Mapping Technology in Wilderness Search and Rescue

by

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List of Abbreviations

AFRCC — Air Force Rescue Coordination Center
CASP — Computer-Assisted Search Planning
COP — Common operating picture
ELT — Emergency Locator Transmitter
GIS — Geographic Information Systems
GPS — Global Positioning System
IC — Incident Commander
ICP — Incident Command Post
ICS — Incident Command System
IPP — Initial planning point
ISRID — International Search and Rescue Incident Database
LAST — Locate, Access, Stabilize, Transport
LKP — Last known point
MGRS — Military Grid Reference System
MRA — Mountain Rescue Association
NASAR — National Association for Search and Rescue
NIMS — National Incident Management System
NPS — National Park Service
NWCG — National Wildfire Coordinating Group
PLB — Personal locator beacon
PLS — Point last seen
POA — Probability of area
POD — Probability of detection
POS — Probability of success
PSAR — Preventative search and rescue
ROW — Rest of the world
SAR — Search and rescue
SAROPS — Search and Rescue Optimal Planning System
USFS — United States Forest Service
USGS — United States Geological Survey
USNG — United States National Grid
UTM — Universal Transverse Mercator
WiSAR — Wilderness or wildland search and rescue

Abstract

Wilderness or *wildland search and rescue* (WiSAR) managers and planners create and use maps to plan searches, collaborate on strategy, decide where to distribute resources, and communicate tasks to searchers in the field. Although maps and geographic information play a major role in WiSAR, current digital mapping technology has not been widely adopted to support WiSAR efforts.

The ultimate objectives of this research are to inform the development of useful mapping solutions to support WiSAR and to facilitate their adoption by the WiSAR community. To this end, I address the following three research questions: (1) How is mapping technology currently used to facilitate WiSAR operations, including geocollaborative situations? (2) Are there any key gaps or unmet user needs in existing mapping functionality for WiSAR? (3) What are the key challenges to the adoption and use of new mapping technology within WiSAR teams?

To answer these questions, I conducted an interview study with map users working or volunteering in WiSAR. The results enumerate participants' observations about different forms of mapping technology and their current uses, limitations, advantages, and potential directions for improvement. This study captures a snapshot of mapping technology for WiSAR in 2014. Findings indicate that non-functional considerations—or factors beyond the mapping functionality such as human resources, cost, usability, interoperability, and efficiency—are crucial factors in the usefulness and adoption of mapping technology for WiSAR. Different use contexts and tasks within the mission of a search are better served by particular forms of mapping technology. This study enumerates several opportunities to improve mapping technology for WiSAR.

Chapter 1: Introduction

1.1 Context: Wilderness Search and Rescue

In this study, I address the use of mapping technology to support Wilderness Search and Rescue, including the unique demands of the Search and Rescue map-use context, the potential contribution that mapping technology can offer for Search and Rescue, and the many challenges to map design and implementation in Search and Rescue. ***Search and Rescue (SAR)*** is an emergency situation in which trained professionals are called upon to locate a missing person(s) and assist them to safety (National Association for Search and Rescue 2005). ***Wilderness*** or ***Wildland SAR (WiSAR)*** occurs in largely uninhabited land regions lacking access to manmade amenities, such as shelter and medical facilities. Wildland settings include rural areas, large public spaces such as National Parks, wilderness areas, and mountainous terrain, but also may include urban environments in the wake of a large-scale natural disaster, such as an earthquake or hurricane (Durkee and Glynn-Linaris 2012, NASAR 2005).

Most WiSAR personnel are volunteers with training or professional certification in search, specialized rescue techniques, and/or first aid (NASAR 2005). In the United States and Canada, these volunteers are usually members of WiSAR teams associated with a local political unit such as a county. Other SAR personnel may be employed by a unit of an agency such as the National Park Service (NPS) or the US Forest Service (USFS). Volunteer teams and agency units offer the necessary training and certifications for members, and are called upon by local emergency services to respond to a search or rescue incident. These teams may join associations of SAR teams, such as the Mountain

Rescue Association (MRA) or the National Association for Search and Rescue (NASAR), to share resources for training, recruiting, and advocacy (NASAR 2005). At the federal level, land-based SAR is overseen by the Air Force Rescue Coordination Center (AFRCC), which may provide additional federal support when needed (AFRCC 2014). Heggie and Amundsen (2009) report that an average of 4,090 SAR incidents occurred per year from 1992 to 2007 within National Parks alone, costing the NPS an average of $3.7 million annually. The annual number of searches in the United States is not tracked, but has been estimated to be above 100,000 (Adams et al. 2007).

Search and Rescue is a special case within the broader field of ***emergency response*** (or some combination of the closely-related and oft-interchanged terms emergency/disaster with response/management), or the study and practice of the actions taken following an event to relieve suffering and aid recovery. The mission of SAR often is described by the acronym ***LAST***, standing for ***L***ocate the missing subject of the search, ***A***ccess their location, ***S***tabilize the subject medically so they can be moved, and ***T***ransport the subject to safety (Doherty et al. 2014). SAR teams also participate in other parts of the emergency response cycle (see Figure 1), defined by Cutter (2003) as EVENT → RESPONSE (rescue → relief → recovery) → MITIGATION (reconstruction → preparedness). While 'locate', 'access', 'stabilize', and 'transport' components of LAST are primarily part of Cutter's 'rescue' and 'relief' stages, SAR teams also put great emphasis on 'preparedness', and also may take other actions towards mitigation, including Preventative Search and Rescue (PSAR) measures such as improving signage and public sources of information or re-routing trails in problem areas (Koester 2008).

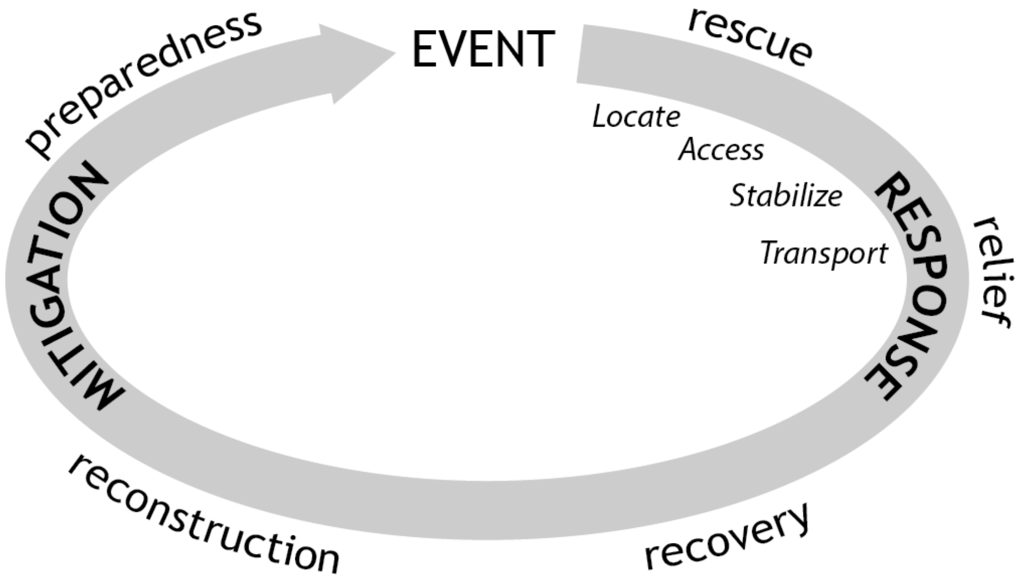


Figure 1: *Cutter's Emergency Response Cycle, with my addition of the SAR mission: Locate, Access, Stabilize and Transport (2003, 440).*

1.2 The Problem: Mapping Technology for Wilderness Search and Rescue

Digital mapping technology has been used in support of SAR for decades; however, the use of such tools by current WiSAR teams presents specific challenges. Computer support for Search and Rescue was adopted by the United States Coast Guard as early as 1974 (Kratzke, Stone, and Frost 2010). Computer-Assisted Search and Rescue Planning (CASP) provided probability maps to help locate objects at sea, such as a vessel in distress (Daniel H. Wagner Associates, Inc. 2005). CASP was succeeded in 2007 by the Coast Guard's Search and Rescue Optimal Planning System (SAROPS), which continues to be used today (Kratzke, Stone, and Frost 2010, 1). SAROPS takes into account environmental data or estimates, including currents and winds; information about the missing object, including last known position, time missing, and intended route; and unsuccessful searches, or areas of verified absence, as a search progresses. The system produces a probability distribution for an object's location correlated to time and suggests "operationally feasible search plans that maximize the increase in probability of detecting the object" (Kratzke, Stone and Frost 2010, 1). Modern Geographic Information Systems (GIS) software can offer forms of spatial modeling similar to CASP and SAROPS. However, probability models are not the only way in which computer-based mapping technology can support search and rescue today. Tomaszewski (2015) states that GIS software is an information management tool in emergency response, serving to collect and disseminate information. SAR-specific GIS toolsets for civilian, land-based SAR first emerged in 2006 (Doke 2012). Current SAR-specific GIS tools include extensions to Esri's ArcMap program: MapSAR and Integrated Geospatial Tools for SAR (IGT4SAR); SARX, a custom toolset for Esri's ArcGIS Explorer; the website SARTopo.com and its offline version SARsoft, and other commercial and non-commercial products. GIS software currently is used to varying degrees by WiSAR teams across North America (Pfau 2013). Some WiSAR teams have put GIS to extensive use and integrate it with other mapping technology as a routine part of their incident management (Pedder 2012). However, many other WiSAR teams lack domain knowledge about the geographic information properties, sources, formats, applications, and programs needed to make the most effective use of a full GIS software package possible. Teams also encounter other barriers to adopting new mapping technology, including time and money constraints, lack of adequate training, and technological incompatibility, all of which result in path dependence on familiar systems (Pfau 2013).

Further, the time elapsed during a search is a critical factor in subject survival (Adams et al. 2007). Research on emergency response and map symbol standards suggests that such a time-sensitive mission may demand having a familiar and reliable system in place at all times, limiting the capacity for flexible experimentation with new technology (Robinson, Roth, and MacEachren 2011).

Doherty (2014, para. 3) notes that "GIS is still not widely used in missing person search operations and other SAR functions," and proposes a vision to establish GIS as part of the "standard of care" in WiSAR incident management. Existing policy in wildland fire management is one potential model of established industry-wide guidelines for GIS technology. The National Wildfire Coordinating Group (NWCG)—consisting of the National Park Service, US Forest Service, and other federal and state agencies—mandates GIS-based methods of data management as part of its Standard Operating Procedures (NWCG 2014) for wildland fire incidents. Though such standards may offer lessons about GIS for incident management in a wildland context, the unique challenges of WiSAR demand unique mapping solutions.

Considering such challenges to adoption, Pfau (2013, 11) suggests that "the functionality common in many full GIS packages is not a necessity for all search and rescue missions" emphasizing that different forms of technology should "coexist and complement one another" (14). GIS is not a replacement for existing tools; *The Fundamentals of Search and Rescue* textbook (NASAR 2005) maintains that paper maps are indispensable for WiSAR teams in the field, citing concerns with the reliability of electronic devices. It is clear that a comprehensive examination of mapping technology for WiSAR must address many forms of mapping technology, from paper maps to analytically-capable GIS software, and that mapping solutions for WiSAR must integrate various forms into a system, drawing on the advantages of each to support WiSAR efforts. Case studies demonstrate that GIS can play a critical role in certain difficult WiSAR situations (Ferguson 2008; Cleland and Johnson 2014). Thus, proponents of GIS use in WiSAR argue that teams would benefit from an awareness of GIS capabilities and the ability to use GIS in combination with other forms of mapping technology in such situations.

1.3 Purpose and Scope

In order to offer useful mapping solutions and to facilitate their adoption by WiSAR teams, we must identify the ways in which mapping tools contribute or could contribute to WiSAR mission goals as well as the barriers impeding the adoption and use of mapping technology by WiSAR teams. To this end, I contribute a sketch of mapping technology use in WiSAR today, as described through interviews with WiSAR specialists, defined as individuals with training or professional certification in WiSAR. These interviews allowed me to capture the wide variety of ways that mapping tools can be used to support WiSAR, to characterize the diversity of opinion among WiSAR specialists, and to discuss the problems, limitations, and barriers to use that WiSAR specialists encounter when using or considering these tools. Specifically, I address the following three research questions:

1) How is mapping technology currently used to facilitate WiSAR operations, including geocollaborative situations?
2) Are there any key gaps or unmet user needs in existing mapping functionality for WiSAR?
3) What are the key challenges to the adoption and use of new mapping technology within WiSAR teams?

I interviewed twenty-four (n=24) WiSAR specialists about their experience and opinions regarding the design and use of mapping technology in support of WiSAR. I focused on technology that supports the searchers in their tasks, choosing not to discuss at length any geo-enabled devices that a subject might carry with them (e.g., Personal Locator Beacons, e911). This study was limited to a discussion of WiSAR in the United States and Canada and did not address other branches of Search and Rescue, such as urban and maritime situations.

I describe the details of this study in the following chapters. Chapter 2 reviews the relevant background literature, introducing frameworks from WiSAR, distributed cognition and geocollaboration, cartographic interaction and GIS functions, software engineering, and emergency response. I draw on this existing literature to create a coding scheme used to analyze the interviews. I discuss the participants, the interview method, and qualitative data analysis in Chapter 3. I present the results of the analysis and subsequent conclusions in Chapter 4. Finally, I provide a summary of results and related discussion in Chapter 5, suggesting directions for further research.

Chapter 2: Background

This chapter is organized into three sections, providing background for each of the three research questions listed in Section 1.3, respectively. First, I introduce the use case of WiSAR, including the standards for initiating a search, decision-making tools for search management, and the related concepts of distributed cognition and geocollaboration. In the second section, I define functional requirements of mapping technology, summarizing considerations for geographic information, visual representation, cartographic interaction, and GIS functions. Finally, in the third section, I introduce non-functional requirements and related challenges encountered in the use of mapping technology for emergency response and Wildland Search and Rescue.

2.1 Search Use Case/Context

Although WiSAR teams frequently conduct rescue missions in which the subject's location is known, this study focuses on the 'search' component of WiSAR.[1] A search begins with a report of a missing person, which activates a WiSAR response team. Typically, a WiSAR team then will conduct the following ***initial actions*** (Phillips et al. 2014), also known as ***reflex tasking*** (Koester 2008):

- <u>Investigation</u>: A WiSAR team member collects information about the missing person, or the ***subject,*** and the ***reporting party,*** or the person who reported them as missing, as well as the specifics of the event, including the subject's plan or intentions, the ***Point Last Seen (PLS)*** verified by an eyewitness, or the

[1] Rescue can also be a geographic problem; see Doherty, Guo, and Alvarez's (2013) suitability analysis of helicopter landing zones.

Last Known Point (LKP), suggested by an indication of the subject's presence, such as their car at a trailhead parking lot, or their signature in a summit ledger.

- Defining the search area: An ***Initial Planning Point (IPP)*** is designated, which may be the PLS or the LKP. Based on the IPP, the time the subject has been missing, the subject's mobility, and other factors, a theoretical ***search area*** is designated, although there is always consideration that the subject may be somewhere in the ***rest of the world*** (***ROW***), or anywhere outside of the search area.
- Establishing the Incident Command System (ICS): As specified in the National Incident Management System (NIMS), trained search personnel assume roles within the ***Incident Command System (ICS)***, which structures the responsibilities of each individual. An ***Incident Commander (IC)*** takes responsibility for all response activities. For each of the standard management functions—Planning, Operations, Logistics, and Administration/Finance—a ***section chief*** may be designated as needed. The ICS expands with the scope of operations (Federal Emergency Management Agency 2013). An ***Incident Command Post (ICP)*** is designated to serve as the location from which operations and resources are coordinated. At the beginning of a search, actions are considered to be in the first ***operational period*** of time during the incident; operational periods are used to structure actions taken through time and usually last 12 or 24 hours (FEMA 2013).
- Containment: Measures known as ***containment*** are taken to prevent the subject from leaving the search area, including placing WiSAR team members at locations such as trailheads and roads.
- Hasty Search: To conduct a ***hasty search***, groups of searchers, or ***field teams***, are deployed to look for the subject in the ***field,*** or in the physical space of the search area, as soon as is reasonable. Phillips et al. (2014, 169) note that "the term [hasty] refers to deployment of resources and not to the tactic of actual searching." These groups may traverse the area on foot or may use another form of transportation such as horseback, all-terrain vehicle (ATV), snowmobile, or helicopter.

These initial actions often are all that is needed to resolve the situation. Phillips et al. (2014, 167) state that "A 10-year review of US National Park Service search incidents (2003–2012) found that 96% of all search incidents were resolved in less than 1 day through initial actions." Koester reports that 93% of 12,900 searches that reported search time were resolved within the first 24 hours (2008, 47). Although infrequent, searches that do extend beyond the first operational period can become very data-intensive (Durkee and Glynn-Linaris 2012) and increase in urgency as the subject's chance of survival decreases over time (Adams et al. 2007). Additional resources and personnel may be called upon, including more field teams, search dogs and their handlers, helicopters, and airplanes. Throughout, WiSAR mission goals are to locate and help the missing person and to keep search personnel safe while doing so. A search ends in discovery of the subject at the ***found location*****—**whether uninjured/not-ill, injured/ill, or dead—and may require subsequent rescue; however, if the subject is not found after a suitable period, search activities may be suspended or reduced due to risk to the searchers or exhaustion of search resources.

Mapping technology plays an important role in accomplishing the mission goals of a search. Tomaszewski (2015) describes a framework for the tasks that mapping technology supports in emergency response generally, as shown in Figure 2. First, mapping technology fills a ***reference use*** role to provide geographic context. Second, mapping technology is used to ***gather situation inputs,*** or incident-specific information from various sources. Mapping technology allows responders to perform ***data analytics***, including filtering, querying and modeling, and is also employed to

produce new map products, such as printed maps or new digital data layers. Finally, ***map product use*** supports cognition, planning, decisions, actions, and communication. The process is recursive, as decisions and actions generate new situation inputs.

