Wilderness Search and Rescue: Sources and Uses of Geospatial Information

28 April 2013

Loren D. Pfau

Penn State University MGIS Candidate

Abstract

Wilderness Search and Rescue (SAR) is concerned with locating, treating and transporting lost or injured parties, often in remote and difficult to access terrain. The nature of these activities requires the use of geospatial data and tools. Although, SAR teams still rely primarily on paper topographic maps during each search, there has been an increase in the availability of geospatial data from a variety of sources (e.g. e911, cellphone, personal locators and a variety of social networks (e.g. Facebook and Twitter). In addition, a variety of GIS technologies are available, ranging from traditional desktop systems (comprising full analytical capabilities) to numerous web-based and smart phone applications (mainly used to present information with limited analytical capabilities) offering the ability for the integration and analysis of geospatial data, both of which are useful for wilderness SAR. Thus the purpose of this study was to evaluate data and technology that can be effectively used in wilderness SAR and determine what will be appropriate for volunteer-based SAR organizations to use that have limited resource and limited GIS expertise during time-sensitive missions?

A survey was conducted to determine the types of data and tools that are currently used by different SAR teams (N=72 complete responses). Several technologies were evaluated during field missions by Alpine Rescue Team in Evergreen, Colorado during July and August 2012. The findings from this study showed that the majority of SAR teams used electronic mapping programs and paper maps for mission planning and management instead of full GIS systems (all use paper maps; four electronic mapping programs were all used more frequently than any full GIS package). Current barriers to teams adopting full GIS were as a result of cost, complexity of the software and the lack trained personnel. Though GIS can provide more sophisticated analyses of geospatial data than the simpler mapping technologies its use may not be required on all missions, since the majority of missions (92%) were completed within 10 hours. Instead, new technologies such as tablets with mapping software and online GIS systems that provide easy and quick access to geospatial data offer capabilities that may improve mission planning and do not require a significant effort to learn to operate. In addition geospatial data from SAR missions should be collected and analyzed at the team level to identify “hotspots”, improve lost person behavior, aid in training, familiarization and planning activities. Efforts should be undertaken to develop a common data collection format that could be utilized by many teams and aggregated for analyses to benefit the SAR community.

In conclusion, new geospatial tools and data sources are developing rapidly, and offer the possibility of improving the efficiency and outcomes of missions. Keys to successfully employing them will be recognizing the value, and limitations, of these new tools and learning how best to integrate them into SAR operations.

Keywords: wilderness search and rescue, GIS, lost person behavior, geospatial technology, geo-location data, web-mapping, smartphone, tablets, interactive maps, time-sensitive mission, emergency response and crisis management

Introduction

Wilderness search and rescue missions are time critical with survival rates decreasing over time. Each year millions of people visit national, state and county parks enjoying a variety of outdoor activities. Of these a small percentage are reported missing. Between 1992 and 2007 a total of 65,439 Search and Rescue (SAR) missions were conducted in National Parks in the US (3% fatalities, 31% ill or injured persons, and 66% non-injured or ill persons) (Heggie and Amundson 2009).

Search and Rescue (SAR) is both an activity and body of knowledge devoted to locating lost or missing persons, rendering aid and if necessary transporting the individuals to a place of safety. Although the terms search and rescue are interrelated they are distinct activities (Stoffel 2005). Rescues usually entail a subject at a known location, while search is the process of locating a missing person "*alive and in as short a time as possible*" (Koester 2008) that has both spatial and temporal components that influence how it is planned and managed (Doherty 2011).

