a silly one that they didn't just build the strobe light in, or at least build it into the the spotlight because you got to pick one or the other. Are you going to be blind, but other people can see you? Or vice versa. [P6]

This participant went on to mention that there are creative ways to get around this problem such as attaching a small strobe light physically to the drone. However, this attachment is not integrated into the drones systems, thus it cannot be controlled remotely through the app. Additionally, the manufacturer's flight control applications have built-in restrictions for consumers, such as measures to prevent pilots from flying too high or into restricted air space. There are also limitations on flight if the pilot does not have access to a quality GPS signal. In the context of SAR, this can create issues that limit the success of drone usage. While participants stated they do not wish to break any regulation surrounding drone use, there are other third party applications that can be used to bypass some of these restrictions but do not have the full functionality of the manufacturer's application.

> I have probably 10 different apps relating to using drones. And they all have kind of different functions. Some of them are really good for doing mapping stuff, or some of them are good for doing a film stuff, or maybe this one doesn't have a lot of this limitations that when running a search can be you know, a hamstring. [P6]

A central feature of drones that make them so useful in the context of SAR is their camera and ability to send a video feed to the pilot. There are variations within the model series participants used, such as high resolution cameras, thermal cameras, or zoom capabilities. Each of these cameras can be useful in the context of SAR, but participants preferred the model with the integrated higher zoom:

> The zoom obviously is really useful for search and rescue because you can zoom in on faraway stuff. We're trying to see "Oh, is that something underneath that tree way over there? Oh, is that a cow or a bush?" Three miles off or something. So it makes it really nice for zooming in on specific little things. [P6]

While the zoom function is great for finding objects far away, the thermal camera sensor can also be useful for finding living people on a mission. In their current state, however, both options are not offered on the same drone.

Drones require an increase in visual attention and access to drone diagnostic readings. A participant stated that the a visual heads up display (HUD) that shows users important information about the status of the drone, or gives users a more interactive visual directly in front of their face that displays drone diagnostic information [P6] could be beneficial. Currently this information is displayed on the monitor for the drone camera feed. If there is only one pilot and no other team member to relay visual information to the pilot or team it can be difficult to fly and keep track of this diagnostic information simultaneously.

Overall, there are several quality-of-life functions that come with advancements of technology that would make their application more effective within SAR. An improvement to the video feed being sent back to the pilot would make live searching more effective. Often when flying the drone at greater distances, geographical obstructions (e.g., trees, hills, cliffs) can disrupt the feed, causing it to stutter or drop frames. This often requires the drone team to review the recorded footage at full resolution later, which can delay a find. Features like increased flight time and distance would be welcome improvements that would make these tools even more powerful for SAR teams.

Creative Collaborative Drone Applications

Beyond the critical use of drones for conducting searches, participants identified a number of other creative uses for using drones collaboratively during missions. These tasks include things like attaching a cell phone signal booster onto a drone and lifted into the air to provide better communication signals and using the drones to guide other team members:

> You can attach the radio set in repeater mode on to the drone, send the drone up 100–200 feet in the air, and now you've got line of sight between your radios to the drone and you can get communication back to a team that you didn't have it with before. And that also applies with cell phone stuff, too. I actually know there was a couple teams in Texas who during a really massive flood, and it knocked out a lot of infrastructure. And so they actually managed to get it working there. [P6]

> It's been really helpful for helping guide other teams, maybe not even to a subject but just around a tricky piece of terrain, maybe they were going to try to climb up some cliffs that would have been hours of wasted time and a lot of unnecessary danger to them. When 100 feet to the left, there's an actual trail you can use. So that's also a really good use, it doesn't have to be limited just to the actual searching for the subject. There's other things too, like guiding people. [P6]

Later in the interview the participant reported using drones to transport files to the command center:

> The guy with the drone at the top, flew down to me, I caught his drone, and put the the SD card in his drone, he flew back up there, he walked over to incident base and just handed them the the files, the videos that I had taken. [P6]

As the participants explains, there are a variety of creative applications for drones in the context of SAR. As such, drones not only improve the quality of search but also carry out and support additional team functions that are necessary while on a mission [S19–20].