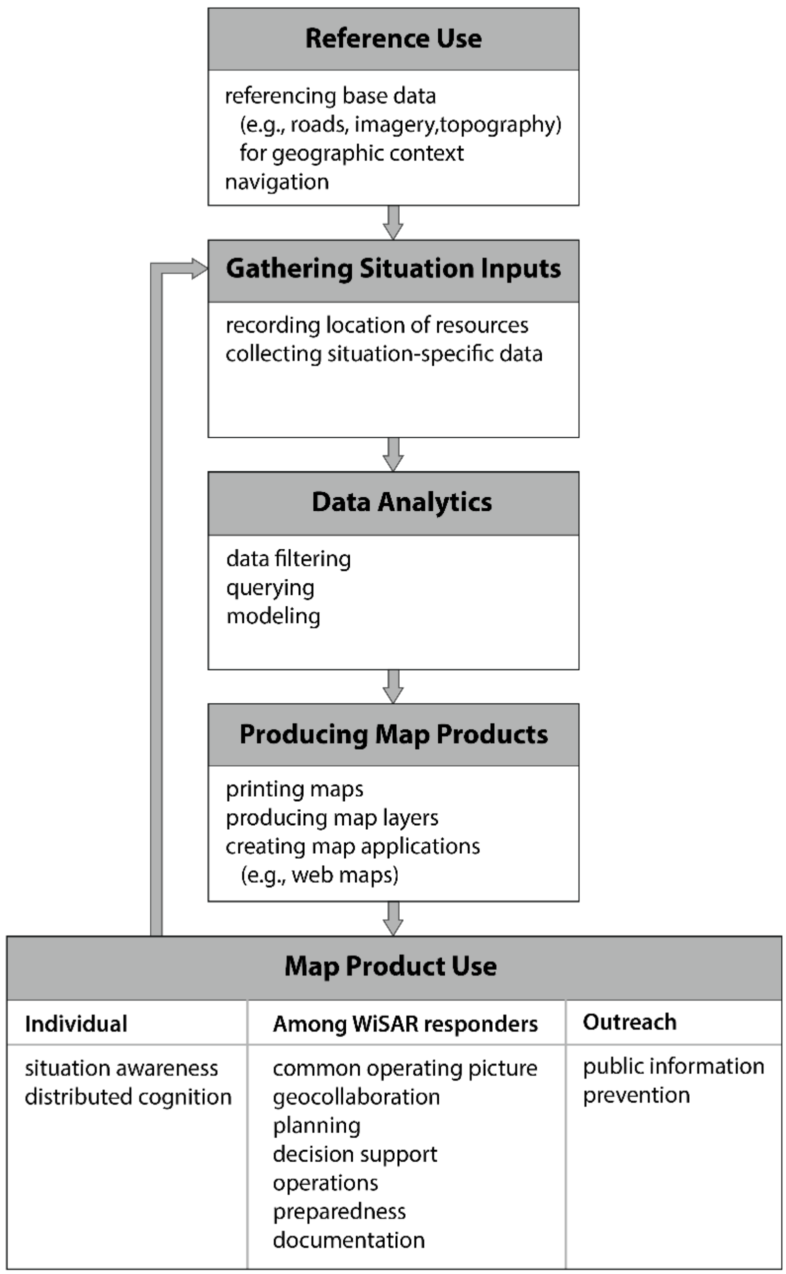


Figure 2: *Use contexts for mapping software in emergency response. Adapted from Tomaszewski (2015, 202)*

Mapping technology may be referenced for context throughout a wildland search, including by personnel in the field for navigation. Field teams commonly carry both paper maps and handheld ***Global Positioning System (GPS) devices***, which connect to satellite systems to sense the user's geographic location. WiSAR training manuals emphasize the limitations of GPS devices that make them potentially unreliable, such as signal reception, susceptibility to heat, cold, or water damage, and battery life. Therefore, standard training for field team personnel includes land navigation with a paper map and a compass; United States Geological Survey (USGS) topographic quadrangles at a scale of 1:24,000 are frequently used by WiSAR field teams (NASAR 2005).

The integrated use of paper maps and GPS devices requires consistent use of a ***geodetic datum***, which describes a reference shape, often a spheroid, used to represent the Earth's surface (NASAR 2005). WiSAR teams in the United States commonly use the North American Datum of 1927 (NAD27), the World Geodetic System 1984 (WGS84), or the North American Datum of 1983 (NAD83) (Pfau 2013). Determining geographic location also requires a coordinate system to describe any specific position on the datum. Common coordinate systems used in SAR include ***geographic coordinates*** (latitude/longitude or lat/lon), ***Universal Transverse Mercator*** (***UTM***), and UTM derivatives, specifically the ***Military Grid Reference System*** (***MGRS***) and the ***United States National Grid*** (***USNG***). While geographic coordinates are conventionally used to communicate with aviation resources, UTM and its derivative systems are better suited for field teams because UTM coordinates use meters to specify locations, a more tangible and consistent unit of measures when navigating in the field. The MGRS and USNG reference the UTM grid, but specify different alphanumeric codes to describe location (Studt and Scott 2012). The US National Grid was designated as the US federal standard for civilian land SAR in 2011; however, it has not been widely implemented (Studt and Scott 2012). In a survey of 74 SAR teams, including 91.8% teams based in the United States, Pfau (2013) found that the most commonly used coordinate system is UTM, used by 72% of teams; 26% of teams used geographic coordinates, and only 1% of teams used the MGRS or USNG.

Mapping technology also plays an important role in the command post; while directing a search, the incident commander and section chiefs add situation-specific information to the reference data and use newly assembled map products to decide how and where to allocate resources. To differentiate geographic space, the search area is divided into ***search segments***, or areas that are designed to be searched by a single field team during one operational period. During each operational period, each field team receives an ***assignment***, or designated task, consisting of a segment to be searched and instructions such as a target POD for the degree of thoroughness. WiSAR search segments often are irregularly shaped[2] (see Figure 3) due to a preference for segment boundaries to be visibly identifiable in the field and the ability of a field team to traverse the assigned area (e.g., a search segment should not be split by a sizeable cliff unless the team is trained and equipped for technical climbing).

[2] As opposed to rectilinear grid cells

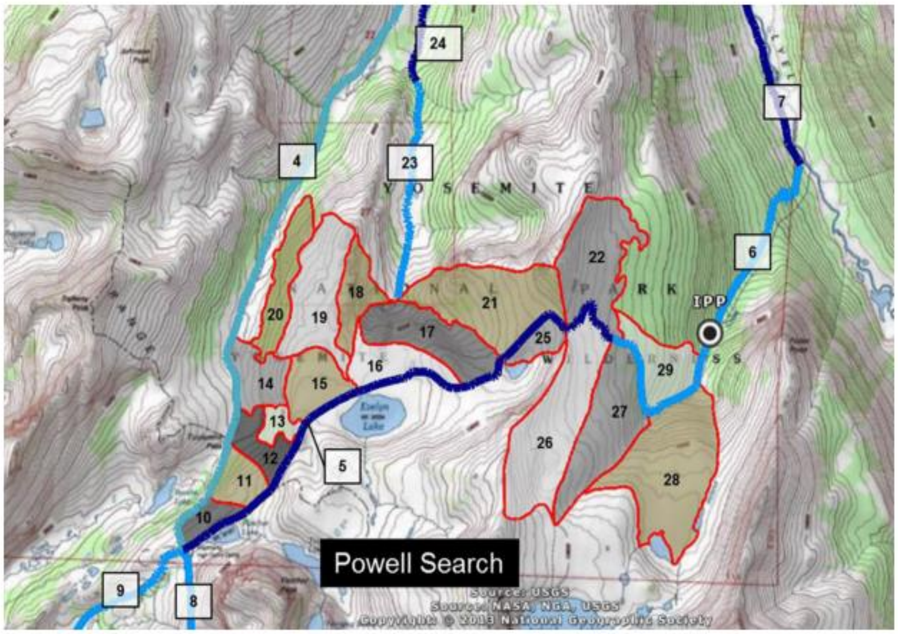


Figure 3: *WiSAR search segments in a hypothetical search (Phillips et al. 2014). Some segments are long, narrow areas which follow linear features such as paths or drainages.*

As a search continues beyond the first operational period, search theory offers WiSAR search planners a basis for allocating resources after initial actions (Koester 2008). The principles of ***search theory*** were developed in the 1940s to guide in detecting enemy submarines (Cooper, Frost, and Robe 2003). Doherty et al. (2014) summarize three components of search theory: probability of success, probability of area, and probability of detection. The ***probability of success*** (***POS***, or of detecting the subject) is the product of the ***probability of area*** (***POA***, or of the subject being present in an area) and the ***probability of detection*** (***POD***, or of the subject being found had they been present in that area):

$$\text{POS} = \text{POA} \times \text{POD}$$

In search planning, probability of area values may be subjectively assigned to partitions of the search area (which may be search segments or larger planning regions) in a collaborative exercise called a ***Mattson consensus*** (Phillips 2014; Koester

2008). In this "mathematical approach to aggregating opinions," (Koester 2008, 312) several WiSAR specialists—each holding requisite search experience and an understanding of the current search circumstances—independently assign a POA value to each partition. A value is also assigned to ROW (rest of the world)—i.e., the possibility that the subject is not within the search area. All submitted POA values are averaged for each partition, and those with the greatest average POA are prioritized when allocating search resources. While paper maps may be leveraged in such an exercise, mapping software is not commonly employed for search theory. Electronic mapping tools can help in search management after initial actions by increasing POD (i.e., increasing the likelihood that the subject will be found) through interventions such as identifying potential hazards that may have given the subject trouble or by improving the accuracy of POA or POD estimates. For instance, Ferguson (2008) suggests that GPS can offer the most reliable documentation of the ground actually covered by a field team, improving estimates of POD (Doherty et al. 2014; Cooper, Frost, and Robe 2003).

The incident commander also may draw on analysis to produce new information and inform decisions. Another aid for search resource allocation is emerging research on ***lost person behavior***, which examines the actions taken by the subject(s) of a search. Statistical analysis of incident data has been used to characterize typical behavior of missing subjects according to subject category (e.g., hiker, hunter, climber). Search predictions and decisions may be made based on the subject's category and associated statistics. Koester (2008) documents thirty-four subject categories, primarily derived from the International Search and Rescue Incident Database (***ISRID***). The ISRID is a collection of SAR incident data which included more than 50,600 incidents as of 2008 (Koester 2008). Although the ISRID is a large dataset, it is incomplete, and there is no comprehensive record of SAR incidents compiled nationally. Along with category-based behavioral trends, Koester summarizes average geographic attributes for each subject category, such as distance between the IPP and found location, elevation difference between IPP and found location, dispersion angle from the intended route, and distance from the closest linear feature, referred to as ***track offset***. These statistics can aid in search planning; however, a global dataset must be used with caution when applied to one local instance. This is emphasized by Doke's (2012) comparison of geographic statistics from the ISRID against incident data from Yosemite National Park, which reveals a significant difference in average horizontal distance between found location and IPP as well as a significant difference in average track offset. This finding highlights the importance of the unique intersection of terrain, climate, land use, and circumstances in any individual search situation. Familiarity with the local terrain, knowledge of local search incident history, and the specifics of the case at hand contribute significantly to the success of searches.

The appropriate time to call off a search without finding the subject is a controversial and context-dependent topic discussed within the SAR community. Following a study of 2,302 past searches, Adams et al. (2007) recommended a 51-hour cutoff time for searches, after which only 1% of survivors remained missing. In a *Letters to the Editor* exchange, multiple SAR experts expressed disappointment at such a definitive guideline (Fortini et al. 2008; Van Tilburg 2008). As a follow-up, Adams, Schmidt, and Newgard (2008) acknowledged:

> …the 41 real people who were still missing at the end of the 50th hour (1.2% of all missing) and their friends and families and the rescuers will not be comforted by these numbers. All that matters to them, very understandably, is the 1 person who hasn't yet been found… We acknowledge that a statistical model… cannot account for the emotional value we all place on saving a single life whenever possible. (75)

The very real consideration of a human life at stake leads to an understandable aversion to reliance on statistics and probability models in the WiSAR community. In any incident, an incident commander may be dealing with the case that defies all odds.

Mapping technology allows newly generated map products and geographic information to inform planning, decision making, and communication. Integrating information and events throughout a search incident requires a high level of contextual understanding known as situation(al) awareness. ***Situation awareness*** is described as "a state of knowledge… pertaining to the state of a dynamic environment" that is achieved through continuous assessment (Endsley 1995, 36). Though generally defined as "knowing what is going on," situation awareness is more than perception; it is a holistic comprehension of relevant information, contributing to the ability to anticipate imminent events and respond according to incident management goals (Endsley 1995, 36-37). Throughout a search incident, maps are used to collect, process, and visualize information, helping to build situation awareness. One useful approach to exploring how maps can be used as cognitive tools in search is ***distributed cognition***, a framework that considers the role of an individual's surrounding environment and objects therein, during cognition. Hollan, Hutchins, and Kirsh (2000) suggest that, through distributed cognition, the human reasoning process can be supported and extended by interaction with external artifacts, including the act of arranging objects in space as well as the creation of visuals, such as maps and other interactive visualizations. During a search incident, a member of the search team may leverage distributed cognition, externalizing his or her thinking, by sketching a map of clue locations to better understand the clue distribution and improve situation awareness.

Distributed cognition becomes collaborative when search planners share and co-develop their reasoning processes through manipulation of a common visual representation. In Cartography and Geographic Information Science, this group activity is described as ***geocollaboration***, or the process of multi-person problem solving using geographic information (MacEachren et al. 2005). In emergency response, collaboration can help build a ***common operating picture (COP)***, or consistently shared situation awareness (Tomaszewski 2015). Geocollaborative activities can be characterized by participants' distribution in space and time; participants may work at the same time or at different times, and in the same place or in different places (MacEachren et al. 2003). All four possible combinations (i.e., ***same-time/same-place***, ***different-place/same-time***, ***same-place/different-time***, and ***different-place/different-time***) may be encountered during a search incident; examples are listed in Table 1. Geocollaboration is a subset of Tomaszewski's fifth use context, *map product use*.

Table 1: *Examples of geocollaboration in four place/time scenarios*

	Same time	Different time
Same place	the IC and section chiefs meet in the command post	a search is turned over to new management
Different place	a search team in the field communicates their location to the command post	information about an ongoing search is sent to a specialist off-site, who contributes advice back to the search managers

2.2 Functional Requirements of Mapping Technology for WiSAR

Identifying gaps or unmet user needs in existing mapping functionality requires an examination of the functionality currently offered, used, and needed in the WiSAR context. Functionality is often specific to a particular form of technology. Pfau (2013) discusses six different forms of mapping technology that I will consider separately for the purpose of this study: (1) paper maps, (2) handheld GPS devices, (3) analytically-capable GIS software, (4) desktop mapping software without full GIS capabilities, (5) web maps, and (6) mobile applications. Table 2 provides examples of each of these forms of mapping technology for WiSAR. These hardware/software combinations can be compared and contrasted by their ***functional requirements,*** defined as the operations software must perform, or what the software must *do*, from any requirement of a paper map to any button provided in a map interface (Roth et al. 2015). Reviewing the functional requirements of WiSAR mapping technology is useful both for articulating conventions and existing best practices in mapping for WiSAR, as well as identifying gaps and opportunities in functionality.

Table 2*: Examples of the six forms of WiSAR mapping technology discussed by Pfau (2013) and addressed in the research reported here.*

Form of Mapping Technology	Examples
Paper maps	USGS topographic quadrangles, US Forest Service Maps
Handheld GPS devices	Garmin eTrex, Magellan eXplorist
Analytically-capable GIS software	Esri's ArcGIS (and extensions MapSAR, IGT4SAR), QGIS
Desktop mapping programs without full GIS capabilities	Terrain Navigator Pro, National Geographic TOPO!, OziExplorer, Garmin Basecamp, DNR Garmin
Web maps	Google Maps/Earth, Bing maps, ArcGIS Online, SARtopo.com
Mobile applications	SARApp, Avenza PDF maps, Gaia GPS, Backcountry Navigator Pro, Esri Collector

In the following, four levels of functional requirements are introduced: (1) geographic information, (2) visual representation, (3) cartographic interaction, and (4) GIS functions. A map is composed of underlying ***geographic information*** and a ***visual representation*** (i.e., the map). In a digital environment, map viewing software may support ***cartographic interaction,*** enabling the user to manipulate the underlying information or the representation, and this interaction can be extended to include spatial analysis through ***GIS functions***. The functional requirements of a map relate to these four domains (i.e., geographic information, visual representation, cartographic interaction, and GIS functions) where applicable to the technology, as shown in Figure 4.

According to Peuquet's (1988) Triad framework, geographic information consists of three components: ***location*** (i.e., spatial information positioning places and regions in the landscape), ***attributes*** (i.e., statistical information description qualities and conditions at locations), and ***time*** (i.e., temporal information description events, periods, and changes in time). When stored digitally, the location component is usually described by one of two dominant geographic data models: either a ***vector data model***, consisting of points, lines and polygons existing in otherwise undocumented space, or a

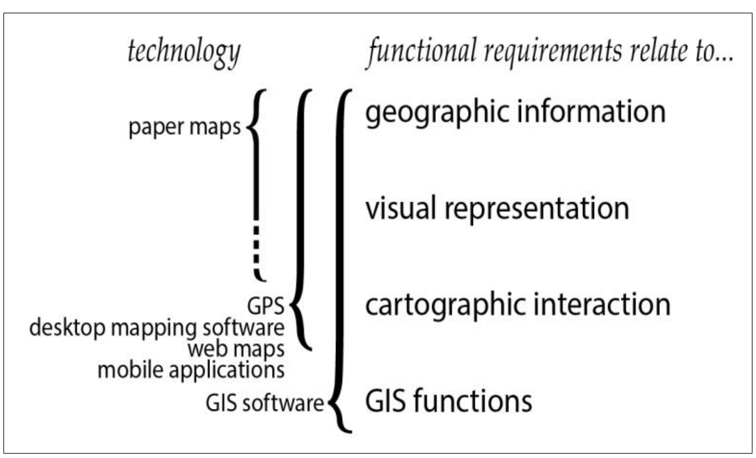


Figure 4: *The scope of functional requirements for each of the six forms of mapping technology . discussed by Pfau (2013).*

raster data model, consisting of a grid of cells comprehensively documenting space (Longley et al. 2005). In a practical application like WiSAR, functional requirements must extend beyond data models to address specific file formats. Common file formats using the vector data model include the shapefile (a combination of the .shp, .shx, and .dbf file formats) and the GPS Exchange Format (.gpx). Common file formats using the raster data model include the Tagged Image File Format (TIFF), Digital Raster Graphic (.drg), and Esri Grid. Pfau (2013) identifies both vector (e.g., field team coordinates, LKP and clues) and raster data (e.g., terrain coverage models, digital elevation models, satellite or aerial imagery) as valuable to WiSAR operations. An example of a functional requirement related to geographic information might be "parse the GPS Exchange Format (.gpx)."

The basic components of a visual representation can be described by its constituent ***visual variables***—such as size, shape, and color hue— the visual dimensions by which a graphic can be varied to encode information, geographic or otherwise (Bertin 1967|1983). Table 3 provides Roth's (forthcoming) definition of each of the common visual variables used in map design, and Figure 5 presents MacEachren et al.'s (2012, 2497) pictorial demonstration of each of these visual variables.