Most people will be familiar with SAR operations in an urban environment (e.g. e911 for ambulance, fire, police) where locations are usually well-defined, such as by an address, a cross street or mile marker on roads (Nortel 2008). When an incident occurs it is relatively easy to locate the subject(s) to dispatch emergency crews for a response. In a wilderness SAR situation this is quite different. Communications in a wilderness setting are often extremely difficult where cellphone coverage is not assured (Keech 2007), thus limiting and excluding the ability of using voice (e.g. e911) and data communications (e.g. twitter, texting etc.) capabilities. Therefore, a person's location is often not precisely known other than through secondary information such as which trailhead the person parked their car; an acquaintances' vague notion about what the person had planned; or perhaps a signature at a summit register (Stoffel 2005, Ferguson 2008). However, where cellphone coverage is available, there has been an increase in the reporting of accidents (e.g. in Grand Teton National Park where 70% of reports are by cell phone (Johnson 2004)) resulting in a threefold effect on rescue operations and in some cases leading to increased use of SAR for minor situations (Medred 2011).

Approximately 93% of SAR missions are completed within 24 hours, with 50% completed within 3 hours and 81% taking between 3 to 12 hours to complete (Koester 2008). As missions exceed 24-hours survival rates decrease, for example to 38% for children aged 4-6 years and to 76% for hikers (Koester 2008). Without the ability to respond to SAR incidents, these fatalities would be 20% higher (Heggie and Amundson 2009).

Search and Rescue operations are comprised of three interrelated activities, SEARCH, RESCUE and RECOVERY, that are fundamental components in emergency management response systems (see (Cova 1999, Johnson 2004, Roche et al. 2011) for examples). During a typical wilderness SAR mission a number of steps are required (Figure 1). Firstly, an **(1)** I**nitial Trigger** where the missing person is reported (e.g. through e911 call, satellite-based emergency notification devices such as a SPOT Personal Communicator or a Personal Locator Beacon) is followed by **(2) Information Gathering** (e.g. obtaining information on person's planned route, activities etc. as well as checking parking lots for missing person vehicle, obtaining current weather reports) resulting in a **Search Decision**. If a SAR mission is required, decisions need to be made as to whether the response should be immediate or delayed. If it is necessary to **(3) Conduct a Search** the SAR team will continue to gather information (e.g. location information from a variety of maps, incorporate local knowledge, obtain weather forecasts, assessment of lost persons (e.g. age, experience, medical information etc.)) that will be used to plan and develop a strategy to find the person. Searches are prioritized within areas, utilizing search theory (based on the work by (Frost 2000, Cooper et al. 2003, Stoffel 2005, Ferguson 2008, Koester 2008, Perkins et al. 2011)) and lost person behavior (Koester and Stooksbury 1995, Koester 1998, Koester 2008, Perkins et al. 2011). Essentially the probability of successfully finding a person (POS) is attributed to the probability the person is in the search area (POA) and the person will be detected (POD) (for details see (Ferguson 2008)). On **(4) Completion** the mission will be logged and a debriefing held to improve future missions (see (Johnson 2004)).

A critical component to the SAR mission is gathering detailed knowledge about the area where the person may be lost. Wilderness SAR organizations use a wide variety of data from disparate sources and have access to an ever increasing volume of geospatial information in both digital and non-digital formats (e.g. USGS paper topographic maps, tourist maps, Imagery available through Google Earth and Google Maps, OpenStreetMap (http://www.openstreetmap.org/) and local websites (e.g. in Colorado - http://14ers.com/) locator information from e911 calls and Emergency Locator Transmitters including emerging sources such as SPOT locator beacons as well as through social media sites (e.g. Facebook and Twitter). Therefore, a challenge facing SAR teams lie in understanding what information is available, reliability of information; how to access information; and utilize, manage and integrate these different data types during time-sensitive missions both during the planning stages as well as in the field.

Although, GIS is not used by all SAR organizations it is increasingly being used for the management of SAR missions (Theodore 2009). Due to the ability to integrate, manage and analyze geospatial information GIS systems have been used for a wide range of emergency management applications (e.g. wildfire management (Ramsay 2010, Brewin 2011)); optimize search and rescue by the US Coast Guard (Netsch 2008); Avalanche mitigation and forecasting ((Scott 2009, McCollister and Birkeland 2010); and analyzing the spatial distribution of 911 calls (Rosenshein and Scott 2011).