DISCUSSION

We return to our question of: how are established and emerging technologies used in SAR? Our results indicate that technology use in the context of SAR is both complex and inventive. Participants expressed the variety of challenges they face when using technology in the field and described ways they overcome obstacles that are intrinsic to SAR work, e.g., geographic challenges, issues with communication, mission control, logistical challenges. Our data indicates there are not only gaps in development of practical and effective technologies for the SAR community, but there are systemic barriers that prevent SAR communities from being able to easily adopt new technologies.

Our participants are all from volunteer SAR teams and, as indicated in our findings, most of the equipment they use is acquired by individuals. While there may be state-wide or national organizations that help connect SAR teams, funding for local SAR teams can be very limited. Our participants explained that they have jobs, families, and lives outside of their volunteer SAR work. While missions generally take precedence, SAR teams do not have the capital to purchase costly new technologies and field equipment. The lack of consistent funding leads teams to improvise with the technologies they do have to create tools and methods that improve outcomes of SAR missions.

In the following sections, we explore how SAR team members think about the technologies they have and what their capabilities mean for the team in the face of constantly differing scenarios. We also discuss how innovation is approached within the SAR community and how efforts from technology developers and SAR organizations can lead to new possibilities for SAR teams in the field. Finally, we discuss the limitations of this work and potential future research.

Constraints and Implications for Future SAR Technologies

Our participants use ICTs in a variety of ways when conducting missions, organizing the team, sending communications to each other, and locating individuals. Participants indicated that the types of ICTs used varies between groups and individuals, with some items being commonplace as they are functionally necessary and widely available to the team. Tools such as radio communications, cell phones, and GPS and mapping equipment are ubiquitous. However, even these tools can vary based on the existing infrastructure in the region in which the SAR team is operating (e.g., radio / cell towers, quality of maps). Further, due to limitations in the field or in the equipment itself teams must often work around any issue that may arise. While common constraints on equipment, such as battery life and the need to carry battery packs or inadequate water proofing on digital devices, can impact any user, these issues are mission-critical for responders.

Responders must also overcome more complex and situated technical difficulties that can affect the success of a mission. Searching a very remote area, radio and cellular equipment often has reception problems, which force SAR responders to adapt to maintain lines of communication. A participant reported harnessing a radio repeater to the back of a drone to maintain line of sight with team members to radio reception would be maintained. Another participant talked about the use of private radio towers that are scattered around their search jurisdiction to retain quality service, the use of these towers is purchased at a low rate by the SAR team so their radios work when they need them in these areas.

It is worth noting that many non-functional / quality requirements (Preece et al. 2015; Pfleeger and Atlee 2009) of mobile equipment end up being more important than functional requirements. The value of battery life or waterproofing may handily eclipse the value of running the latest, most usable operating system. In designing for SAR contexts, the ruggedness of the equipment is a strong deciding factor in uptake.

We believe examples like these can inform future design of communications equipment. They also speak to the unique challenges that SAR teams must overcome to do their jobs effectively. The purpose of this work originally was to gain a better understanding of how to aid SAR teams with technological advances and human-centered design based on the needs of teams as they arise. While this may eventually take the shape of completely new technologies, it is clear to us, based on the reports of our participants, that what is most needed are improvements and better access to existing technologies and tools. For example, drones that may otherwise be used for searching a wider area are instead being used to keep communication lines open between team members. Teams that do not have a substantial amount of self-funding do not always have multiple drones for field use.