Table 3: *Roth's (forthcoming) definitions of Bertin and MacEachren's visual variables*

Visual Variable	Definition
location	the position of the map symbol relative to a coordinate frame
Size	the amount of space occupied by the map symbol
color hue	the dominant wavelength of the map symbol on the visible portion of the electromagnetic spectrum (e.g., blue, green, red)
color value (lightness)	the relative amount of energy emitted or reflected by the map symbol
color saturation	the spectral peakedness of the map symbol across the visible spectrum
orientation	the direction or rotation of the map symbol from 'normal'.
grain or texture	the coarseness of the fill pattern within the map symbol
arrangement	the layout of graphic marks constituting a map symbol
Shape	the external form (i.e., the outline) of the map symbol
fuzziness or crispness	the sharpness of the boundary of the map symbol
transparency	the amount of graphic blending between a map symbol and the background or underlying map symbols

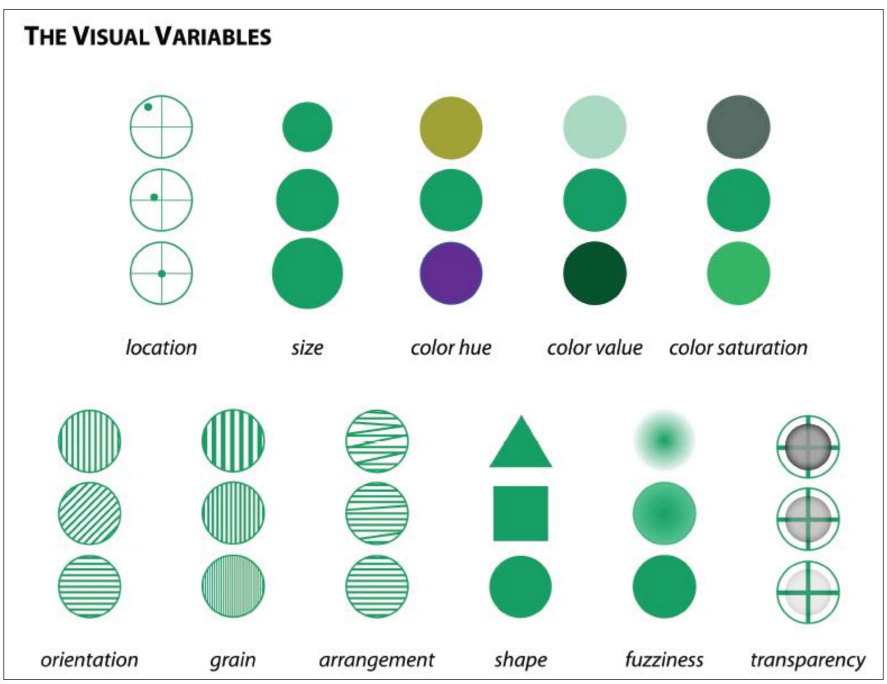


Figure 5: *Visual variables, demonstrated graphically. (MacEachren et al. 2012, 2497).*

Visual variables often are employed to encode attribute information in maps; for instance, color lightness may be used to represent the population density of counties across the country. In the WiSAR context, color-coding field teams' assignments to differentiate between types of field teams (e.g., showing air-scent canine teams' routes in blue while helicopter routes are shown in red) is an example of a functional requirement related to visual representation.

The image of the map itself is frequently accompanied by ***map elements***, or common features of maps that also constitute part of the visual representation. Slocum et al. (2009) provide a list of eight common map elements, as listed in Table 4. Reference maps carried by field teams typically include the following components at a minimum (NASAR 2005):

Map elements:
- an indication of north
- a coordinate grid
- an indication of scale —usually represented by a scale bar

Geographic information:
- measurable elevation and contour — usually represented by contour lines
- water bodies and water courses
- manmade features such as roads, trails, and buildings

Table 4: *Map elements (Slocum et al. 2009, 188)*

Map Element	Definition
Frame line and neat line	The frame line encloses all map elements; the neat line defines the extent of the mapped area
Mapped area	The region of Earth being represented
Inset	A smaller map included within the context of a larger map
Title	A statement of the map's theme
Legend	A definition of map symbols
Data source	An indication of where the map data was obtained
Scale	An indication of how much reduction has taken place
Orientation	An indication of direction, often by north arrow or graticule

If a map user is able to manipulate the visual representation, functional requirements extend to cartographic interaction. Roth (2013) describes a set of ***interaction operators***, or basic interface functions that enable map users to manipulate the visual representation according to their needs. Roth's taxonomy of interaction operators includes functions for manipulating the kind, layout, and order of presented maps (reexpress, arrange, sequence), functions for manipulating the design of a given map (resymbolize, overlay, reproject), functions for manipulating the user's viewpoint to the map (pan, zoom), functions for examining features within the map (filter, search, retrieve, calculate), and non-map functions that enable map-specific operators (import, export, save, edit, annotate). Table 5 lists and defines the interaction operators considered in this research. An example of a functional requirement concerning cartographic interaction would be "allow the user to overlay various map layers."

Paper map functionality may extend to cartographic interaction when annotation is allowed or through other manual methods of manipulating the representation. In WiSAR, a traditional way to manage the visual representation of many, often overlapping, layers of information is to use transparent sheets of plastic material.[3] These sheets are placed over paper basemaps, with the incident data manually drawn on these overlays (LaValla and Stoffel 1989). This manual method may quickly become unmanageable due to increasing data quantities; thus, streamlining the preparation, management, and interpretation of such overlays is a natural application of GIS software (Ferguson 2008).

GIS software can further extend cartographic interaction through various spatial analysis capabilities. Roth's (2013) ***calculate*** operator encapsulates the broad range of user-defined spatial analysis capabilities available when the mapping technology does have GIS support. Albrecht (1995) identifies 144 GIS functions, which allow manipulation of the representation or the underlying information. Ferguson (2008) illustrates ways in which three of these GIS functions—buffer, hillshade, and viewshed—can generate additional geographic information to help in search management. Given the IPP, a ***buffer***, or an area within a specified distance of some feature, can be used to map the distances at which certain percentiles of similar subjects have been found, according to ISRID data. A buffer also can be used to approximate the geographic area covered by a field team following a linear feature such

[3] Such sheets are sometimes referred to by the trademarked name for one such product, Mylar, or alternatively referred to as 'acetate,' referencing another clear sheet material, cellulose acetate

as a trail. Given elevation data, a ***hillshade*** can generate information about the topography of the search area to allow planners to designate search segment boundaries that are more recognizable in the field, and a ***viewshed*** analysis can be used to identify potential gaps in radio communications coverage (Ferguson 2008). The "ability to create a buffer area along a trail segment" is an example of a functional requirement for a GIS function.

Table 5: *Roth's (2013) Operator-based Interaction Primitives*

Function	Interaction Primitive	Definition
Manipulate the kind, layout, and order of maps	reexpress	interactions that change the map type
	arrange	interactions that manipulate the layout of linked components of a coordinated visualization (e.g., a map and a graph)
	sequence	interactions that generate an ordered set of related maps
Manipulate the design of the map	resymbolize	interactions that change the design parameters of a map type without changing the map type itself
	overlay	interactions that adjust the feature types included in the map
	reproject	interactions that change the map projection translating coordinates on the curved Earth to a flat plane
Manipulate the user's viewpoint to the map	pan	interactions that change the geographic center of the map and is used when a portion of the map is off screen
	zoom	interactions that change the scale and/or resolution of the map
Further examine features within the map	filter	interactions that identify map features meeting one or a set of user-defined conditions
	search	interactions that identify a particular location or map feature of interest
	retrieve	interactions that request specific details about a map feature or map features of interest
	calculate	interactions that derive new information about map features of interest
Enable other operators	import	interactions that load a dataset or previously generated map
	export	interactions that extract a generated map or the geographic information underlying the map for future use outside of the visualization
	save	interactions that store the generated map, the geographic information underlying the map, or the system status for future use within the visualization
	edit	interactions that manipulate the geographic information underlying the map, which then alters all subsequent representations of that information
	annotate	interactions that add graphic markings and textual notes to the visualization

2.3 Challenges & Non-Functional Requirements of Mapping Technology for WiSAR

Mapping experts who seek to improve the effectiveness and aid the adoption of mapping technology for WiSAR also must understand the challenges beyond functional requirements that make adoption and effectiveness difficult in the WiSAR context. ***Non-functional requirements***, or conditions and constraints of software beyond its functionality that impact its viability and adoption, may be named as solutions to these challenges (Sidlar and Rinner 2009). Examples of non-functional requirements include usability, flexibility, interoperability, security, cost, coherence, and reliability (Chung and do Prado Leite 2009). I extend the concept of non-functional requirements past its original software-based definition to include any design considerations for mapping technology that are distinct from the basic mapping functionality supporting representation and interaction described in Section 2.2. An example of a non-functional requirement might be a need for a paper map to be water resistant for use by a field team. This non-functional requirement is necessitated by a context-specific challenge that WiSAR field teams face: that of exposure to weather conditions.

Multiple scholars have enumerated specific non-functional challenges for emergency response GIS (Cutter 2003, Zerger and Smith 2003, Tomaszewski 2015), with some specifically addressing WiSAR (Ferguson 2008, Pfau 2013). These challenges encompass what Cutter (439) calls “constraints on the utilization of GI Science,” what Pfau (1) calls “barriers to teams adopting full GIS,” and what Zerger and Smith (123) call “limitations of GIS” and “non-technical GIS impediments.” Figure 6 provides a summary of five contributions (Cutter, Zerger and Smith, Tomaszewski, Ferguson and

Pfau), depicting groupings of challenges faced in using GIS for emergency response and WiSAR. For this research, clusters of related challenges are identified as categories of non-functional considerations. Some challenges relate to more than one category; for instance, the challenge of 'cost of training' identified by Pfau is situated between 'human resources' and 'cost;' these challenges were placed in the most relevant category.

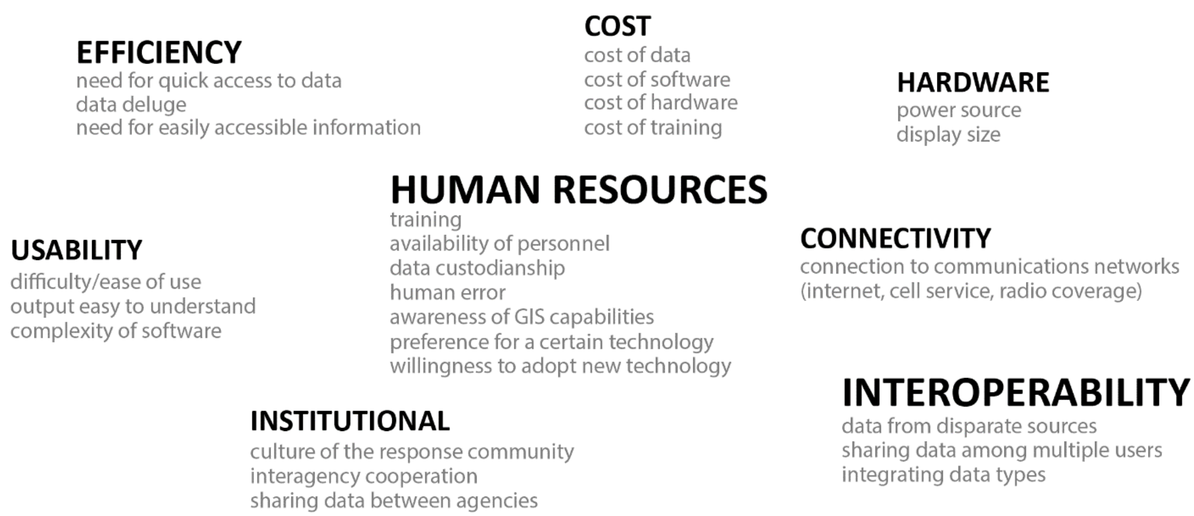


Figure 6: *Non-functional challenges mentioned in five sources. Categorical clusters are identified in all capital letters. Categorical cluster titles are scaled according to the frequency with which corresponding challenges are mentioned in the five sources. The categories 'Human resources' and 'Interoperability' are mentioned by all five authors.*

Tomaszewski (2015, 105) names ***cost,*** or financial expense, as the "first and foremost" consideration in choosing a GIS for emergency response. The challenge of limited financial resources features prominently in Pfau's (2013) work, which focuses on volunteer WiSAR teams. Pfau enumerates several separate costs associated with mapping technology:

> …many search and rescue organizations are volunteer groups that are self-funded (i.e. through donations, fundraising and memberships) and may not have sufficient funds to purchase software, hardware, data and training therefore resulting in lack of expertise in operating GIS. (5)

As a consequence of cost, Pfau notes a resultant problem: a lack of expertise. I grouped challenges relating to personnel, such as expertise, training, and availability, into a category labeled ***human resources***. Human resources challenges appear in all five of the publications listed above. The category also encompasses the issue of awareness (or lack thereof) of the capabilities of GIS among emergency responders, a factor emphasized by Cutter, Zerger and Smith, and Tomaszewski. Tomaszewski names awareness of GIS as one of two primary areas for improvement in emergency response, describing the other as the need for "coordination, sharing, and interoperability of GIS resources" (9). Inter-agency cooperation and related ***institutional*** challenges are most strongly emphasized by Cutter and include rules and regulations, willingness of agencies to cooperate, and other issues that arise from the culture of the response community.

Interoperability challenges, defined here as pertaining to the ability of different technologies to exchange information (not in the interagency cooperation sense that Tomaszewski uses), are mentioned in all five sources. Interoperability challenges include the transfer of data to other programs and the ability of a technology to allow sharing of data with other users (i.e., the concept of geocollaboration introduced in Section 2.1).

Challenges of ***connectivity*** to communication networks, including local servers, cell phone networks, and the internet, relate to both a device's ability to connect and the wilderness setting of WiSAR operations. As Ferguson (2008) points out, such networks often are unavailable in the WiSAR context. The environment in which searchers work, particularly for outdoor teams in the field, calls attention to the properties of a technology as a material object. ***Hardware*** traits, or physical properties of a device including display size and power sources, are identified by Zerger and Smith (2003), Cutter (2003), and Ferguson.

Due to the context of an emergent situation, ***efficiency*** concerns are of particular importance. The ability to access data quickly, was identified by Cutter, Pfau, and Zerger and Smith (2003) as an important factor in the effectiveness of GIS for emergency response. Efficiency of tasks may be facilitated by the design of a technology's user interface. Ease of use, or ***usability***, is discussed by Cutter (2003) and Pfau (2013), both pointing out the importance of an understandable user interface given the complexity of GIS software.

The interviews conducted in this study discuss many problems, advantages, and solutions that pertain to the categories described above. A problem in a particular category does not necessarily demand a solution specific to that category; deficiency in one category may be resolved by improvement in another. For instance, problems with ease of use or software complexity may be addressed through training solutions. Additionally, a non-functional consideration may be addressed by a functional solution. Identifying problems in these areas as well as suggested solutions (which may pertain to a separate category) in a WiSAR context will help direct efforts in technology design, in education, and in other measures to improve mapping technology for WiSAR.

Chapter 3: Methods

In this study, I used the qualitative interview method to elicit expert experiences and opinions about the role of mapping technology for WiSAR. Suchan and Brewer (2000) assert that qualitative methods are well suited to cartographic researchers studying map design and use in real-world contexts, as broad questions asked of a small set of expert participants offer great insight. Further, as Cutter observes "[in emergency response] there is a large disconnect between the language used and needs of the research and the applications communities" (2003, 442). Thus, a qualitative study capturing the needs of the WiSAR community in the words of practicing WiSAR specialists is both timely and important.

3.1 Participants

Twenty-four (n=24) WiSAR specialists participated in the interview study, discussing their experience using mapping technology for WiSAR and their opinions on how mapping technology could be improved to better support WiSAR. An individual was eligible for participation if he/she had training or professional certification in Wilderness Search and Rescue (i.e., could be considered a WiSAR specialist) and had observed the use of mapping technology to support real WiSAR missions (i.e., not just training exercises, but situations in which a subject genuinely was believed to be missing or in distress). Two additional interviews were recorded, but were not included in the analysis due to eligibility. Participants discussed their experience with WiSAR in seven US states and two Canadian provinces: nine in California, six in Colorado, two in Virginia, two in Minnesota, and one participant each in Arizona, Oregon, Utah, British

Columbia and New Brunswick. Participants represented at least 17 separate WiSAR team affiliations, including four National Parks.

One participant did not report background information. Of the rest, most participants (22/23) currently were active with a WiSAR team, and many (15/23) had filled the position of search manager or incident commander. Participants had a cumulative total of 422 years of SAR experience, individually ranging from 3 to 44 years, with an average of approximately 18 years of SAR experience. Table 6 summarizes participants' self-described level of familiarity (from one to five, or 'inexperienced' to 'expert') with six types of mapping technology.

Table 6: *Participants' self-described level of familiarity with six types of mapping technology*

	Number of participants at each level of familiarity: 'Inexperienced' 1	2	3	4	'Expert' 5	Mean level of familiarity
Paper maps	-	-	1	3	19	4.78
GPS devices	-	-	3	9	11	4.35
GIS software	4	4	4	4	7	3.26
Desktop mapping	-	2	8	10	3	3.61
Web maps	-	5	10	4	4	3.30
Mobile maps	5	9	3	6	-	2.43

Eight (8/23) participants had classroom training with GIS software, and five (5/23) had a degree in Geography, GIScience, or a related discipline. Twenty-two participants held a post-secondary degree; of those, thirteen held a master's degree and one held a doctoral degree.

3.2 Materials and Procedure

Interviews followed a ***semi-structured*** protocol in which a similar set of key questions is presented to each participant, while allowing opportunity for follow-up probe questions throughout the interview (Suchan and Brewer 2000; Rubin and Rubin 1995). Table 7 details key and probe questions included in the interview protocol.

Interview questions were organized into five sections. Following an initial background section, participants were asked to discuss the six forms of mapping technology as identified in Pfau (2013). Questions in this second section asked participants to describe the current use of these mapping technologies in WiSAR (Research Question #1). Participants then were asked to discuss problems and limitations encountered in the SAR context, which served to identify unmet needs in mapping functionality (Research Question #2) as well as non-functional considerations (Research Question #3) specific to each form of technology. The second section of questions also sought opinions on how each technology could be designed to better support search, driving the discussion toward approaches for overcoming the difficulties in using mapping technology for WiSAR. The third interview section then enriched this discussion by eliciting stories from experience using mapping technology for WiSAR, including inquiry about specific challenges related to functional and non-functional requirements. The fourth section of questions circled back to the current state of practice using mapping technology for WiSAR (Research Question #1), focusing the discussion on multi-user geocollaborative use contexts. Each interview finished with a short debriefing section to collect final thoughts.

Twelve interviews (12/24) were conducted in person and twelve (12/24) interviews were conducted by phone. I received permission to audio record twenty-three (23/24) interviews, with one captured by handwritten notes only. The interview protocol was designed to last approximately 60 to 90 minutes; recorded interviews lasted between 55 and 140 minutes with an average of approximately 81 minutes. Audio recordings were transcribed, either through a transcription service or by members of the study team. The cumulative length of the transcripts and notes was approximately 204,266 words. Qualitative analysis (see Section 3.3) was applied to both the transcripts and the handwritten notes.