Environmental Systems Research Institute (ESRI), a leader in the GIS industry, has also been an active proponent and developer of using GIS in emergency management (Johnson 2000) and is extending this to include SAR (Doherty and Rudol 2007, Ferguson 2008, Doherty et al. 2011). For example, in Yosemite National Park GIS has been used to manage large search efforts since 2007. GIS has been used to not only manage base maps and imagery data but also to define search area segmentation (Doherty 2011, Doherty et al. 2011). Due to the analytic capabilities of GIS there has been an increase by SAR teams to use this type of technology. For example, Russo (2004) demonstrated how GIS capabilities could be used to pinpoint the most probable location of a lost snowboarder by using cell phone information and elevation information in GRASS. In addition, the Mountaineer Area Rescue Group in West Virginia is using GIS as a search management tool (Ferguson 2008) which uses lost person behavior statistical data with a variety of layers such as imagery and elevation to allow search managers to segment and prioritize search areas, plan search strategies, and document clues and search patterns, enabling for quick decisions to be made. Although the features contained within a GIS are highly useful for SAR (i.e. visualization of search area, integration and management of variety of data sources, documentation of

SAR mission, modeling and analytical capabilities) related activities many SAR teams have been slow in adopting this technology (Russo 2004, Ferguson 2008). There are likely many reasons for this and may include that 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 (Russo 2004). Of the 94 teams that currently comprise the Mountain Rescue Association (MRA), 82% are volunteer teams {MRA, n.d. #152}. To help overcome this barrier a new effort is being established to train SAR teams about GIS and how this technology can be used in SAR missions. As a result, ESRI has developed SAR-specific toolset, MapSAR, an extension that can be added to ESRI's ArcGIS software (http://www.mapsar.net/)(Pedder 2011d, Pedder 2011b, Pedder 2011a, Pedder 2011c, Durkee and Glynn-Linaris 2012)).

Many of the aforementioned examples utilize traditional desktop based GIS systems that have full analytical capabilities making it easy to implement complex models for determining lost person behavior and search theory planning. However, as Internet and wireless connectivity have improved new forms of geospatial and GIS applications have emerged, offering enhanced geo-location based capabilities to users of smartphones, tablets and other mobile computing devices (Vermes 2006). Many of these devices use global positioning system or other location identification techniques (e.g. cell tower or Wi-Fi hotspot positioning) that enable users to access a large range of location-based services such as providing easy and accurate updates to social media websites such as Facebook and Twitter. These data can then be accessed through a variety of tools, many of which now have mapping components (e.g. GeoChirp (http://www.geochirp.com/); TrendsMap (http://trendsmap.com/) and Twitterfall (http://twitterfall.com/)).

So with a variety of GIS technologies available, ranging from traditional desktop systems (comprising full analytical capabilities) to numerous web-based and smart phone applications (mainly used to present information with limited analytical capabilities) what will be appropriate for volunteer-based SAR organizations that have limited resource and limited GIS expertise? The purpose of this study was to evaluate what data and technology can be effectively used in wilderness SAR during the different SAR stages (see Figure 1 and described earlier). To accomplish this a variety of data and technologies were evaluated by the Alpine Rescue Team, based in Evergreen, CO. Alpine Rescue Team (ART) is the only nationally accredited mountain rescue team in Colorado with memoranda of understanding to provide search and rescue services with three different county sheriffs (Clear Creek / Jefferson / Gilpin) covering approximately 1309 square miles (Figure 2). At a national level, ART meets the 2004 FEMA Standards as a Type 1 Mountain Rescue Team. The team is also one of only twelve mountain rescue teams in the state of Colorado that is fully accredited by the MRA (http://www.mra.org/), an international organization of teams specializing in mountain search and rescue, and safety education (Alpine Rescue Team, n.d.). The author of this paper is a long-time member of the Alpine Rescue Team (ART) and was able to access team mission records for the purpose of this study.

In the context of wilderness SAR this study attempted to address the following questions:

- Evaluate data and technology that can be effectively used in wilderness SAR?

- What will be appropriate for volunteer-based SAR organizations that have limited resources and GIS expertise?