While not the primary focus of this work, it should be noted why SAR teams cannot take advantage of existing technologies that can already meet their needs. Participants indicated to us that a central issue that arises when working to buy new equipment or try new technologies is cost. Many of the tools that SAR teams use (e.g., drones, weatherproof clothing and bags, farther-reaching radios, premium cell phones) are expensive and typically fall outside of the budgetary capacity of volunteer SAR teams. While our participants have continued to be successful in their work despite budgetary challenges, design with SAR teams in mind would further improve their success in the field.

In some cases, it is not that SAR teams do not know about better technologies that exist, but they simply cannot afford them. Our participants acknowledged that it is difficult for volunteer based teams to provide the funding for expensive tools like advanced drone technologies or licenses for mapping software. We argue that concerted efforts to design technologies and systems for SAR teams that both meet their needs in the field and are affordable will lead to better results from these emergency response teams.

Creativity in Emergent Situations

Creative ICT use within SAR teams was not a topic initially intended for exploration in this work. However, based on reports from our participants, it is clear that they do engage in creative behaviors in the field to compensate for technological limitations. It should be noted that participants did not explicitly describe these behaviors as creative – often creativity is not immediately recognizable; instead, participants identified the means of resolving needs as they arise in the context of their work. While there is research regarding creativity in emergent situations, there appears to be limited attention to it within the SAR community (Kendra and Wachtendorf 2003).

When thinking about creativity in the context of emergent situations, it is helpful to relate its characteristics back to the Four C Model of Creativity developed by Kaufman and Beghetto (2009), which identifies types of creativity: Big-C, little-c, pro-c, and mini-c. This framing gives definition to creative technology use in the context of SAR. The creative work done by SAR teams in preparation for and during missions can be described as both "little-c" and "pro-c". Little-c is everyday creativity that involves the interaction of "aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context" (Kaufman and Beghetto 2009; Plucker et al. 2004). Pro-c describes the work done by experts or teams of experts within the context of their respective fields (Kaufman and Beghetto 2009). The work of these SAR professionals goes beyond the personal creativity described by Kaufman and Behetto's "mini-c", but does not rise to eminence of "Big-C" work (e.g., the major breakthrough creativity that is ascribed to great artists and designers).

SAR teams in the field are often required to innovate with the tools available so they can successfully complete the mission. Actions, such as using drones to position radio repeaters, help navigate other team members, or transport SD cards, uses well-understood tools and adapts them within the realm of understood possibilities to meet a need of the team. P7 informed us that a member of their team developed homebrew software for the team that would make messaging and establishing the geolocation of missing persons easier, and this development is unique to their team. In this sense, it is a novel creation for their team but similar technologies exists in other areas.

Further, these novel uses of technologies feature massive parameter spaces – another way in which they require creative thinking. Thinking to attach the repeater and working out how are the start of a solution to the issue of extending radio range. At the same time, there is a need to determine altitude and location for the drone, while accounting for battery life on various devices, transmission power of various devices (e.g., drone's controller, radio repeater, individual radios), restricted air-spaces, weather etc.; understand and communicate how this impacts the operational area; and coordinate activity around it (e.g., the drone's pilot).

It seems that with regards to emerging technologies, where there do not exist well-defined best practices, there exists space for SAR workers to engage in creative use of the technologies. This creativity is distributed across organizations, with individuals and small teams independently developing creative uses. We believe that further investigation into the creative efforts of SAR teams is necessary to better understand this phenomenon and how creative uses of emerging technologies impact team success and technology adoption. Further, there is a need to establish a means for sharing and communicating creative practices across the distributed field of SAR teams and workers.

Limitations and Future Directions

In the present research, we set out to understand and design of SAR training and practice. The study has its own limitations. Most of the participants had less experience related to emerging technologies, such as drones, and were only able to provide limited insights. The COVID-19 Pandemic limited our ability to observe and interview responders. In future work, we plan to develop further insights through first-person experience with SAR training and operation by participating in SAR training activities and missions.