Table 7: *Interview Protocol*

Background
In a SAR context, tell me about the agency or organization you work with and your current job title.
What are your everyday job responsibilities in that position?
What is your educational background?
Do you have any classroom training in GIS?
How many years have you been working in SAR?
Give me an overview of your job responsibilities during a SAR incident.
Are you typically involved in the field, the command post, or both?
How many incidents does your SAR group respond to annually?
What is your level of familiarity with each of these mapping technologies (on a scale of inexperienced to expert, or 1 to 5): • Paper maps • Handheld GPS devices • GIS software • Desktop-based mapping programs (that are not a full analytical GIS) • Web-based maps • Mobile applications
Mapping Technology
Which geographic data sources or layers do you have readily available for your area?
Are there any data layers that you would like to have, or wish existed?
For each type of mapping technology, I'd like to know: • How does your SAR team currently use that type of mapping technology? • Do you encounter problems or limitations with that format of mapping technology? • Do you have ideas or opinions on how that technology could be designed to better support search? We'll address each type of mapping technology in turn: • Paper maps • Handheld GPS devices • GIS software • Desktop-based mapping programs (that are not a full analytical GIS) • Web-based maps • Mobile applications
Stories from Experience
When you look at a map of a search incident, what are you looking for? (For instance, do you try to anticipate the missing person's thought process? Do you look for locations to put radio repeaters?)
Can you tell me about an instance when mapping technology positively contributed to ending a search?
Can you tell me about any instance when you encountered these challenges: • Mapping technology or data was not trusted in a search incident • Data quality issues • Incompatibility issues with devices or file formats • Permission or authorization limiting access to geographic data Money as limiting factor in which mapping technology you use for SAR
Collaboration
What does it look like when WiSAR personnel are collaborating with a map in each of these situations: • Same-place/same-time (example: command post) • Different-place/same-time (example: communicating between command post and field) • Same-place/different-time (example: transferring the management of a search) • Different-place/different-time (example: remote support of SAR missions)
Final Thoughts
* Do you have any comments on infrared cameras? Unmanned Aerial Vehicles?
Is there anything else you thought we would talk about?
What should we be researching in the SAR industry and in the academic context?
Any final questions or comments?
* Questions marked by an asterisk were asked of later participants, after the subject had been raised in previous interviews.

3.3 Qualitative Data Analysis

I followed tenets of ***qualitative data analysis*** to organize the interview responses according to important concepts or themes related to the research questions (Miles and Huberman 1994, Rubin and Rubin 1995). The interviews first were unitized, or separated into phrases, by splitting the complete transcript into statements representing a single experience or opinion. ***Codes*** representing concepts or themes significant to the research then were applied to all statements that discussed mapping technology in terms of current uses, limitations, advantages, or suggestions for improvement. The codes used in this study are ***concept-driven*** as they are derived from the relevant literature discussed in Chapter 2 and not primarily from the transcripts themselves (Brinkman 2013).

Table 8 lists and defines the complete list of 36 codes used for qualitative data analysis in this study. This table also lists a short identifier used throughout this text to refer to each code (e.g., the identifier for the paper maps code is T1). Codes fall into four categories:

(1) ***forms of mapping technology***, based on Pfau (2013) (See Table 2);

(2) ***statement types***, or whether the statement pertained to a current use, a limitation, an advantage, or a suggestion;

(3) ***use contexts***, based on Tomaszewski (2015) (See Figure 2) and including the geocollaborative situations from MacEachren (2003) (see Table 1);

(4) ***requirements***, including both mapping functionality requirements and non-functional considerations, which are mutually exclusive. Mapping

> functionality codes are drawn from cartographic literature (see Figure 4), and non-functional considerations codes are drawn from the literature on emergency response and GIS (see Figure 6).

The first two code categories organize statements for comparison, the third relates to Research Question #1, and the final category relates to Research Questions #2 and #3.

All transcript statements received a code relating to the first category (forms of mapping technology; Category #1), enabling comparative discussion by form of mapping technology. The second category (statement types; Category #2) also facilitates comparison of statements, and dictated the application of codes in the latter categories, as shown in Figure 7. Statements describing a current use required a code in the use contexts category (Category #3) and did not receive any further codes. For example, the statement "each of the primary search teams uses a GPS so we're actually creating a [record] of where that team searched" was coded: *GPS devices* (T2), *current use* (S1), *gathering situation inputs* (U2). Statements either describing a problem or limitation or, alternatively, identifying an issue as not being a problem or actually being an advantage, could optionally have a use context code (Category #3), but needed to include a requirements code (Category #4). For example, the statement "web maps are a great tool; their only drawback is the connectivity" was coded: *web maps* (T5), *limitation* (S2), *connectivity* (NFR5), and was not specific to a particular use context. The following statement *is* specific to a particular use context: "just open Terrain Navigator and you can quickly and easily print maps right out of there," and was coded: *desktop mapping* (T4), *advantage* (S3), *producing map products* (U4), *usability* (NFR7). Finally, statements that were considered suggestions could link a technology either to a use context code (Category #3) alone, or to a requirement code (Category #4) with or without a use context code.

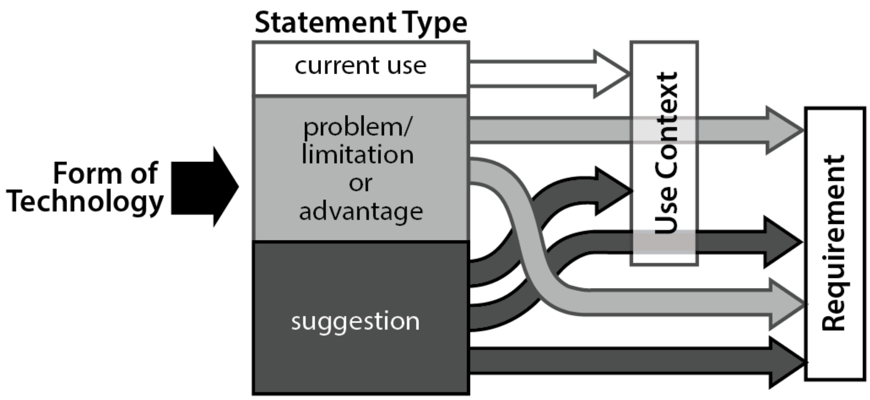


Figure 7: *Coding logic for each statement. Depending on statement type, a statement might be assigned a use context code and/or a requirement code.*

I first coded all 24 interviews, treating my notes from the single unrecorded interview session as the unitized statements for that participant. A second researcher then applied the same coding scheme to three of the transcripts (representing 9.59% of the total codes applied). Coding by the second researcher resulted in 92.37% inter-coder reliability, suggesting reliability in interpreting and applying the coding scheme. A total of 5,056 individual codes were applied across 1,552 separate coded statements, with each coded statement receiving either three or four codes. An average of 64.7 statements and a median of 62.5 statements, were coded per interview. In Chapter 4, I report the ***frequency*** (overall number of statements receiving each code) and ***extensiveness*** (overall number of participants referencing the code) of each code, and summarize participant discussion regarding each form of technology.

Table 8: *Coding Scheme*

Forms of mapping technology (required)		
T1	Paper maps	A statement about paper maps. Examples: USGS topographic quadrangles, US Forest Service maps
T2	GPS devices	A statement about handheld GPS devices. Examples: Garmin, etrex, Magellan.
T3	GIS software	A statement about analytically-capable GIS software. Examples: ArcMap, QGIS
T4	Desktop programs	A statement about desktop mapping software without full GIS capabilities. Examples: Terrain Navigator Pro, National Geographic Topo, ArcGIS Explorer, and SARX
T5	Web maps	A statement about web-based maps. Examples: Google maps, Bing maps, ArcGIS Online, SARtopo.com
T6	Mobile apps	A statement about mobile mapping applications. Examples: Backcountry Navigator Pro, Gaia GPS
T7	Other technology	A statement about another form of technology. Examples: aircraft, Unmanned Aerial Vehicles (UAVs), satellites, radio, tracking systems, cell phone pings/triangulation, ELTs, PLBs, infrared, FLIR (Forward-Looking Infrared), e911, reverse 911, radio direction finding, Garmin Rhino, GPS Speaker Microphones, signal boosters for cell phone reception, and Bluetooth, Printers, projectors, whiteboards, and online collaboration tools that aren't geographic such as email, Sharepoint, Dropbox, and Google Drive.
T8	General mapping tech.	A statement about more than one of the above technologies or mapping technology generally, including statements about data.
Statement Type (required)		
S1	Current use	A statement about what technology is currently in use for a particular use context
S2	Limitation	A statement about a problem, limitation, or drawback of a technology
S3	Advantage	A statement about something that's not a problem, is an advantage, or works well about a technology.
S4	Suggestion	A statement about what could or should be improved about a technology. Participants may give an example of something they've seen work elsewhere. "It would be nice if _______", "_____ would be helpful"
Use Context		
U1	Reference Use	A statement about the use of mapping technology to provide reference data for a geographic location, including existing roads, trails, elevation, contours, and other features, navigation Examples: driving directions, scoping out the area
U2	Gathering Situation Inputs	A statement about the use of mapping technology to capture or generate *incident-specific* information such as PLS, LKP, search area, search segments, GPS track logs, clues, etc. or to input, import, or combine geographic information. Examples: downloading or importing data, adding or plotting clues to a map
U3	Data Analytics	A statement about the use of mapping technology to analyze geographic data, including filtering, modeling, querying
U4	Producing Map Products	A statement about the production of map products, including printing maps, creating new layers
U5	Map Product Use	A statement about the use of map products for planning, decision making, situation awareness, *collaboration (see geocollab)*, operations, communicating, search management, media/publicity, public information, or documentation. ***Geocollaboration is a subset of this code. Where possible, a statement was coded according to the specific geocollaboration situation
U6	Same-place/same-time	A statement about same-place/same-time geocollaboration
U7	Different-place/same-time	A statement about different-place/same-time geocollaboration Example: real-time tracking of search teams
U8	Same-place/different-time	A statement about same-place/different-time geocollaboration
U9	Different-place/different-time	A statement about different-place/different-time geocollaboration
U10	Other use context	A statement about another specific use context

Table 8 *(continued): Coding Scheme*

Requirements: Mapping Functionality		
MF1	Geographic information	A statement about the functional capabilities of a mapping technology relating to geographic data or information, including map/data layers, geographic file formats, data resolution, spatial accuracy, and lost person behavior
MF2	Visual representation	A statement about a functional requirement relating to visual representation. Examples: colors, labels, layout, formatting, 3D representation, shaded relief/hillshade, grids such as lat/lon or UTM, map elements such as a north arrow or scale bar
MF3	Cartographic interaction	A statement about a functional requirement relating to cartographic interaction. Examples: annotation, turning on or off layers (overlay), and converting between datums (reproject)
MF4	GIS functions	A statement about a functional requirement relating to GIS functions. Examples: spatial analysis, buffering, viewshed, watershed, probability distribution, and enforcing topology
MF5	Other mapping functionality	A statement about another form of functionality related to the mapping capabilities of the technology
Requirements: Non-functional Considerations		
NFR1	Human resources	A statement about a non-functional requirement or challenge relating to human resources. Examples: availability of personnel, level of comfort with a technology, training, technical ability, knowledge, learning curves, training materials, competency, technophobia, system custodianship, keeping a system up to date, level of comfort or familiarity, personal preference for a certain technology, and awareness of the capabilities of GIS
NFR2	Cost	A statement about a non-functional requirement or challenge relating to financial cost
NFR3	Institutional	A statement about a non-functional requirement or challenge relating to an agency or organization. Examples: Includes rules and regulations, cooperation, communication/sharing with people in other organizations, permission, authorization, or access to data, licensing, copyright, team-level resistance to technology
NFR4	Interoperability	A statement about a non-functional requirement or challenge relating to the ability to exchange information with other technologies. Examples: incompatibility, compatability, devices talking to each other, 'plugging in' devices or data, 'seamless' transitions between software
NFR5	Connectivity	A statement about a non-functional requirement or challenge relating to connectivity to networks. Examples: internet, cell phone reception, radio service, wifi, satellites connection, and local servers
NFR6	Efficiency	A statement about a non-functional requirement or challenge relating to the time constraints of the situation, Examples: processing time, accomplishing something quickly, not doing things twice, overwhelming quantities of situation-specific data (data deluge)
NFR7	Usability	A statement about a non-functional requirement or challenge relating to ease of use, usability, simplicity, or user interface
NFR8	Hardware	A statement about a non-functional requirement or challenge relating to the physical object of a mapping technology. Examples: power sources, battery life, display size, display resolution, durability, size, or weight
NFR9	Other NFR	A statement about a non-functional requirement which does not clearly fit into any of the above categories. Examples**:** support from the software developer, device internal memory, ownership of the devices (personal vs. property of the team), reliability, validity of a model (e.g., behavior model)

Chapter 4: Results

Chapter 4 describes the results of the qualitative analysis applied to the interviews. The chapter is organized into eight sections. The first six sections address each of Pfau's (2013) six forms of WiSAR mapping technology, with the seventh section capturing discussion about other mapping technologies; the eighth section synthesizes participant discussion that applies across technologies. In each section, I first summarize how the given technology currently is used in support of WiSAR (Research Question #1). I then enumerate the perceived advantages and limitations of the given mapping technology (Research Questions #2 and #3), and include suggestions for improving the technology and promoting adoption.

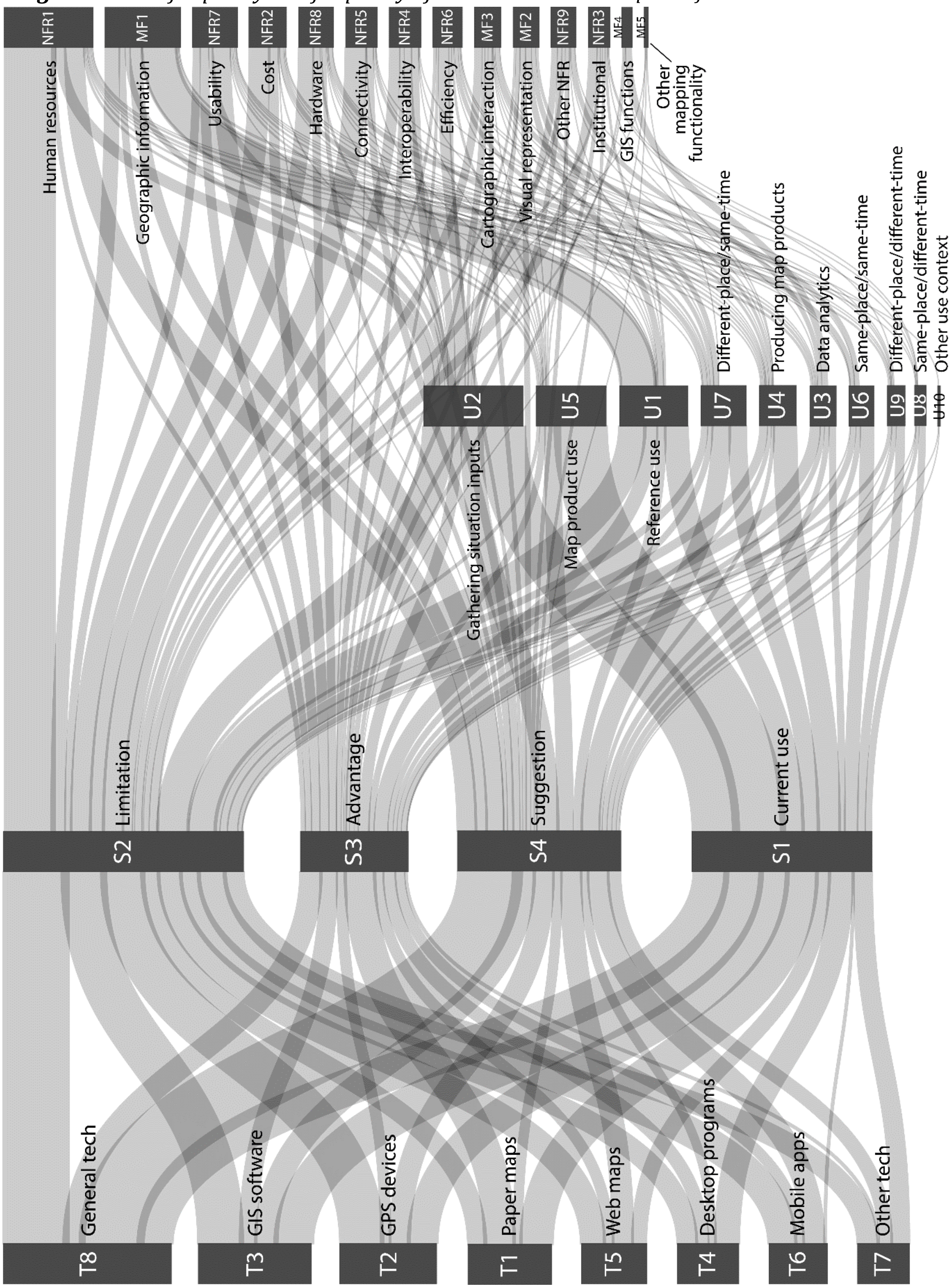
Table 9 lists the frequency, extensiveness, and percentage of all coded statements corresponding to each of the 36 key codes described in Chapter 3. Figure 8 presents a Sankey diagram of code relations across the four categories. In the diagram, dark rectangles are scaled according to each code's frequency. A technology code was applied to every coded statement. As shown in the final column of Table 9, the most commonly applied technology code was *general mapping technology* (T8), representing 24.0% of all statements. The *limitations* (S2) code stands out as the most-applied code in the statement type category. Codes in the final two categories—use context and requirements—were not required for every statement (though every statement required at least one or the other); for 42.8% of statements, use context was not specified, and for 31.4% of coded statements, a requirements code was not applicable. The most-discussed use context was *gathering situation inputs* (U2), followed by *map* *product use* (U5) and *reference use* (U1). In the requirements category, one code in each subset stood out as the most-discussed: *geographic information* (MF1) in the mapping functionality subset, and *human resources* (NFR1) in the non-functional subset.

In Figure 8, the lighter, curved lines connecting the dark rectangles illustrate the frequency of the combination of two codes that they connect. For instance, at the top of the figure, there is a strong connection between *general mapping technology* (T8) and *problems or limitations* (S2). The diagram also indicates a strong connection between *problems or limitations* (S2) and the non-functional consideration *human resources* (NFR1). This graphic does not indicate the frequency of full combinations of three or four codes, and instead only illustrates the volume of connection between particular pairs of key codes; an interactive version of the Sankey diagram enabling exploration across all four categories of codes is available at: http://cmrRose.github.io/Thesis/Sankey_allConnections.html. Codes applied to the interviews represented 494 unique combinations across the four code categories, instantiated from 3,856 possible combinations.