Methodology

Survey

To determine how different SAR teams employ geospatial data and tools to plan missions, a survey was conducted to understand what data is currently being used and identify limitations in the uptake of GIS type technologies. A survey was created in SurveyMonkey (http://www.surveymonkey.com/) composed of 24 questions (see Supplementary Information for details). The survey was posted on the Mountain Rescue Association's listserver (http://ml.islandnet.com/mailman/listinfo/sar-l) from 2 – 22 March 2012.

Application of Geospatial Technologies to Wilderness SAR

Based on Koester (2008) 50% of searches are completed in less than 3 hours, 81% are over within 12 hours and 93% are completed within 24 hours. In some cases, GIS type tools maybe too complex to be employed for short duration operations. However, many SAR groups, including Alpine Rescue Team, may be able to benefit from using less comprehensive mapping technologies. To evaluate this, GIS based technologies were used during real missions and assessed based on a variety of factors that include cost, ease of use, training requirements, functionality, data requirements and ability to share maps and data. Four GIS based technologies were investigated that include (1) the use of a full GIS with advanced analysis (e.g. ESRI™ ArcGIS), (2) a web-based GIS solution and (3) use of mobile device and compared to (4) electronic mapping software currently utilized.

(1)Utilizing desktop GIS Solution

To use the full functionality of a GIS required the development of a minimum essential data set that included physical geographies (e.g. topography, elevation, water bodies, and imagery), infrastructure data (e.g. roads, trails, entry points, camping and picnic locations) and ART SAR mission data. Data were acquired from a variety of sources and analyzed in ESRI™ ArcGIS ArcView 10. All data was converted to NAD 27 datum and UTM Zone 13 projection if not natively available in that format.

***(a) Physical geographies*,** such as topography, elevation and water bodies were obtained from a variety of sources. Topographic maps were obtained from the USGS *The National Map* Store (http://store.usgs.gov/b2c_usgs/usgs/maplocator/(ctype=areaDetails&xcm=r3standardpitrex_prd&carea=%24ROOT&layout=6_1_61_48&uiarea=2)/.do) at 1:24000 scale. Digital elevation for the study area was obtained from the USGS (GTOPO30 (http://www1.gsi.go.jp/geowww/globalmap-gsi/gtopo30/gtopo30.html)) at a 1 km resolution. Imagery data were obtained from the USDA National Agricultural Information Program (NAIP) (http://datagateway.nrcs.usda.gov/) at 1 meter resolution. Lakes and streams came from the Colorado Department of Transportation (CDOT) Data Catalog (http://dtdapps.coloradodot.info/otis).

(b) Infrastructure data, such as roads, airports, railways and county boundaries were obtained from the Colorado Department of Transportation (CDOT) Data Catalog (http://dtdapps.coloradodot.info/otis), while national forest assets (e.g. trails, roads and recreational areas) came from the National Forest Service Rocky Mountain Region Geospatial Library (http://www.fs.fed.us/r2/gis/datasets_unit.shtml). All of these data were available in ESRI shapefile format.

(c) ART historical mission data. An important component of SAR operations includes understanding the behavior of a lost person. A number of studies have analyzed incidents data (Kelley 1973, Koester and Stooksbury 1995, Koester 1998, Twardy et al. 2006), resulting in both qualitative and quantitative profiles of lost person behavior by categories of subject type (e.g. hunter, child, climber, etc.) and terrain/climate (e.g. temperate, dry, mountainous, etc.) (Koester 2008, Perkins et al. 2011) and mental state (Koester and Stooksbury 1995, Koester 1998). The most comprehensive database containing search-related missions is held in the International Search and Rescue Incident Database (ISRID) (dbs_Production 2011) which has over 50,000 records as of 2008 collected from search and rescue missions from different parts of the world, such as Australia, Canada, New Zealand, South Africa, Switzerland, United Kingdom, and the USA. This database contains information on subject type, search time (i.e. time it took to find the person when the search was conducted, distance traveled, weather conditions and other search-related data attributes (Koester 2008). To help SAR groups collect information, an Excel spreadsheet is available from http://www.dbs-sar.com/SAR_Research/ISRID.htm.