We expect to put these design implications into practice. As creativity emerged as a theme throughout the course of the research, we plan to further investigate how SAR team members think about creativity in the context of their work and how they would like to see future equipment designed to support in the moment needs. We also would like to further explore drone use in SAR, more specifically understanding team make-up, how teams train in the field, and gain a better understanding of how drones influence SAR missions.

CONCLUSION

The use of information technologies within the context of emergency response teams is an ongoing challenge due to EM rigidity, volunteer team structures, lack of funding, lack of training, and deficiencies in the equipment currently in use. Our participants have illuminated many of the challenges they face with technology in the context of SAR work and how they overcome them. It is clear that our participants interact with technology in a variety of interesting and mission-critical ways. SAR teams must use complex mapping systems, drone technologies, and communication technologies to function and complete their missions as efficiently as possible.

However, our participants feel that there are severe limitations to the equipment that is currently available that needs to be addressed for these technologies to be fully integrated into SAR communities. Field equipment suffers from low battery life, lack of sufficient water proofing, and commercial technologies are not always designed with SAR teams in mind. While drone use has grown significantly in the context of SAR and has been used to great benefit, there are still design flaws that make drone use difficult for SAR teams. Given that our participants come from volunteer organizations the cost, training, and application of these technologies is put entirely on them. Volunteer teams lack funding and standardized training that makes other organizations more effective and efficient. We argue that there should be a more concentrated effort to design technologies for SAR communities that are both effective and affordable. From the perspective of our participants, systems like CalTopo that are designed with SAR as the primary use case are rare and not well known throughout these communities. Intentional design for SAR communities is something our participants believe is necessary and will benefit the success of the missions as technologies change and advance.

We also argue for a greater priority of funding towards EM in general and SAR teams in specific across the USA. While policy implications were not a focus of this work, it is clear that there are significant technological limitations within SAR work that originate from being under funded, at least within the context of the teams we investigated. While SAR teams are not needed everyday, relying on volunteers for work and funding has limits, and our participants have expressed their concerns over this issue multiple times. Well-funded and supported SAR teams would greatly benefit the communities in which they work and would lead to more successful missions, and thus saved lives. Overall it is clear that technology use in SAR will continue to grow and impact the structure, training, and practice of teams and influence the outcome of their work. Further investigation into SAR practice surrounding emerging technologies and the design implications thereof is necessary and will be the focus of future work.

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APPENDIX A: RESEARCH INSTRUMENT

The following questions were used for both the interviews and questionnaires; the questionnaire allowed free response for all questions. Following work on prototypes, we had originally included questions on wearable computing devices; as we chose not to use this data, we are excluding them from the instrument. Interviews were semi-structured, and researchers asked follow-up questions as well as more detailed questions pertaining to participants' particular expertise and experience.

General Questions

- name (confidential)
- gender
- age
- each US&R job held, rank, and time held

Supervising

- Before entering a situation, how do you plan with your team and how much time do you spend planning?
- Does the planning process involve other remote teams? If yes, who are they?
- How do you communicate?
- Do you often had more communication problem with the remote team than your team?
- How do you moderate communication with members of the team?
- What technologies are used in the field? How these technologies are helpful? How to improve?
- How do you navigate in the environment when searching for victims?
- What type of maps is used to navigate the environment?
- How do you use compass and GPS during search and rescue?

In the Field

- How do you keep track of the search plan?
- How do you maintain awareness of your location and your team member's location during search and rescue?
- How do you handle if you lose communication with the team?

Others

- Do you feel that current urban search and rescue planning methodologies are adequate and safe?
- Do you feel that modern search and rescue technologies used are sufficient and safe?
- Do you think using drone would change search and rescue? In what term? In which part of the operation you think it would fit more?
- What are the current shortcomings of search and rescue (also the planning methodologies)?
- How do you see the future of search and rescue?
- What kind of problems does the team face during training and operations? What would it be useful to have more training on (e.g., context, procedure)