Table 9: *Extensiveness, frequency, and percentage of total discussion for each code. Darker shading indicates relatively higher frequency or extensiveness.*

ID	Code	Extensiveness	Frequency	% of Total Discussion
T1	Paper maps	23	188	12.1%
T2	GPS	23	213	13.7%
T3	GIS	22	251	16.2%
T4	Desktop program	21	137	8.8%
T5	Web map	23	146	9.4%
T6	Mobile app	22	130	8.4%
T7	Other technology	23	115	7.4%
T8	General tech	24	372	24.0%
				= 100%
S1	Current use	23	402	25.9%
S2	Limitation	24	537	34.6%
S3	Advantage	24	243	15.7%
S4	Suggestion	24	370	23.8%
				= 100%
U1	Reference use	22	152	9.8%
U2	Gathering situation inputs	24	223	14.4%
U3	Data analytics	15	57	3.7%
U4	Producing map products	21	81	5.2%
U5	Map product use	24	157	10.1%
U6	Same-place/same-time	20	54	3.5%
U7	Different-place/same-time	21	100	6.4%
U8	Same-place/different-time	18	23	1.5%
U9	Different-place/different-time	16	37	2.4%
U10	Other specific use case	3	3	0.2%
				= 57.2%
MF1	Geographic information	23	169	10.9%
MF2	Visual representation	20	56	3.6%
MF3	Cartographic interaction	19	58	3.7%
MF4	GIS functions	6	21	1.4%
MF5	Other mapping function	4	6	0.4%
NFR1	Human resources	23	195	12.6%
NFR2	Cost	23	81	5.2%
NFR3	Institutional	21	46	3.0%
NFR4	Interoperability	23	69	4.4%
NFR5	Connectivity	20	69	4.4%
NFR6	Efficiency	23	64	4.1%
NFR7	Usability	21	100	6.4%
NFR8	Hardware	20	77	5.0%
NFR9	Other NFR	17	54	3.5%
				= 68.6%

Figure 8: *Code frequency and frequency of connections between pairs of codes.*



4.1 Paper Maps

The *paper maps* (T1) code was assigned to the transcripts 188 times (12.1% of all coded statements). Table 10 lists the extensiveness of the *use context* codes (U1-10) for *current uses* (S1) of *paper maps* (T1). For *reference use* (U1), paper maps help WiSAR personnel orient themselves to the search area and consider the incident in its geographic context. USGS topographic quadrangles are commonly used for reference (U1), along with National Geographic maps and more locally published commercial maps (e.g., Fisher maps in northern Minnesota, Latitude 40 maps in Colorado, and Tom Harrison maps in California). While some WiSAR teams make photocopies of commercial or government paper maps, many teams print their own paper maps from digital files. Some WiSAR teams have access to large-format printers and thus the capability to produce poster-sized prints for *reference use* (U1).

Table 10*: Current uses of paper maps*

Use Context	ext.
U5 - Map product use	13
U6 - Same-place/same-time	12
U1 - Reference use	12
U7 - Different-place/same-time	10
U8 - Same-place/different-time	6
U2 - Gathering situation inputs	6
U9 - Different-place/different-time	1

Paper maps are leveraged in the *map product use* (U5) context for two primary purposes: (1) planning, including building situation awareness, and (2) communication of assignments to field teams, often with an emphasis on getting WiSAR teams into the search area as quickly as possible. Maps prepared with pre-drawn search assignments are used to improve efficiency in areas where searches occur frequently.

Paper maps are used frequently and offer unique advantages for *same-place/same-time geocollaboration* (U6). Large paper maps provide a detailed view of a large search area, enabling WiSAR teams to build a common operating picture; as one participant noted,

> it's about the only format you can really see a whole lot of the map, all at once. And you have the advantage of everybody looking at exactly the same thing, all non-verbals are picked up on, people can communicate at their best.

Participants also stated that annotation, or drawing and writing on paper maps (a form of *cartographic interaction*; MF3), is common and helpful for *same-place/same-time* (U6) geocollaboration. A second participant stated that a paper map is "incredibly useful, it gets thoughts and collaboration going, so in my opinion there's no better tool than a large format map that people can gather around and talk to each other and mark on." A third participant discussed advantages to paper maps over electronic devices for *same-place/same-time* (U6) geocollaboration, stating:

> where somebody's sitting behind the computer driving and doing all that, the people observing are kind of at the mercy of what that person is doing. The paper map [allows] you to interact with the map at your own pace and not at somebody else's pace.

Thus, the nature of the paper medium itself may make paper maps better suited than digital technology to facilitate distributed cognition.

For *different-place/same-time* (U7) geocollaboration, paper maps often are used by field teams to communicate their location to the command post verbally over radio. Location may be reported as coordinates or as a description, either with respect to geographic features on the ground (e.g., 'at the junction of trail Y and trail Z') or in reference to labels on a paper map (e.g., 'at the e in River'). In the latter scenario, it is important that spatially distributed collaborators have access to an identical *visual representation* (MF2). For *same-place/different-time* (U8) geocollaboration, paper maps were noted as part of the standard documentation for transfer of command in the Incident Command System. Paper maps are used to *gather situation inputs* (U2) when field teams annotate paper maps with clues and other significant landmarks.

Several advantages of paper maps make them a continuing staple of WiSAR teams. Reliability (NFR9) was emphasized as an advantage of paper maps by many participants. One participant stated: "We can always come back to that no matter what; it works." Many participants also cited the importance of being independent from power sources in the field, a *hardware* consideration (NFR8). As a second participant emphasized, "They're reliable, they're portable, they don't run out of electricity, they're not subject to electronic failure." Some participants also stated that paper maps were relatively inexpensive (NFR2) and easy to use (NFR7), or that inexperienced users could be taught to use them quickly (NFR1).

Certain aspects of paper maps presented problems for some participants, while other participants already had solutions in place to avoid these disadvantages. Some participants listed the print quality and readability (issues with *visual representation*; MF2) or durability of material (a *hardware* consideration; NFR8) as disadvantages of paper maps, while others indicated that they do not encounter such problems. One participant suggested that paper maps could be improved by allowing erasable annotation (MF3), wanting "maps you could draw on and more easily erase…like a whiteboard." However, other participants stated that they already use laminated maps to support annotation, with one participant critiquing dry-erase markings as being too easily erased or overwritten. Regarding considerations for *human resources* (NFR1), four participants noted a lack of expertise with paper maps among volunteers, but six participants reported greater familiarity or preference for paper maps over other forms of mapping technology.

The most commonly-cited problems with paper maps related to their static nature. The currency of the *geographic information* (MF1) was a frequent complaint, as trails, roads, and even terrain could change in the years since a paper map had been published. Participants reported challenges in maintaining a physical collection of maps, such as storage space, finite quantities of maps (limitations of the physical form, or *hardware*; NFR8), and the *human resources* (NFR1) needed to keep a map collection up-to-date. Another participant emphasized the dynamic nature of a search, stating, “the moment you print [a paper map], it becomes outdated,” suggesting a demand for more a more dynamic form of mapping technology.

To some participants, paper maps offered a limited picture of the geography when compared to the wide variety of available *geographic information* (MF1) layers available digitally. For instance, several participants mentioned problems with the newest editions of USGS topographic maps eliminating features that were previously shown, such as built structures and other infrastructure. As one participant stated: “now power lines and pipelines and things we really need in SAR have magically disappeared off the map.” Providing multiple sets of custom-printed maps, including aerial imagery, was a solution used by one participant and suggested by others.

The static paper map form also results in a limited capacity for *cartographic interaction* (MF3). As a participant stated, “One of the advantages of the digital world is being able to turn layers on and off. You can't do that very well on the paper map." No *data analytics* (U3) are directly available in the paper format, and information transfer, or *interoperability* (NFR4), with digital technology (e.g., manual digitization, scanning, etc.) is limited. Manual methods of overlay (e.g., transparencies) (a simple form of *data analytics*; U3) and paper map annotation (e.g., drawing or writing)—which are both *cartographic interactions* (MF3)—are limited in terms of precision and encounter scaling issues as increasing incident information clutters the maps. Finally, one participant indicated that paper was a poor method of documentation (an example of the *map product use* context; U5) as a single definitive paper copy posed a risk of becoming lost.

Suggestions for the improvement of paper maps primarily coincided with the map content (MF1-2). Participants suggested that paper maps could be improved by more up-to-date, more detailed, or more accurate *geographic information* (MF1). While some participants suggested that paper maps should simply depict more geographic information—with one saying, "show more data" and another claiming, "more information on the maps is always better"—a third participant preferred that paper maps be more selective, stating "the thing that comes to my mind is clarity, that sometimes you'd like to get rid of some layers." In terms of *visual representation* (MF2), the inclusion or improvement of graticule and scale bar map elements was recommended.

4.2 Handheld GPS devices

Table 11: Current uses of GPS devices

Use Context	ext.
U2 - Gathering situation inputs	21
U5 - Map product use	12
U1 - Reference use	6
U7 - Different-place/same-time	4
U3 - Data analytics	1
U4 - Producing map products	1

The *GPS devices* (T2) code was assigned to the transcripts 212 times (13.7%). *Current uses* (S1) of GPS devices corresponded to *use contexts* (U1-10) as shown in Table 11. GPS devices commonly were used for *gathering situation inputs* (U2). All but one of the participants' teams used GPS devices to record a ***track log***, or a series of coordinate readings recorded at a set time interval to indicate the route of a team as they carried out an assignment in the field. Several participants also reported field teams marking ***waypoints***, or individual coordinate readings, to record important point locations, such as possible clues. Track logs and waypoints are downloaded from a GPS device to a desktop mapping program or GIS software, connecting via cable.

For the *map product use* (U5) context, participants reported using GPS devices to communicate search segments to field teams by uploading search segments or reference points to a GPS device before issuing it to a field team. Some GPS devices allow map images and layers to be uploaded. Track logs and waypoints are sometimes used in debriefing sessions with field teams. Additionally, track logs serve as important documentation; as one participant described,

> …you're going to start with them track-logging, from the very beginning. …From a search documentation standpoint, especially if we end up [reducing search resources[4]] because we can't find the person… I want to be able to say: within the first three hours, this is where we were. And this is where we were the next day, and this is where we were the next day and this is what we covered.

[4] switching to *limited continuous mode*, in which the search remains active through other missions to the area or training exercises

For *reference use* (U1), GPS devices allow searchers in the field to orient themselves and become familiar with the search area, to navigate, and to determine their coordinate location. For *different-place/same-time* (U7) geocollaboration, searchers in the field reference GPS devices to determine their coordinate location and subsequently report the coordinates verbally to the command post through radio communication.

One generally agreed-upon advantage of GPS devices was their durability, an important *hardware* (NFR8) consideration also raised with paper maps. As one participant stated “GPSs were manufactured to be rugged from the start. They’re intended to be used outside and dropped and beat around.” Although the need for batteries was seen as a drawback in comparison to paper maps, the ability to replace GPS batteries (normally standard AA) was seen as an advantage over *mobile devices* (T6) with integrated batteries. Participants also noted that GPS devices had small screens and poor display resolution compared to *mobile devices* (T6)—both *hardware* (NFR8) limitations. The positional accuracy of *geographic information* (MF1) collected from GPS devices was called into question by some participants, but most found GPS information accurate enough for the needs of search, provided that the GPS could connect with satellites. Some participants encountered problems with losing satellite signal (a *connectivity* issue; NFR5) either in isolated areas or for short periods of time.

A field team member must be able to accomplish three basic tasks with the GPS interface: (1) clearing a track log (so that it does not record coordinates while searchers are in transit to and from their assignment), (2) creating a waypoint if needed, and (3) setting the coordinate system and datum. Problems with messy track logs and data collected in the wrong coordinate system or datum were attributed to training issues (a *human resources* consideration; NFR1). Some participants emphasized the need for clear instruction during briefings to ensure that all search personnel used a consistent datum and coordinate system, and one mentioned the use of a brief 'cheat sheet' document to improve GPS data consistency.

Many participants had encountered problems with the *interoperability* (NFR4) of GPS devices, most commonly with the issue of missing the appropriate cable to connect certain GPS devices to a computer. This issue often pertained to older models of GPS devices, with one participating stating:

> We still have some people who have the older [GPS devices] that require serial cables and we struggle a little bit with those … that's getting to be less and less, but there was a time where it was a real struggle to keep enough cables.

Although the interoperability of GPS devices is becoming less of a problem, the issue still is encountered frequently. WiSAR teams had different strategies for mitigating this problem, including stocking as many different GPS cables as possible or requiring every searcher to bring a cable for their individual GPS device. Some teams resolve such *interoperability* (NFR4) issues by providing or requiring particular models of GPS; however, other teams have little control over which devices are used when receiving support from other search organizations.

Participants reported problems to varying degrees with the inefficiency (NFR6) of downloading track logs from GPS devices, ranging from "Sometimes a bit of delay [occurs] when you have a bunch of teams coming in at the end of the day" to "the downloading is a big bottleneck that we currently have." Efficiency of downloads also depended on the availability of someone familiar with the procedure, a *human resources* (NF1) limitation.

Three participants stated that GPS devices were user-friendly (NFR7), but six participants found GPS interfaces unintuitive or suggested that GPS interfaces could be improved. Three participants specifically mentioned the difficulty of entering information associated with waypoints. As one participant phrased it, “I don’t know if you’ve ever tried to enter character strings into a GPS, but it’s a real pain in the neck.” Specific suggestions for improving GPS user interfaces included making waypoint entry easier, including a prompt to remind users to clear the track log, and making the interface simpler.

Other suggested improvements for GPS included *hardware* factors (NFR8): larger screens, lighter weight, and longer battery life. Suggestions related to *geographic information* (MF1) included improving accuracy and including additional basemap information with the devices. One suggestion was made that a person be designated to handle GPS and reduce the workload for a GIS specialist.

Mirroring discussion about current limitations of GPS devices for WiSAR, many of the suggestions for improving GPS devices related to uploading or downloading and *interoperability* (NFR4). Some participants suggested making downloads from GPS faster and easier, and two participants suggested that a wireless download method could improve *efficiency* (NFR6). Another participant proposed a method of pre-configuring the datum, coordinate system, and track log settings, asking for “an application where you plug the GPS into the computer and you hit a button and the GPS is automatically configured… every coordinate system, track log, is identical on every GPS." One participant called for GPS manufacturers to standardize and use common data transfer protocols, and multiple participants encouraged more support for uploading custom layers. Some participants noted that certain devices were limited to proprietary formats, and one noted that WiSAR teams rarely received special support from GPS manufacturers because they did not command enough of the market share.

Finally, the *cost* (NFR2) of GPS devices presented a limitation for many teams. Several participants observed that more expensive GPS devices offered better functionality. One participant stated, "the prohibiting factor is: how good of a system can you afford? The systems are out there that are really good… the more you spend on them, the better they work and the easier they are to interface." Several participants said that, given an unlimited budget, they would send more GPS devices into the field—as many as one per individual searcher.

4.3 GIS Software

Table 12: *Current uses of GIS software*

Use Context	ext.
U5 - Map product use	15
U4 - Producing map products	12
U3 - Data analytics	9
U2 - Gathering situation inputs	7
U1 - Reference use	4
U7 – Different-place/same-time	2
U9 – Different-place/different-time	2

The *GIS software* (T3) code was assigned to the transcripts 252 times (16.2%) and was the most frequently discussed of the six specific forms of mapping technology (T1-6). Table 12 shows the frequency of *use contexts* (U1-10) for *current uses* (S1) of *GIS software* (T3). In the most extensively mentioned use context—*map product use* (U5)—GIS software is employed in two areas: (1) to facilitate planning and (2) to document the incident. Within planning, GIS software is used as an editing interface to create search segments or as an information management system to organize both geographic and non-geographic incident information. GIS is used to organize geographic incident information including track logs, clues, witness statements, hazards, and assignments, which facilitate planning by: (1) helping to estimate the searchers' degree of ***coverage***, or the thoroughness with which completed assignments had been searched, (2) drawing attention to areas that had not yet been searched, and (3) allowing queries of incident data by location. As one participant described:

> you may be reporting about… activity done in a segment in operational period one, and then in the same segment have activity in operational period three or four…through GIS we can relate all that activity together to help us understand everything that's going on in that particular region.

Non-geographic incident information also could be integrated with the geographic information, such as search team member sign-in and reporting party information.

Documentation (a component of *map product use*; U5) using GIS was considered important for after-incident review and record-keeping. GIS-based documentation can enable follow-up efforts in unresolved searches. One participant described the use of GIS software as a record of local search history:

> because [a long search] happens so rarely in the lifetime of a searcher or an agency, how do you capture something that happens [only] every ten years or so but may recur because the terrain hasn't changed? …That's another use for GIS: capturing the long-term geospatial memory of your people and the history of your searches.

Documentation using GIS also proved valuable in illustrating the efforts of the search team to the families of lost subjects and to news media, and in highlighting the professionalism of the search organization.

For *reference use* (U1), GIS offered access to the greatest selection of base data. This base data often was leveraged to *produce map products* (U3). Printing paper maps from GIS software allows WiSAR teams to incorporate relevant base layers and incident-specific data as well as customize the *visual representation* (MF2). GIS could offer the greatest degree of control over the content and layout of a map. One participant emphasized the value of map customization for WiSAR, describing an experience as a GIS specialist for WiSAR:

> You could see people come to the realization that I could get them a customized map … People would start coming in and asking for a specific thing… changing the maps to more closely represent what's going on in the search. The whole point of that is to allow the overhead team to visualize what's happening on the ground. You can make the maps fancier or less fancy depending on what you want to represent.

Several participants had used GIS to print assignment-specific maps for field teams, and some had produced maps for briefings or for pre-planning. GIS software also was used to prepare files for upload to a GPS device.

In the *data analytics* (U3) context, *cartographic interaction* (MF3) had been leveraged in GIS to overlay and filter incident data and to narrow search areas based on *GIS functions* (MF4) by assessing cell phone coverage, terrain barriers to travel, and simple ring models of the distance a subject could have traveled. Analysis of elevation data was used in at least five ways: (1) to create search segments, (2) to assess the difficulty of traversing areas for field teams, (3) to identify areas of avalanche risk for searcher safety, (4) to optimize placement of radio repeaters, which extends the area of coverage for radio communications, and (5) to evaluate wind patterns for air-scent canine teams. Data analytics in GIS software also had been used to estimate the probability of detection (POD) for completed search assignments based on track logs collected from field teams.

Participants reported using GIS to *gather situation inputs* (U2) by downloading track logs and collecting other incident data. In this use context, GIS software helps to ensure that nothing 'falls through the cracks.' Participants noted that GIS offers an advantage where systems of paper debrief forms had failed. One participant remembered a clue on a paper form becoming "buried" and "never followed up on;" in retrospect, it was found that the forgotten slip of paper might have ended the search earlier. A second participant described the unreliability of annotating paper maps with sticky (or post-it) notes, stating:

> [GIS] gets around the problem of somebody put a sticky up on the map on the wall and the sticky blew down and was found on the floor. Now where does the sticky go? …There have been searches where a significant sticky has fallen to the floor.

The ability to collect all situation inputs in one place, organize them geographically, and subsequently categorize, filter, and turn on or off layers (overlay) using *cartographic interaction* (MF3) enabled better search management. Participants noted that GIS software becomes more important for handling situation inputs as an incident extends beyond the first or second day.