To help standardize digital data collection and provide the team with the ability to feed back into the ISRID database data, a modified version of the aforementioned spreadsheet was used. SAR missions conducted by ART recorded in paper format, has not previously been analyzed. Data from paper records were manually entered into a modified version of the aforementioned spreadsheet. During the transfer of information it became clear that not all of the data fields were relevant and some additional fields were required. A total of 32 attributes were used to collect information on SAR missions between 2008 and 2011, as contrasted with the 26 used in the standard ISRID database (See Table 1). Additional fields include place last seen (PLS), found location (UTM coordinates) and altitude (meters). Although ISRID already includes information on distance travelled and change in altitude from PLS to Found Location, it was not required to include the coordinates of these locations. Providing these additional details are useful for calculating the necessary ISRID metrics as well as for allowing for mapping and analyzing the data spatially in GIS-related software applications, such as ESRI ArcGIS. A total of 383 missions were conducted between 2008 and 2011. Of these 135 records were used in this study and imported into imported into ESRI™ ArcGIS ArcView 10 and will be referred to as SAR mission data. The remaining 248 missions were excluded for a variety of reasons that include: missions were in support of other SAR teams (i.e. outside of the team's 3-county response area) and did not represent typical response areas; missions in which the subject extricated him- or herself, or which were located by bystanders or law enforcement, prior to team members being inserted into the field; and missions in which subject location data was missing.

To analyze the spatial distribution of SAR missions point pattern analysis methods that have successfully been used to analyze the spatial distribution of 911 calls (Rosenshein and Scott 2011) were employed. Kernel density estimates were used to create surfaces to easily identify areas where incidents of lost persons were concentrated throughout the study area. Additional analysis included calculating changes in height between PLS and Found Locations. Analyzing displacement between lost and found locations was performed by connecting PLS and Found Locations through the use of the XYLine tool in ArcGIS. This allowed for the observation of connectivity between points, directional movement and to calculate the distance between PLS and Found locations to examine movement.

(2) Web-based GIS solutions

Mashups are web-based geospatial depictions a combination of information from multiple sources displayed on a single map (Gupta and Knoblock 2010). Mashups have been used in recent events such as the 2010 Four Mile Canyon fire near Boulder, CO, to allow users to view houses that were destroyed by the wildfire and help those in need to find the locations of shelters (Ramsay 2010) Ushahidi (http://www.ushahidi.com/) used mashups to depict the impact of the Haiti earthquake (Meier 2012)and Pakistan floods (http://pakreport.org/ushahidi/) through the collection of information from multiple sources (e.g. Twitter, SMS, email). Data were collated and displayed on a web-based map to help disaster response teams deliver relief aid more efficiently (Sutter 2010). This type of map was extremely useful during the earthquake in New Zealand in 2010 to help locate nearby emergency services (Roche et al. 2011) and during the 2011 Japan earthquake and tsunami to provide information on radiation levels from the damaged nuclear reactor sites (see http://geocommons.com/maps/61424; http://map.safecast.org/).

Online mapping tools such as ArcGIS Online (http://www.esri.com/software/arcgis/arcgisonline/) offers the ability to build a database that integrates data from a variety of sources (e.g. ESRI basemaps provided through map services (http://www.esri.com/software/arcgis/arcgisonline/services/map-services), spreadsheets (e.g. ART historical mission data), and ESRI shapefiles (see data described above)). The data can then be shared through easy to use interfaces through a URL. Since the maps are interactive, users are able to view and query data and attributes as well as perform simple tasks such as measure distances and delineate areas and features through basic drawing tools. For the purpose of this study ESRI's ArcGIS Explorer Online, a mapping tool that is part of ArcGIS Online, was used. An online account was created for the ART and customized and stored within the ArcGIS Online My Content section. Bing Maps Hybrid was used as the basemap due to its high resolution imagery and roads overlay. Additional layers provided through ESRI's web service including the USA Topo Maps layer to provide users with a view of the terrain and trails. In addition, new lost person location information was added as a point feature directly within the tool. Team mission leaders were provided access to the mission maps with instructions on how to use ArcGIS Explorer Online. Each map stored by its author has a unique name and URL. Maps and data can only be altered permanently by the owner of the account and members of the ART group that has been granted editing privileges, thus maintaining the integrity of the data.