Nearly all discussion (86/90 of the coded statements) regarding the *limitations* (S2) of *GIS software* (T3) corresponded to *non-functional considerations* (NFR1-9). While some participants noted that GIS software can be expensive (NFR2), participants from three separate search teams stated that the Esri Nonprofit Organization Program provided a significantly reduced cost license of ArcGIS. Regarding *efficiency* (NFR6) of

GIS to support initial actions, one participant asserted that GIS could be deployed quickly, stating that “after the computer's booted up basically within ten minutes we've had five or six tasks written up and printed that are then ready to go into the field.” However, another participant stated that GIS did not always produce map products quickly enough for the very first field teams, commenting that “after the initial assignments are out there, then MapSAR pretty much runs the show. Because it does take a while to put [incident data] into the GIS software.” For many WiSAR teams, the timing of deploying GIS depended on the availability of personnel with GIS experience, again pointing to a bottleneck related to *human resources* (NFR1).

Many participants described GIS software as complicated, difficult to use, or not user-friendly (NFR7). Several participants noted that GIS software takes a significant investment of time and effort to learn, an investment that may not be possible for many WiSAR team members. Participants noted that both WiSAR volunteers and non-volunteer park rangers in the National Park Service are busy with many other obligations and need to invest their time in maintaining other search-related certifications, such as first aid. Search organizations that use GIS software tend to rely on specific people with the expertise to use it (NFR1). In the absence of a trained specialist, teams employed alternative mapping technologies, which leads to *efficiency* (NFR6) problems when transitioning to a GIS later. Further, despite training directed at WiSAR team members, some of those without a GIS background from their profession or education may choose not to use GIS software, even when available, due to a lack of confidence. One participant stated, “when push comes to shove, it’s really only somebody who has it in their background who has the confidence to do it in the middle of a mission." Finally, participants noted that some WiSAR personnel were either disinterested in committing the time or intimidated by the perceived difficulty of learning the software (NFR1).

Participants acknowledged the possibility of seeking GIS specialists to aid in WiSAR, but that the GIS specialist would require training in search to be useful to the team. One participant stated, "I've got one person I've been training and she's a GIS tech… It's taking her a bit of time to understand how we do things in search and rescue rather than a city work environment." Some participants noted a recent program in which members of the GISCorps, a volunteer organization for GIS professionals, were trained to volunteer in WiSAR. Referring to the GISCorps volunteers, another participant explained the crucial approach that GIS specialists need to adopt:

> They're not searchers and there's just that piece that they're missing. When we say, 'there's [a search] going on, we need somebody out here to get this thing going'…[they respond,] 'well okay, let me finish what I'm doing out here at work' …they just don't get the concept of, 'we've got to get out there' or the concept of 'we have hundreds of people coming in tomorrow morning, so we need to have everything ready at six a.m.' ...that's the training issue.

The GISCorps effort was in its first year of implementation, and SAR-trained GISCorps volunteers had not yet been deployed to help on any WiSAR searches. The project may require more buy-in from WiSAR teams; as one participant pointed out, even seasoned WiSAR specialists trying to incorporate GIS into WiSAR are sometimes met with skepticism and resistance.

There was controversy among participants over the validity or usefulness of modeling lost person behavior or subject mobility using GIS software (leveraging *GIS* *functions*; MF4). I identified four different positions that participants articulated on the issue. Some participants (Position #1) were using GIS software to generate heat maps of probability of area (POA) based on ISRID data collected in a similar ecoregion and terrain. There then were participants (Position #2) who felt that POA modeling could be useful, but that only local lost person behavior data should be considered relevant. Many participants called for more local lost person behavior data collection and analysis.

Some participants felt that the behavior of past subjects had no relevance in a new search and objected to POA modeling. Of these, some participants (Position #3) did believe that the terrain imposed predictable (i.e., model-able) physical limits to travel; as one participant said:

> The actions they took were not going to apply to anybody but them. People are so different… I lean more towards terrain analysis rather than prior victim subject behavior because the terrain isn't going to change. There are just certain things people cannot do in certain terrain and that's what you have to work with. So I like the models that are coming out for distance and travel costs… but to try and take what people have done before and use that to predict what people will do again is very difficult.

Finally, another critic (Position #4) felt that too many situation-specific factors affect the behavior and movement of a subject and thus too many assumptions are made in modeling both POA and subject mobility. This participant also worried that critical search management decisions would be made based on these limited models:

> there are too many human variables involved in that. If you have an inexperienced search manager and the computer says, 'Go look over here,' they're going to because the computer said to, not because of any other input."

When discussing whether such models remove some of the judgment in search management, a proponent of statistical behavior modeling argued that models offer a valuable alternative perspective on the situation, stating that "It moves closer to preventing bias, personal bias and team bias … by considering the evidence more holistically than just based on personal opinion." This participant went on to explain that ISRID statistics are just one of many factors that contribute to a suggestion—not a prediction—to help establish priority areas to direct search resources. A fourth participant felt that POA models could supplement, rather than supplant, judgments, stating:

> I think anybody who has experience is going to use their own experience anyhow and look at what the computer suggests…and [say] 'well, that [suggested segment is] nice, that one's okay, that one's silly and then one got left out so I will just add that myself.' But after watching what new people who have no experience sometimes come up with… they need all the help they can get.

Critics of POA and mobility models (Position #4) still felt that GIS could offer valuable *data analytics* (U3) by providing objective spatial analysis through *GIS functions* (MF4) such as viewshed, slope, and aspect. One participant stated, "a viewshed is an analytical tool driven by data, not by any supposition," Another participant advised that any *data analytics* (U3), even those based solely on terrain, are limited by assumptions and by the underlying data. Using the example of a radio coverage map approximated by simple viewsheds[5] from radio repeater locations, this participant stated, "It doesn't tell us for real what happens in the field… if you don't

[5] Radio coverage is more complex than line-of-sight; a viewshed is not a precise model of radio wave propagation.

realize it's a model and not fact, then you run into problems." This participant and others emphasized the importance of understanding the uncertainty and assumptions of all *geographic information* (MF1).

As with the discussion on limitations, suggestions for improving GIS software also pertained primarily to *non-functional considerations* (NFR1-9). Many participants suggested making GIS software easier to use, simpler, or more intuitive (NFR7), while retaining its analytical capability. One participant suggested an interface tailored to automatically suggest search segments based on a probability model; other participants objected to the use of probability models or automated planning suggestions.

Many suggestions pertained to personnel knowledge or expertise (NFR1). Awareness of GIS capabilities is one of the first hurdles to adopting GIS software in WiSAR. One participant described a search manager's unfamiliarity with GIS, stating "She didn't know enough to understand how you could use GIS. She just understood it to mean literally making a map, basically copying a USGS map into a poster size," This participant went on to say that practical examples are the best way to facilitate adoption, continuing "you've got to demonstrate this stuff. You can talk about it all you want, but you've got to show folks who aren't technically-oriented how it's useful."

Some participants believed that more training in GIS is needed across WiSAR teams (NFR1). Some participants articulated a need for more availability of trained GIS experts (NFR1). Other participants emphasized that training also is needed in basic geographic concepts, such as coordinate systems. One participant called for recognition of the need for fundamentals, stating that "I think the disconnect is…from the highly trained GIS people, not understanding the huge, huge gap in your average person being able to grasp and use this stuff." Another participant suggested beginner-friendly documentation, requesting "step by step, straightforward, bulleted out, anybody can pick up." However, one participant pointed out the difficulty of keeping exhaustive documentation up-to-date as technology changes rapidly. Several participants promoted user-friendly desktop mapping programs that are *interoperable* (NFR4) with GIS software. Such programs could be deployed early by any available WiSAR personnel and allow a smooth transition to GIS software when trained personnel became available.

4.4 Desktop Mapping Programs

The *desktop mapping programs* (T4) code was assigned to the transcripts 137 times (8.8%). As introduced above, desktop mapping programs differ from GIS software in that they do not support *GIS functions* (MF4), or full spatial analysis capability. Table 13 shows the extensiveness of *use contexts* (U1-10) for *current uses* (S1) of *desktop mapping programs* (T4).

Table 13*: Current uses of desktop mapping programs*

Use Context	ext.
U4 - Producing map products	15
U2 - Gathering situation inputs	11
U5 - Map product use	7
U1 - Reference use	4
U7 - Different-place/same-time	1
U8 - Same-place/different-time	1
U6 - Same-place/same-time	1

All but one of the participants' WiSAR teams used a desktop mapping program in some capacity if they did not use GIS software. In the *producing map products* (U4) context, desktop mapping programs were used primarily to print paper maps. Participants described printing maps for debrief, for planning, or for field teams, often customized to the individual search assignment. Creating maps in desktop mapping programs was described as quick and easy (NFR6,7); as one participant put it, "that software does an excellent job at what it was intended to do, which is typically produce a map for you."

When *gathering situation inputs* (U2), desktop mapping programs were most frequently used to download track logs from GPS devices. While some participants noted that this process was *efficient* (NFR6) and easy (NFR7), others found that the *efficiency* (NFR6) could be overwhelmed by data volume. Desktop mapping programs also were used to record clues and field team locations reported verbally by radio. In the *map product use* (U5) context, desktop mapping applications were leveraged to organize incident-specific information (e.g., track logs, waypoints, clues, and segments) and for planning, including drawing search segments. They sometimes were used for general *reference* (U1) of the terrain.

Desktop mapping programs encompass several different programs, each with different functionality and intended purpose. Lacking the GIS functions which define GIS software, desktop mapping programs rely on *cartographic interaction* (MF3) for on-the-fly map interpretation, including overlay, filter, calculate distance, and edit (used to draw segments). However, many participants found the implementation of these interaction operators limited, indicating that certain programs could not efficiently overlay, filter, or reproject the map, and some programs had frustratingly limited ability to edit features (e.g., polygons during the process of drawing segments). Some participants noted that certain desktop mapping programs are limited to built-in basemaps, which impacts the available *geographic information* (MF1) in that program and on any paper maps printed from it. Regarding *interoperability* (NFR4), some desktop programs can readily exchange files with GIS software, while others cannot.

Good *usability* (NFR7) and familiarity among WiSAR teams (NFR1) were noted as benefits of desktop mapping programs, but programs that offer more *mapping functionality* (MF1-5) were noted as more difficult to use (NFR7). Unlike GIS software, participants did not associate any special training prerequisite with proficiency in desktop mapping programs. However, participants still correlated expertise with time spent using the programs; as one participant stated, "your ability to use this software is a function of how much you personally use it." Another participant observed that "it's a perishable skill, if you're not operating it on an ongoing basis, it's almost like you have to relearn it again when a search comes up." Participants reported that *cost* (NFR2) was a limiting factor for WiSAR teams to access certain programs and that cost could also impact expertise:, noting that "they might be able to afford one copy [of a desktop program], [but] not enough for everybody to play with, in which case it becomes less useful because nobody has experience with it."

There was little consistency among *suggestions* (S4) for desktop mapping programs. Like paper maps, two participants suggested that SAR-specific needs for *visual representation* (MF2) could be better met through inclusion of ICS symbology or more readily available map elements (graticule, legend, etc.). One participant proposed extending desktop program functionality to *GIS functions* (MF4); however, another participant objected:

> I have seen people try to push the limits on some of the desktop software and I find it's just not the way to go... only real GIS software can handle many models.

> [Desktop mapping programs] can be improved, but I think it's a waste of time and people should move on to real GIS…

A third participant suggested that desktop mapping programs could be improved by better *interoperability* (NFR4) with GIS software, rather than expanded GIS functions. Thus, desktop mapping programs may best serve WiSAR by supporting a few specialized tasks and enabling a smooth transition to GIS software when other capabilities are needed.

4.5 Web Maps

The *web maps* (T5) code was assigned to the transcripts 146 times (9.4%). Table 14 shows the extensiveness of *use contexts* (U1-10) *for current uses* (S1) of *web maps* (T5). Web maps primarily were used to *reference* (U1) the geographic context of the search area or more specifically to view imagery or terrain before arriving on site. Participants also found web maps to be a simple and efficient (NFR6-7) *reference* (U1) for driving directions to unfamiliar locations. One participant noted that Open Street Map can be a source of trails data that is otherwise unavailable.

Table 14: *Current uses of web maps*

Use Context	ext.
U1 - Reference use	11
U9 – Different-place/different-time	5
U5 - Map product use	4
U7 - Different-place/same-time	3
U2 - Gathering situation inputs	3
U4 - Producing map products	1

In both *different-place/same-time* (U7) and *different-place/different-time* (U9) geocollaboration, some participants described using web maps to provide situation awareness for remotely located (i.e., not at the command post) search planners, who could contribute advice or prepare plans and materials for upcoming operational periods. In the *map product use* (U5) context, participants reported using a web map—

usually Google Earth— to view terrain at oblique angles for planning. For instance, oblique views supported estimation of avalanche hazards in areas with heavy snow pack and steep terrain. Oblique views of the terrain also allowed search planners to approximate the subject's perspective as they moved through the landscape, helping to suggest possible decisions and scenarios leading to the subject's disappearance. Web maps also were used during meetings or training (U5) to give an overview of a past incident.

The crucial limitation of web maps was a lack of internet *connectivity* (NFR5) at the location of WiSAR operations, frequently even at the command post. During a WiSAR search, the command post might not be housed in a building, with WiSAR teams instead using a specially-equipped vehicle. Further, many participants noted inaccuracy in the *geographic information* (MF1) of web maps, including a lack of detail or occasionally completely incorrect features. Other problems with mapping functionality in web maps included: (1) a limited ability to edit features and to encode attributes and relationships in the data (MF3), (2) limited support for different coordinate systems and projections (MF3), and (3) a frustration with labels being omitted at certain scales (MF2). Though often described as easy and user-friendly (NFR7), web maps sometimes required expertise (NFR1), especially in transferring data from or to another mapping technology. Participants mentioned cloud-based incident management systems, including D4H and Mission Manager, which were noted as expensive (NFR2) and not widely used due to lack of *connectivity* (NFR5).

One advantage of web maps is the ability to access the same map from multiple computers, facilitating collaboration. One SAR-specific web mapping tool—SARTopo.com—allows edits simultaneously for *same-time* (U6, U8) geocollaboration. If internet access could be improved (NFR5), participants suggested using web maps for *different-place* (U7,9) geocollaboration.

A recent effort by the Mountain Rescue Association (MRA) is just beginning to show the benefits of web mapping for data collection (U5). Annual reports of search incidents from MRA member organizations are now submitted through a web-based form with embedded map input—Esri's GeoForm. Each form updates a web map displaying the results of the survey across all MRA teams. One participant noted that collecting location information is a step in the right direction:

> Until the Esri app [GeoForm] there wasn't any kind of geographic information in it except where the team was [based]. I think that's an opportunity…kind of crying out for national data collection with the opportunity for people to see their own data and share it in their region.

The ability to view the data as a visual product contributes to user adoption and makes the reporting process more beneficial to individual teams. As another participant said,

> People can see value of showing where all their searches are and using this as a live map that they can show… it wasn't until we came up with the mapping idea last year where people say…oh, so this puts dots on a map, and that I get, and I can see that real-time… The visual aspect was really exciting.

The former participant also noted, however, that collecting a single point location for each incident might be unclear and that a more comprehensive set of well-defined attributes could help build a database of local lost person behavior, which could be even more valuable:

> In [this] county, if we were doing that, we'd have in 10 years something that would be useful to train our search members on. I know this is true. People get lost in the same places and they often end up in similar places, and if we were tracking that better we could analyze it and make use of that information.

Recording local lost person behavior was just one of the many uses that the latter participant envisioned for the new MRA dataset—other opportunities extended beyond the immediate search incident to include other parts of Cutter's emergency response cycle: (1) documentation for team fundraising and budgets (preparedness), (2) records for improving wilderness medical training (preparedness), or (3) public information maps as preventative measures (mitigation).

As the last potential use of the MRA map indicates, web maps create opportunities to interface with a wide audience of the public. One participant stated that "the big advantage of a web map is communicating that information to a wider audience." One application of web maps that was tested, but only used a few times, was to inform visitors of an unresolved, ongoing search and to crowd-source witnesses. One participant explained, "hundreds, thousands of people, are out hiking. …they are all searchers, whether they see something or whether they don't see something. So, if you can capture where they go… you're starting to eliminate terrain that you have to search." This participant went on to note that a dedicated person was needed to update and maintain such projects, which can be difficult to find among volunteers.

To improve web maps for WiSAR, participants suggested better integration with other technology (NFR4), including GIS as well as standard ICS forms. One participant suggested that map tilesets, or the collection of image files that mosaic at particular scales (i.e., zoom levels) to form a 'slippy' web map, could be licensed and made available for users to download, cache, and legally reprint for WiSAR (an *institutional* barrier; NFR3). Another participant suggested offering templates for printing customized maps. Other participants suggested improvements to mapping functionality, including better support for the *cartographic interactions* (MF3) overlay and reproject, symbology similar to print maps (a *visual representation* consideration; MF2), and efficient handling of .gpx files (relating to *geographic information*; MF1).

4.6 Mobile Applications

Table 15: *Current uses of mobile apps*

Use Context	ext.
U2 - Gathering situation inputs	3
U1 - Reference use	2
U7 – Different-place/same-time	1
U6 – Same-place/same-time	1

A total of 130 statements (8.4%) were coded as relating to *mobile applications* (T6). While 58 statements pertained to a *problem* (S2) with mobile technology, only 7 statements (5.4% of statements about mobile apps) pertained to a *current use* (S1); extensiveness of *use contexts* (U1-10) are shown in Table 15. A total of four participants from four separate states reported that their search teams used mobile applications in an official capacity during a search. Participants from two separate WiSAR teams had just begun to try using mobile applications, and three additional participants noted having seen searchers use mobile applications in an unofficial capacity.

When *gathering situation inputs* (U2), two participants mentioned using mobile applications to report the phone user's location, and one participant had seen cell phones used to record track logs. One participant indicated that searchers in the field had used mobile maps in an unofficial capacity for reference (U1), while another participant mentioned that search pilots used mobile applications for *reference use*

(U1). One participant described the use of mobile apps for *different-place/same-time* (U7) tracking of searchers by the command post. One participant had used maps on a tablet to collaborate in a *same-place/same-time* (U6) briefing scenario.

The most commonly mentioned drawback to mobile devices was the lack of connectivity to cell phone reception or internet service (NFR5). No participant confirmed consistently having widespread cell phone reception in search areas. Opinions were divided regarding the accuracy of mobile coordinate readings (MF1). Five participants considered mobile devices accurate enough for WiSAR and one noted stronger satellite connectivity on a mobile device compared to a handlheld GPS device, while six participants considered mobile devices too inaccurate (MF1). As one participant stated, "the accuracy… I don't trust them. …because the people that are using them are the people that we're going for in the field that are lost." *Hardware* concerns (NFR8) with mobile devices also were commonly noted. Battery life is limited and consumed quickly by mapping applications, and an integrated battery is not as readily replaced as the standard AA batteries in GPS devices. Many participants did not consider mobile devices to be durable, weather-resistant, or 'rugged' enough for field teams. Many mobile devices currently used for WiSAR were personally owned, and one participant noted that searchers preferred to use their personal devices. These factors raised the question of team responsibility for replacement in the case of a damaged device (NFR9).

One key advantage of mobile applications is their ability to wirelessly exchange data (NFR4). Some participants had used email or Bluetooth technology to efficiently

(NFR6) collect track logs from field team members. Participants found mobile devices familiar and user-friendly to volunteers (NFR1, 7). Participants noted that mobile devices were less expensive than both radios and GPS devices, and that applications were also inexpensive (NFR2). Certain mobile applications had the ability to cache map data (coded as *other mapping functionality*; MF5) for *reference use* (U1) without connectivity to cell phone reception or internet service.

One participant suggested a need for mobile apps and devices tailored to WiSAR use, and/or support from the app or device developers for requested features (NFR9). As another participant put it, “understand who the end user is, especially in SAR.” Various participants named specific features that they would want supported: (1) a default view of coordinate readings for their location (not just the ‘blue dot’ conventionally displayed to show the user’s location), (2) improved durability and battery life or replaceable batteries, and (3) an efficient method for transferring data from the device to a computer. Some participants suggested incorporating features common in mobile devices, such as high resolution screens or cameras, into GPS devices (NFR8). However, one participant stated that there is not enough of a market to support devices or apps developed specifically for WiSAR.

Suggestions were made to improve the *geographic information* (MF1) available through mobile applications by supporting GIS-friendly file formats and by providing more base datasets, ideally accessed through an organized catalog to make them easy to browse and to make users aware of what is available. It was clear that any mobile device for field teams must be able to cache data (MF5) and function with intermittent or complete lack of *connectivity* (NFR5).

Some participants suggested improving *connectivity* (NFR5) in the command post or even throughout the entire search area. Such signal boosting was recognized as possible, but prohibitively expensive (NFR2). Given some method of connectivity, participants saw potential for live synchronization of individual devices with a centralized, updating source of incident data to facilitate *same-time* (U6, U8) geocollaboration for planning and situation awareness. Similarly, real-time tracking of individual devices from the command post could facilitate same-time collaboration between the command post and field teams.

4.7 Other Technology

A final *other technology* code (T7) captured notable statements relating to a specific technology used for mapping in WiSAR that was not discussed above. A total of 115 statements (7.4%) were coded as other technology (T7), and the following themes were consistently mentioned. Statements about other technology included: thirty-one statements (27.0%) related to real-time tracking (U7), which is addressed in Section 4.8 due to its relevance to *GPS* (T2) and *mobile devices* (T6); thirty-one statements (27.0%) pertaining to Unmanned Aerial Vehicles (UAVs); seventeen statements (14.8%) related to technologies that detect a transmission from the missing subject; and thirteen statements (11.3%) describing the use of email and other web-based file-sharing tools for *different-place* (U7,9) collaboration.

Although legal restrictions (an *institutional* limitation; NFR3) precluded most current use of UAVs by WiSAR teams, two participants had seen UAVs used in search, although the UAVs did not contribute to finding the subject. Other participants discussed the possibility of future use. Although UAVs called to mind a live video feed for many participants, one participant stressed that using a UAV to directly search for the subject was currently not the most effective use of the technology, saying “in my view, the thing it does the worst is flying around there looking for someone… there are lots of uses for [a UAV] that are better.” This participant went on to suggest alternative uses for UAVs that enhance a WiSAR team’s geographic information or mapping capabilities: (1) obtaining up-to-date aerial imagery of the search area for situation awareness—an instance of *gathering situation inputs* (U2)—or (2) serving as a platform for equipment to extend a communications network and improve *connectivity* (NFR5). Other participants also suggested that real-time aerial imagery from a UAV could be an *efficient* (NFR6) method of *gathering situation inputs* (U2) in open fields or a desert environment, where a subject might be easy to spot. Some participants suggested that there is potential for obtaining an initial look at treacherous terrain such as swift water creeks, gullies, or cliff bands to seek an indication of a subject, but a UAV would not be trusted to confirm the subject’s absence.

UAVs are limited by short flight times and sensitivity to weather conditions such as wind (*hardware* considerations; NFR8). They also require a competent operator (a *human resources* limitation; NFR1). UAVs were considered expensive (NFR2), although less expensive than a helicopter for situations in which they might be a viable substitute. Some felt that a public wariness of UAVs, or drones, would prevent teams from adopting them, while others felt that having UAVs as a resource (as with search dogs now) may eventually become an expectation.

Another form of *other technology* (T7) consisted of systems that receive a transmission from an electronic device carried by the search subject. Although these were intentionally excluded from the scope of this study's interview questions, several subjects mentioned their use. Participants reported increasing use of data from the subject's cell phone as well as some use of Personal Locator Beacons (PLBs) (e.g., SPOT) to aid in searches. Participants reported inaccuracy of *geographic information* (MF1) ("as much as a half mile or a mile") from Phase II Enhanced 911, a location-reporting system for emergency calls, as well as PLBs on some occasions. Though many participants reported no problems in obtaining cell phone data (NFR3), usually through law enforcement, some had encountered trouble. One participant stated, "You can't go Sunday night in a rainstorm saying oh, I need this stuff, you have to do your homework ahead of time," emphasizing that WiSAR teams need to preemptively establish procedures for obtaining such data.

Finally, email and online file-sharing tools (e.g., Sharepoint, Dropbox, Google Drive, wiki sites) were essential in *different-place* (U7,9) geocollaborative contexts to exchange geographic files or map images. This file sharing was used to seek opinions from search experts who could not be present at the incident command post. One notable example was the use of a wiki site to allow multiple collaborators to share opinions and build upon others' ideas. Online file-sharing also allowed WiSAR managers to divide the task of producing new maps, either to take advantage of the map design and technology expertise of someone off-site, or to reduce the workload for on-site staff—allowing them to sleep or to travel to the incident site while off-site staff prepared assignment maps.

4.8 General Mapping Technology

The *general* (T8) mapping technology code was used to identify statements that could not be definitively assigned to one mapping technology in particular. The *general* (T8) code was applied to 372 statements, comprising 24.0% of coded statements. This section captures important themes that were not strongly associated with just one of the previous seven sections, but may have been mentioned in connection with more than one of Pfau's six forms of technology (T1-6). I first address themes relating to the *use contexts* (Category #3; U1-10) in order of extensiveness as listed in Table 16. I then organize the remaining topics by requirement (Category #4; MF1-5, NFR1-9).

Table 16: *Current uses of general mapping technology*

Use Context	ext.
U5 - Map Product Use	16
U6 – Same-place/same-time	10
U8 – Same-place/different-time	7
U7 – Different-place/same-time	6
U2 - Gathering situation inputs	6
U3 - Data analytics	3
U1 - Reference use	3
U4 - Producing map products	2
U9 – Different-place/different-time	1

Across technologies, there were several patterns in the way that maps were used to support the *map product use* (U5) context. First, maps were used in WiSAR to form and evaluate possible subject scenarios. As one participant described, "if we know roughly what [the subject's] destination or plans were, then we're always looking at the map saying, 'you didn't make it to wherever you're going… why? Where have you gone wrong?'" Participants used maps to look for possible ***terrain traps***, or locations that the topography might funnel a moving subject into based on likely routes or paths of least resistance. Maps also were used to delineate the search area, to identify important locations for containment, to design search segments, and to make logistical decisions as far as how to get field teams safely into and out of their assigned areas. As the search unfolds, they are used to plot clues and completed assignments. Participants highlighted the importance of maps in documentation of search incidents. Participants emphasized that maps are essential across WiSAR tasks; as one participant stated, "spatial information [has] relevance in basically all aspects of search."

Mapping technology broadly was acknowledged as important in all four WiSAR geocollaboration contexts (U6-9). In *same-place/same-time* (U6) geocollaboration, the emphasis was placed on building a common operating picture. For *same-place/different-time* (U8) geocollaboration, digital mapping files were transferred to the incoming collaborators. Maps supported *different-place/same-time* (U7) geocollaboration through verbal communication with spatially-distributed collaborators using the same visual representation. For *different-place* (U7,9) geocollaboration, two participants reported using remote support command staff in both *same-time* (U7) and *different-time* (U9) contexts.

Mapping technology was used to *gather situation inputs* (U2) from verbal radio communications, track logs, debriefing sessions, and witness interviews. A notable topic that arose from this area of discussion was the possibility for automated transmission of coordinates. Most participants reported that field team locations are currently obtained through verbal communication, which is vulnerable to mistakes. Participants had observed mistakes in recording coordinates including misinterpreted handwritten numbers, misrecorded coordinate formats (degrees-minutes-seconds instead of degrees decimal minutes), and mismatched datums. As one participant stated: "coordinates lend themselves to transmission other than by voice." Participants noted that devices with this capability (e.g., GPS speaker microphones) are available; however they were not widely used among participants' WiSAR teams.

Real-time tracking of field teams by the command post—an instance of *different-place/same-time geocollaboration* (U7)—was mentioned in connection with *GPS* (T2) and *mobile* (T6) devices, along with *other technology* (T7), including GPS speaker microphones, satellite trackers including Personal Locator Beacons (PLBs) (e.g., SPOT, DeLorme inReach), amateur (or ham) radio, and two-way radio (e.g., Garmin Rhino), all of which can facilitate this capability. There was some debate over the usefulness of real-time tracking of teams in the field. Although some participants felt that real-time tracking was unnecessary, other participants suggested ways in which real-time tracking could improve search efficiency or management. Participants suggested that real-time tracking of field teams (U7) could improve search *efficiency* (NFR6) in a least three ways: (1) by eliminating the need for downloading track logs upon the field teams' return (although it was unclear whether a real-time tracking would be as detailed as a GPS track log), (2) by saving field teams the trouble of plotting and reporting their coordinate, or (3) by allowing staff in the command post to consider the progress of teams in planning decisions, especially in the (rare) case of teams spending more than a day in the field completing an assignment. Participants also indicated that real-time tracking could enhance field team safety and could allow the command post to re-direct or re-assign teams in the field based on their location if operations priorities change.

The remaining statements regarding *general mapping technology* (T8) are organized by requirement (MF1-5, NFR1-9). The extensiveness of requirement codes is reported in Table 17.

Table 17: *Requirements of general mapping technology*

Requirement	ext.
MF1 – Geographic Information	20
NFR1 – Human Resources	19
NFR3 - Institutional	19
NFR2 - Cost	16
NFR6 – Efficiency	13
MF2 – Visual Representation	11
NFR4 - Interoperability	11
NFR7 - Usability	11
NFR9 – Other Nonfunc. Req.	10
MF3 – Cartographic Interaction	8
NFR5 – Connectivity	7
NFR8 – Hardware	3
MF5 – Other mapping function	1

The *general mapping technology* code (T8) was most extensively applied to statements about *geographic information* (MF1). Many participants identified datasets that they wished to obtain, or wished existed. Participants stated that more up-to-date *geographic information* (MF1) would be useful, particularly more recent or higher-resolution imagery and better trails information. Some participants noted that a very detailed land cover layer could help inform search assignment planning, by discerning “what places are going to take more effort to search and what places can you get through in a few minutes with a few people.” Some participants noted that historic maps or features, such as old roads, would be valuable to WiSAR teams because old features were still present in the landscape.

One interesting aspect of discussion related to *geographic information* (MF1) was the importance of the temporal component. This was especially noted in connection with *same-place/different-time geocollaboration* (U8) for transition of command, but also important for general situation awareness (U5). One participant noted that their team created timelines of events, in addition to maps, to better understand an incident as it unfolded. Another participant suggested that temporal information should be better integrated into geographic file formats and better supported by mapping technology, including GIS software.

An overarching theme throughout the discussion of mapping technology was the idea that expertise, or the available *human resources* (NFR1), is just as important as having access to a technology. As one participant said of GPS devices, “they’re only as good as you know how to use them.” Illustrating this point, another participant mentioned “I’ve seen somebody put a post-it note on a computer screen because they didn’t know how to make the dot on the computer screen.” Mapping functionality only can be leveraged if the requisite expertise is available; as one participant put it, “Sometimes I’m not 100 percent sure how much it is that the program has the problem and how much of it is just that the people using the programs don’t have enough familiarity to do what we want to do.” Another participant felt that when functionality exceeded the limits of available expertise, it could become a disadvantage: “Anytime you get overloaded with technology, it’s as much of a barrier as not having enough technology.” One participant emphasized that this is analogous to other areas of technical expertise in WiSAR, stating that “like any other skill in SAR, if you’ve got people that know how to do it, it's going to go smooth…if they don’t, then that’s a little bit more difficult. But it’s that way with everything.”

Some participants had encountered *institutional* (NFR3) barriers to obtaining geographic information. Fourteen participants stated that permission or authorization had not been a problem in accessing geographic information; however, seven participants stated that their teams did not have access to certain potentially-useful datasets, such as closed trails, social trails, infrastructure, and real-time satellite images. Participants had encountered data access restrictions with private companies as well as agencies at all levels of government, including cities, counties, state parks, and federal agencies. Participants noted that working on federal agency computers restricted administrator privileges to the computer system and hindered the sharing of files with non-government agencies, presenting an *institutional* (NFR3) barrier to collaboration. Participants also noted a lack of standards for aggregating incident information or exchanging geographic information with other WiSAR teams or cooperating agencies. Finally, some participants noted resistance of WiSAR teams to the use of certain mapping technology; thus, *institutional* (NFR3) challenges may come from within an agency or team.

The issue of financial *cost* (NFR2) was raised in connection to every form of mapping technology. Cost is always a factor for volunteer organizations and public agencies. A tension exists between the limited resources of most WiSAR teams, an expectation of free labor (volunteering), and the difficulty of providing free labor and inexpensive tools. One participant stated, “if you’re offering a valuable and useful [mapping technology] that you’re going to update and maintain; the free model just doesn’t work… it takes time to develop these things. …people want them for free…and there's not enough ad[vertisement] money there either." Participants also noted that there is not enough of a market in WiSAR to fund research and development of new technology.

Finally, some participants made recommendations for organizing mapping workflows during a search, and many of these solutions aimed to improve *efficiency* (NFR6). Emphasis was placed on distributing tasks to relieve the demand on a single computer and user. To prevent crowding around the GIS computer, some participants recommended the use of a separate monitor or a projector to display an updated map in the command post for general situation awareness, or in the debriefing area, ideally accessing a definitive, updated data source such as a central database. Participants also suggested a dedicated computer or screen for the debriefing field teams or a dedicated computer and operator for downloading track logs. One participant had tried this system and encountered difficulty: "if you have a track download machine and then a planning machine … they wind up with information silos on each machine and it's harder to get a common operational picture where you see all the information at once." This participant had also tried a local networking solution, and noted problems with adoption due to the technical expertise (NFR1) required to set it up:

> I was trying to build a remote server software that somebody could run and then have several machines access through the browser and I had a lot of trouble with adoption there… it requires technical savvy to get up and running.

Improving the coordination of many simultaneous, map-related tasks in WiSAR may prove to be either a *human resources* issue (NFR1) or a challenge of blending *interoperability* (NFR4) with *usability* (NFR7).

Chapter 5: Summary and Future Directions

Chapter 5 summarizes results and presents final discussions. In the first section, I review key uses, limitations, and advantages of each form of mapping technology, relating the study results to the original research questions. In the second section, I discuss the limitations of this research. In the third section I propose future research directions emerging from the interview study. I conclude with a final statement on the utility of mapping technology for WiSAR.

5.1 Results Summary

This study asked the questions: (1) How is mapping technology currently used to facilitate WiSAR operations, including geocollaborative situations? (2) Are there any key gaps or unmet user needs in existing mapping functionality for WiSAR? and (3) What are the key challenges to the adoption and use of new mapping technology within WiSAR teams? Addressing Research Question #1, Table 18 summarizes the current uses of each of the six forms of technology from Pfau (2013).

Table 18: *Current uses of six forms of mapping technology*

Technology	Frequently used	Sometimes used
Paper maps (T1)	• Orient searchers to the search area • Planning and situation awareness • Communicate search assignments to field teams • Same-place/same-time (U6) geocollaboration • Consulted by collaborators in different-place/same-time geocollaboration (U7) • Transfer of command (same-place/ different-time geocollaboration; U8)	• Gather situation inputs through annotation
GPS devices (T2)	• Record track log of teams in the field • Mark waypoints • Orient searchers to the search area • Find position and report it verbally	• Communicate search assignments to field teams • Debrief field team • Documentation

***Table 18** (continued)**:** Current uses of six forms of mapping technology*

Technology	Frequently used	Sometimes used
GIS software (T3)	• Facilitate planning: edit segments, organize incident information by location, draw attention to unsearched areas • document the incident • print custom maps • overlay and filter incident data • download GPS track logs • collect clues "nothing falls through the cracks"	• Estimate coverage and POD • local search history, "geospatial memory" • prepare custom layers for GPS • cell coverage model • subject mobility model • POA probability "heat map" • analysis based on elevation data: - create segments - assess segment difficulty - identify areas of avalanche risk - optimize radio repeater location - evaluate wind patterns for air-scent canine - viewshed, slope, aspect
Desktop mapping programs (T4)	• Print maps • customize maps • download GPS track logs • organize incident information • overlay, filter incident data	• general reference for context • draw search segments
Web maps (T5)	• Reference: orient to the search area while off-site, driving directions • View terrain in 3D: approximate the subject's perspective	• crowd-sourced OSM trails data • situation awareness for offsite search planners • View terrain in 3D: avalanche risk • Review an incident
Mobile apps (T6)		• report the phone's location • record track logs • reference • real-time tracking • same-place/same-time geocollaboration • cache map data for use without connectivity
Other (T7)		• receive transmitted location information from the subject
General (T8)	• possible subject scenarios: decision points, hazards, terrain traps • plan containment, search segments and logistics • plot clues, team locations, and completed assignments • documentation • common operating picture • transfer of command (ICS forms)	• remote support for planning

Addressing Research Questions #2 and #3, Table 19 presents a summary of limitations, advantages, suggestions for improvement, and notes relating to each form of technology. The table is followed by a short summary of advantages, limitations, and future directions for each technology.