(3) Utility of mobile devices

Currently paper topographic maps (scale and source) are used in the field. For the region covered by ART, 38 USGS 1:24,000 topographic maps are required to cover the entire region. While a minimum of 1 map is required during a single mission, an old SAR adage is that the area of interest will always be at the intersection of four quads. Electronic versions of the USGS topographic maps are now available for download in pdf format for use on a PC (http://nationalmap.gov/ustopo/index.html).

For the purpose of this study, the "Trimble Outdoors Navigator" application was utilized (https://play.google.com/store/search?q=trimble+outdoors+navigator) on a Google Nexus 7 tablet. The USGS topographic maps and satellite imagery were downloaded from Trimble's online service and cached on the tablet through Outdoors Navigator. Thus enabling 38 USGS paper topographic maps, covering ART's 3 county primary response area (covering 1320 square miles - see Figure 2), to be viewed seamlessly.

(4) Electronic mapping software

Alpine Rescue Team currently uses two software packages during search and rescue missions: Terrain Navigator Pro (http://maptech.mytopo.com) and OziExplorer (http://www.oziexplorer.com). These packages allow for the display of maps, upload and download of tracks/routes and/or waypoints from GPS units used during SAR missions, provide simple distance and area measurements, and 3D terrain views using digital elevation models. In addition, field team positions are monitored through the amateur radio tracking technology Automated Packet Reporting System (APRS) ((Bruninga 2011)). Team members are issued amateur radios connected to a GPS unit which periodically transmits the GPS fix to another amateur radio connected to the mapping software. The GPS fix is uploaded to the map to display the current position. A weakness of this system is that it requires line of site between radios in order to maintain connectivity. For field teams without APRS units, or which have lost connectivity, positions are periodically obtained from a handheld GPS and coordinated radioed to operations.

Terrain Navigator Pro topographic maps are included on the DVD's used to install the program on a PC. Additional aerial imagery of areas of interest may also be downloaded and stored on a PC hard drive. OziExplorer does not come with any prepared maps or imagery, rather users must download or procure topographic maps and imagery from various sources and georeference the data. Similar to a GIS, while there is initially more work to collect and prepare the data, once completed a seamless view of the response area is possible. Since the data are integrated into the system they are able to operate in a disconnected mode. Although, these electronic mapping software packages are less technically challenging than full GIS packages some level of training is required.

Results

Survey

A total of 74 respondents out of 122 completed the survey. The majority of the participants were from the USA (91.8%) with the remainder from Canada, Australia, the United Kingdom and South Africa.

The three primary datum's used by SAR teams include NAD 27 (47%), WGS 84 (41%), and NAD 83 (12%). The primary coordinate system used is Universal Transverse Mercator (UTM) (72%) followed by geographic coordinates (26%). One percent of the teams use the US National Grid and Military Grid Reference System.

The most commonly used GIS technologies include Google Earth (55 respondents), MapTech Terrain Navigator (45 respondents) and National Geographic Topo (20 respondents) with few using GIS software packages with full analytical capabilities (15 respondents) (Figure 3a). Of these the top three are visualization or electronic mapping packages rather than a GIS with advanced functionality. The key reasons why some groups did not use GIS or electronic maps (N=7) included that they were "*Too Difficult to Use*"; "*Too Costly to Purchase, Train or Maintain*"; and that there was "*Lack of Expertise with the Organization to Operate*."

Geospatial data typically used during a SAR missions ranged from paper maps, clue and field team locations, weather forecasts and aerial imagery while digital elevation models, terrain coverage models, avalanche forecasts and geo-tagged photos were less used (Figure 3c). The use of avalanche forecasts may be limited to teams that operate in areas where avalanches are prevalent.