Table 19: *Advantages, limitations, suggestions, and notes by technology*

Tech	Advantages	Limitations	Suggestions	Notes
Paper (T1)	Same-place/same-time (U6) + easy annotation + large format + detail across a large area + space to gather around + user interacts at their own pace Reliability (NFR9) + no batteries + no electronic failure Human Resources (NFR1) + familiar and preference Efficiency (NFR6) + quick access Usability (NFR7) + easy to use and learn	Geographic Information (MF1) - out of date - limited layers - static Cartographic Interaction (MF3) - limited precision - not scalable - no interaction with the data Documentation (U5) - single master copy may be lost Interoperability (NFR4)	Geographic Info. (MF1) • more up-to-date • more accurate or detailed Visual Representation (MF2) • include scale bar • improve graticule	Ability to print custom maps allows inclusion of more current data and control over both the visual representation and the material
GPS (T2)	Hardware (NFR8) + durable + batteries easily replaced Geographic Information (MF1) + accurate Gathering Situation Inputs (U2) + track logs	Hardware (NFR8) - small screen - poor display resolution Human Resources (NFR1) - training - availability of someone familiar with downloads Interoperability (NFR4) - cables Efficiency (NFR6) - downloads Usability (NFR7) - difficult to enter info. Cost (NFR2)	Interoperability (NFR4) Efficiency (NFR6) • wireless download • automatic settings sync Usability (NFR7) • user interface Hardware (NFR8) • larger screen • lighter weight • longer battery life	Standardizing equipment, when possible, improves
GIS (T3)	Geographic Info. (MF1) + greatest selection of data Visual Representation (MF2) + control over representation and map elements Data analytics (U3) + query data by location + modeling + spatial analysis Gathering situation inputs (U2) + nothing falls through the cracks + scalability	Human Resources (NFR1) - requires investment to learn - reliance on expert users Usability (NFR7) - difficult to use Cost (NFR2)	Usability (NFR7) Human Resources (NFR1) • awareness of GIS • training • availability of trained personnel Interoperability (NFR4) • integration with simpler programs	

***Table 19** (continued): Advantages, limitations, suggestions, and notes by technology*

Tech	Advantages	Limitations	Suggestions	Notes
Desk-top (T4)	Producing map products (U4) + printing custom maps Gathering situation inputs (U2) + downloading track logs Usability (NFR7) Familiarity (NFR1)	Efficiency (NFR6) - scalability Cartographic Interaction (MF3) - limited overlay, edit Human Resources (NFR1) - perishable skill Cost (NFR2) Geographic Information (MF1) - limited to built-in base data	Visual Representation (MF2) • ICS symbology Map elements Interoperability With GIS software	Strength in doing one or a few specialized tasks very well, then allowing interoperability with GIS
Web maps (T5)	Different-place Geocollab.(U7,9) + simultaneous edit Visual Representation (MF2) + oblique view Usability (NFR7) Documentation (U5) Outreach (U5) + public interface	Connectivity (NFR5) Geographic Information (MF1) -lack of detail -incorrect features Cartographic Interaction (MF3) - Limited edit and attributes -limited reproject Visual Representation (MF2) - Limited detail at smaller scales Human Resources (NFR1) - expertise needed for data transfer Cost (NFR2) of commercial incident management systems	Interoperability (NFR4) Cartographic Interaction (MF3) Usability (NFR7) • map printing templates Visual Representation (MF2) • ICS symbology Geographic Information (MF1) • support file formats	Potential beyond the immediate search task, including other parts of Cutter's emergency response cycle (e.g., mitigation, preparedness)
Mobile apps (T6)	Cost (NFR2) Usability (NFR7) Hardware (NFR8) + high resolution screen + camera Familiarity (NFR1)	Connectivity (NFR5) Hardware (NFR8) - durability - battery life Geographic Information (MF1) -position accuracy Not enough of a market in WISAR to support custom app/device development Cost (NFR2) of boosting signal	Interoperability (NFR4) • wireless data transfer (email or Bluetooth) Geographic Info. (MF1) • more base data included • GIS-friendly format support Same-time geocollab. (U6,8) • real-time data sync tracking User-centered design for WiSAR Connectivity (NFR5)	
General (T8)	Situation awareness Common operating picture Documentation	Human Resources (NFR1) - tech is only as good as expertise Cost (NFR2) - volunteers cannot afford to spend the time - can't develop and maintain free mapping tools - not enough of a market for research and development Institutional (NFR3) - access to information - lack of standards for exchange or aggregation of geog. Info - resistance	Human resources (NFR1) Geographic Info. (MF1) • more up-to-date data • high res. imagery • historic data • temoral component Distributed workload (across computers and users) • central data repository Automated coordinate transmission Real-time tracking	

Paper maps will continue to be a staple of the field team due to efficiency, non-dependence on power sources, and reliability. In the command post, the large format paper map may uniquely facilitate planning and situation awareness, particularly in the *same-place/same-time* (U6) geocollaboration context. The ability to customize and print maps during a search incident is an important factor in their usefulness, but paper maps will remain limited by their static form and relative lack of *interoperability* (NFR4) with other forms of mapping technology.

Like paper maps, GPS are a nationwide standard in WiSAR and are very familiar to WiSAR teams. They are needed for their durability, accuracy, and the essential ability to capture the precise route of a field team. They are limited by *interoperability* (NFR4) issues, such as a lack of support for custom uploaded layers, and related *efficiency* (NFR6) issues with data exchange, including data transfer exclusively by cable. *Usability* (NFR7) and *hardware* (NFR8) are potential areas for improvement, where GPS manufacturers might draw from new developments in mobile technology.

WiSAR needs do not often exceed the mapping functionality (MF1-5) offered in *GIS software* (T3); but GIS falls short in terms of non-functional considerations (NFR1-9). The advantages of information management, analysis, and scalability come at a cost of investment. *Usability* (NFR7) and *interoperability* (NFR4) improvements can boost the effectiveness of GIS software for routine tasks; however, *human resources* (NFR1) remain the greatest challenge to taking full advantage of its analytical capability. GIS skills should be recognized as a technical specialty within WiSAR, and volunteer teams should pursue ways to bring GIS experts into WiSAR. The *human resources* (NFR1) non-functional requirement encompasses not only expertise and training, but also the issue of awareness of GIS capabilities throughout WiSAR. As one participant stated, “more so than teaching people how to use GIS, there's teaching people what GIS can do for them.” The fact also remains that WiSAR searches extending past the first few operational periods are few and far between, which results in both little practice in deploying GIS and a reinforced perception of it as unnecessary—these may prevent GIS from being deployed in the critical instances when data management or analysis are key to ending a search.

Desktop mapping programs play an important part in the *efficiency* (NFR6) of at least two essential WiSAR tasks: (1) printing maps with some degree of customization and (2) downloading track logs. WiSAR teams also have widespread familiarity with these types of programs. Users do not need to be specially trained to use most desktop mapping programs, although they require practice to build and maintain proficiency. A desktop program that is strong in both *usability* (NFR7) and *interoperability* (NFR4) with GIS systems can prove useful by allowing users with limited proficiency to create or work with GIS-friendly data formats. Desktop programs may be best deployed to accomplish just a few tasks very well.

Given consistent and reliable internet access, web maps would be used much more commonly in WiSAR. Lack of connectivity will continue to limit their usefulness during the emergent event of a search; however, they have great potential to be used as-is more effectively in other parts of Cutter’s emergency response cycle (see Figure 1), such as documentation and public outreach. Many of the suggested mapping functionalities are either supported by existing tools—indicating a need for more familiarity with the available web mapping interfaces—or possible with some expertise in web maps; these could be made more accessible through tailored user interfaces for WiSAR. The need for offline mapping tools in WiSAR runs counter to the current trend in cartography towards web-based applications; therefore, the immediate search component of WiSAR may become a more isolated use case, and see less benefit from forthcoming advancements in cartography.

Overall, many participants expressed optimism about the potential of *mobile apps* (T6), but were hesitant to invest in or rely upon mobile technology due to *connectivity* (NFR5) limitations. There may be overlooked potential for the use of mobile devices in the command post as they offer the possibility for individuals to interact with a map at their own pace (a noted advantage of paper maps), combined with the possibility of better integration with digital file formats and live synchronization. Desirable features of mobile devices might be blended with the advantages of GPS devices to improve mapping technology for field teams. The increasing ubiquity of mobile technology helps to drive the development of features for compact devices (e.g., cameras, high-resolution screens) that the handheld GPS market did not support.

Other types of mapping technology (T7) are emerging and will have increasing relevance in WiSAR, especially location-reporting devices carried by the subject (e.g., cell phones, PLBs). WiSAR teams will need to build an understanding of the uncertainty and potential uses of these technologies. Overarching limitations of mapping technology included *human resources* (NFR1), *cost* (NFR2), and *institutional barriers* (NFR3). The most suggested areas for improvement across all technologies were *human resources* (NFR1), including training, availability, and awareness, and *geographic information* (MF1), with participants articulating a need for more or better base data.

5.2 Limitations

There were several necessary limitations to the research design that scope the findings and restrict the generalizability of results. First, the interview questions in this study focused on the 'search' component of search and rescue, or the 'Locate' component of the acronym LAST. It was evident from interview responses that mapping technology plays a significant role in other parts of the emergency response cycle, including documentation, preparedness, and prevention.

My concept-driven qualitative analysis represents only one of many possible ways to organize a large amount of interview data. The transcribed statements could have been organized in many other ways to reveal different themes not treated in this research. My coding scheme represents a simplified model of mapping technology for WiSAR: the discussed forms of technology rarely are clear-cut; the use contexts for these technologies are complex, overlapping, and constantly shifting; and the advantages and limitations of the discussed mapping requirements impact each other significantly in practice. Further, the coding scheme conflates related but not-identical concepts such as 'easy to use,' 'simple,' 'intuitive,' and 'user-friendly;' abstracting such terminology blurs the more nuanced opinions that participants expressed. My concept-driven coding scheme, derived from the literature, omitted some concepts that became evident during the coding process—notably the non-functional requirement *reliability* and the forms of technology designated as *other technology* (T7). The coding scheme also offered little differentiation within broad categories such as the *map product use* (U5) context or *general mapping technology* (T8), an active decision to keep the coding scheme manageable during qualitative data analysis.

Further limitations are linked to this study's sample of participants. The participant sample may be biased towards WiSAR specialists with a particular interest in GIS. Age of participants was not recorded, but some discussion pointed to age as a factor in familiarity and comfortability with certain forms of mapping technology (e.g., older WiSAR team members being less comfortable with GIS, and younger WiSAR team members being more familiar with mobile technology, less comfortable with paper maps, or too trusting of digital technology). Additionally, with a sample size of 24 participants, there were several important ideas that were each articulated by only one individual participant; thus, a larger sample size, or a different set of 24 participants, might have yielded slightly different results.

The environments in which this study's participants conducted WiSAR could be consistently described as varied terrain (e.g., mountains, canyons, hills). Most participants also dealt with WiSAR in forested areas. There are wildly different environments (e.g., desert, tundra, or humid-tropical) that are also considered wilderness or wildland, which may present different challenges for search and rescue.

5.3 Future Directions

This study describes current practice and opinions regarding mapping technology for WiSAR. The results suggest many future research directions. Refinement of lost person behavior and subject mobility models, and evaluation of the appropriate ways to use these models in search, would improve existing mapping functionality. Participants emphasized an understanding of the end user, indicating a need for user-centered design. One participant proposed a need for a system of plugin-based tools to allow WiSAR teams to choose specific mapping functionality to meet their needs.

Although I asked about all four geocollaborative situations, these use contexts did not appear as a major theme in my results. There are further research opportunities in examining use contexts, such as geocollaborative situations, in greater depth through participant observation of actual searches in progress. Wondering how other WiSAR teams put mapping technology to use, participants seemed to suggest a need for forums to discuss and compare their use of mapping technology with other teams across the country.

Considering the broader context of WiSAR as a subset of emergency response leads to questions about the applicability of developments in other fields. For instance, can WiSAR borrow and adapt mapping technology and practices from other fields of emergency response, such as wildland fire? What are the key ways in which WiSAR is different from those fields, and how might the borrowed mapping technology be adapted? Finally, one participant suggested that, rather than redesign mapping technology for WiSAR, WiSAR operations could be modified to take better advantage of mapping technology.

5.4 The Case for GIS in WiSAR

One participant stated that "searches are still solved by people out on foot, thrashing around in terrain. GIS is just a tool... it's not some magic something where technology saves the day." What GIS technology offers is another tool in the searcher's toolbox—a tool with unique advantages that no other form of mapping technology can replace. If GIS can help focus resources, spark a key insight, or streamline incident management, it may make an important difference in an emergency situation. As one participant put it, "any tool that is going to be there for the betterment of the search and the potential of saving that life, why wouldn't you use it?" GIS capability also can be a benefit to WiSAR teams outside of the emergent search event, supporting documentation, prevention, and preparation.

The challenges to GIS use in WiSAR are surmountable, and many efforts are already underway to improve the usability of, provide training in, contribute expertise from, and promote awareness of GIS. There also have been efforts to expand interoperability across mapping technology, working toward what I suggest is the ideal: not one prescribed system, but a range of compatible tools that leverage the benefits of several different forms of mapping technology, scale to meet the demands of an incident, and facilitate data aggregation across WiSAR incidents.

Glossary

Assignment. A designated task given to a field team during a particular operational period, consisting of a segment to be searched and instructions.

Cartographic interaction. Actions enabling the user to manipulate the geographic information or the representation of a map.

Command Post (CP). See incident command post.

Common operating picture (COP). Shared situation awareness.

Computer-Assisted Search Planning (CASP). A computer system used to estimate Probability of Area (POA) and allocate search resources. Used by the US military as early as 1974.

Containment. Measures taken to prevent the subject from leaving the search area.

Coordinate system. A notation used to describe any specific position on a geodetic datum.

Datum. See geodetic datum.

Distributed cognition. A framework that considers the role of an individual's surrounding environment and objects therein during reasoning, in which the human reasoning process can be supported and extended by interaction with external artifacts.

Field team. A group of searchers deployed to look for the subject in the physical space of the search area. Field teams may traverse the area by foot, or may use a form of transportation, such as horseback, ATV, snowmobile, or helicopter.

Found location. The geographic location at which the subject of a search is found.

Functional requirement. In software engineering**,** the operations software must perform, or what the software must *do.* In this study, extended to include all mapping technology (not just software).

Geocollaboration. The process of multi-person problem solving using geographic information.

Geodetic datum. A reference shape, often a spheroid, used to represent the Earth's surface.

Geographic information. Information with a location component.

Geographic coordinates. A coordinate system using latitude and longitude.

GIS functions. Spatial analyses which calculate new geographic information; performed by a GIS software.

Global Positioning System (GPS) device. A device which connects to satellite systems to sense the user's geographic location.

Hasty search. Part of the initial actions, in which groups of searchers are deployed to the field to look for the subject as quickly as is reasonable. Phillips et al. (2014, 169) note that "the term [hasty] refers to deployment of resources and not to the tactic of actual searching."

Incident Command Post (ICP). The location from which emergency response operations and resources are coordinated.

Incident Command System (ICS). A system for designating the authority and responsibilities of emergency response personnel. See Incident Commander and section chief.

Incident Commander (IC). Within the Incident Command System (ICS), the person responsible for the overall response activities in an emergency response situation. Oversees the section chiefs.

Initial actions. The first actions which are carried out at the beginning of a search. Synonymous with reflex tasking.

Initial Planning Point (IPP). The geographic location used to plan a search, at which the subject was most recently believed to be present. May be the Last Known Point (LKP) or the Point Last Seen (PLS).

Interaction operator. A basic interface function that enables map users to manipulate the visual representation of a map according to their needs.

International Search and Rescue Incident Database (ISRID). A collection of search and rescue incident data from around the world.

Last known point (LKP). The location at which the subject of a search was most recently believed to be present, as suggested by some indication of the subject's presence such as their car at a trailhead parking lot or their signature in a summit ledger. See also Point Last Seen (PLS) and Initial Planning Point (IPP).

Lost person behavior. An area of study concerned with the behavior of search subjects. Also the title of Koester's 2008 book on the subject.

Map elements. Common features of maps. Slocum et al. (2009) list eight common map elements: frame line and neat line, mapped area, inset, title, legend, data source, scale, and orientation.

Mattson consensus. A method of assigning POA to partitions of the search area (and ROW) in which several SAR specialists independently assign POA values, and these values are averaged.

Military Grid Reference System (MGRS). A coordinate system derived from the Universal Transverse Mercator (UTM) coordinate system. The MGRS references the UTM grid, but specifies different alphanumeric codes to describe location. See also United States National Grid (USNG).

National Incident Management System (NIMS). A standard approach to managing incidents in the United States, established by the Federal Emergency Management Agency (FEMA).

Non-functional requirement. In software engineering, a condition or constraint of software beyond its functional requirements that impacts its viability and adoption. In this study, a condition or consideration beyond the mapping functionality of a technology that impacts its viability and adoption.

Operational period. A period of time, often 12 or 24 hours, used in the National Incident Management System to plan emergency response actions.

Point last seen (PLS). The location at which the subject of a search was most recently seen, as verified by an eyewitness. See also Last Known Point (LKP) and Initial Planning Point (IPP).

Preventative search and rescue (PSAR). Measures taken to prevent the need for search and rescue operations.

Probability of area (POA). The probability that the subject is present in an area. Related to probability of detection and probability of success by the formula: $POS = POA \times POD$.

Probability of detection (POD). The probability that the subject would have been detected, had they been present in an area that was searched. Estimated after an area has been searched. Related to probability of area and probability of success by the formula: POS = POA × POD.

Probability of success (POS). The probability of the subject being found. Related to probability of area and probability of detection by the formula: POS = POA × POD.

Raster data model. A geographic data model consisting of a grid of cells comprehensively documenting space.

Reflex tasking. See initial actions.

Reporting party. The person who reported the subject as missing.

Rest of the world (ROW). Anywhere outside of the search area.

Search and rescue (SAR). An emergency situation in which trained professionals are called upon to locate a missing person(s) and assist them to safety.

Search and Rescue Optimal Planning System (SAROPS). A computer system used by the US Coast Guard to estimate Probability of Area (POA) and plan for search operations at sea.

Search area. The geographic region which the subject is believed to be within. The geographic compliment is ROW (rest of the world).

Search manager. A person designated to manage a search. May or may not also be the Incident Commander (IC). In WiSAR, the IC may be a law enforcement official with little WiSAR experience, while the search manager may be a volunteer with WiSAR experience who is not given legal responsibility for the search.

Search segment. An area that is designed to be searched by a single field team during one operational period. WiSAR search segments often are irregularly shaped, as opposed to rectilinear grid cells. See Figure 3.

Search theory. A system developed in the 1940s to aid in the location of enemy submarines. Origin of the concepts Probability of Success (POS), Probability of Area (POA), and Probability of Detection (POD).

Section chief. A person designated to manage one branch of the Incident Command System (ICS). The typical branches are Plans, Operations, Logistics, and

Administration or Finance. Branches and their section chiefs are designated as needed; a small operation may not require all branches.

Situation awareness (or situational awareness). A holistic comprehension of information that is relevant to a situation, contributing to the ability to anticipate imminent events and respond according to incident management goals.

Subject. In this study, the term 'subject' is used to denote the missing person, or the subject of a search.

Terrain traps. Locations that the topography might funnel a moving subject into, based on likely routes or paths of least resistance.

Track offset. In land-based SAR, the minimum distance between the found location and the nearest linear feature.

United States National Grid (USNG). A coordinate system derived from the Universal Transverse Mercator (UTM) coordinate system. The USNG references the UTM grid, but specifies different alphanumeric codes to describe location. See also Military Grid Reference System (MGRS).

Universal Transverse Mercator (UTM). A coordinate system consisting of a 2-dimensional grid.

Vector data model. A geographic data model consisting of points, lines, and polygons in otherwise undocumented space.

Visual representation. The graphical depiction of a map or its map elements. **Visual variable**. The visual dimensions by which a graphic can be varied to encode information. See Table 3 and Figure 5.

Wilderness or Wildland Search and Rescue (WiSAR). Search and rescue that occurs in largely uninhabited land regions lacking access to manmade amenities, such as shelter and medical facilities. Wildland settings include rural areas, large public spaces such as National Parks, wilderness areas, and mountainous terrain, but also may include urban environments in the wake of a large-scale natural disaster, such as an earthquake or hurricane.

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