The most used sources of geospatial data for SAR missions include wireless e911 calls and personal locator technology (e.g. Personal Locator Beacons, SPOT, InReach) while geo-tagged photos and social media sources (Figure 3b) were less frequently used. Of these there was a *"strong understanding"* about SPOT, Personal Locator Beacons and wireless e911 with "*some understanding"* of Twitter, Facebook, geo-tagged photos and smartphone apps and *"no understanding"* of InReach.

SAR mission data for the Alpine Rescue Team

Within the ART study area between 2008 and 2011, 49% of the missions were rescues; 32% were searches (including lost person were 39%) with the remaining 19% a combination of missing persons, recoveries, and SPOT activations (Figure 4b). The missing person category, although a type of search, is typically initiated by law enforcement for individuals with dementia, despondent, etc. Of these 49% of the subjects were uninjured, 41% injured and 10% were deceased (Figure 4a).

The majority of the missions occurred during the summer season (Figure 4c). Mission durations varied from 2 to 24 hours (Figure 4d). Seventy-five percent of the missions were completed within 6 hours, 92% within 10 hours and 100% within 24 hours.

Application of geospatial technologies

Three GIS based technologies were evaluated during ART search and rescue missions, alongside the existing mapping software used. The results of how they were used are presented next.

Desktop GIS - The desktop GIS with full GIS functionality was used to analyze the ART mission data and perform adhoc analysis during field missions. Analysis of the data revealed that the average distance travelled by lost persons was 4.5 kilometers (ranging from less than 1km to over 49km (Figure 5a)) and the average change in elevation was 265 meters downhill (ranging from -1200m (downhill) to +1000m, Figure 5b). Spatial analysis of the ART data highlighted several key areas where people were lost (see Figure 5c).

During July 2012 the desktop GIS was used to perform an adhoc analysis on a lost hiker between the Colorado peaks of Mount Bierstadt and Mount Evans. To help locate the hiker, the Civil Air Patrol developed a viewshed analysis to identify the areas in which the hiker was most likely to be based on the location of the cell tower that the missing hiker's phone had last connected and a digital elevation model of the mountains. The viewshed analysis coupled with reports of his intentions and witnesses who had seen him on the mountains was able to narrow down the search area (Figure 6a). The hiker was found deceased in approximately 18 hours from the time he was reported missing.

Web-based GIS and Mashups Solutions - ESRI's ArcGIS Explorer Online application that was created for the ART was used during a mission in August 2012 to help locate a lost mountain biker through a wireless e911 call. At the time of the call, a large thunderstorm was in progress which precluded the fielding of any team members. However, four ART mission leaders utilized the ESRI ArcGIS Explorer Onlineapplication to view imagery, trails and National Forest Service roads of the area where the biker was lost (Figure 6b) to identify an access point near to the biker's last known location. The ART team, without the need to be dispatched, successfully guided the Sheriff's Deputy to a point near the biker's position so that he could be picked up. The biker was found in approximately 1.5 hours.

Tablet Mobile device – Having access to the full suite of USGS topographic maps has been extremely useful in a field environment without internet connectivity. The tablet is currently used to start mission planning by 3 out of 14 ART mission leaders. Although initially tested on a Google Nexus 7, 2 mission leaders are now also using the Trimble software on Apple iPads (Figure 6c).

Electronic Mapping Software - Terrain Navigator and OziExplorer remain the standard packages employed by ART to manage SAR missions. They have the ability to depict the maps and imagery of the response area as well as capture waypoints and tracks and provide the ability for basic analysis tasks such as measuring distance and area. The APRS interface software gives mission leaders the ability to view near real-time positions of field teams on an automated basis.

Discussion and Conclusions

With increasing availability of data, the aim of this study was to investigate what data and technology can be used effectively in volunteer-based wilderness search and rescue groups with limited resources. Search and rescue activities rely heavily upon geospatial data with many SAR organizations using a wide variety of data from disparate sources (see Figure 3a-c) ranging from paper maps to a variety of electronic geospatial information (e.g. e911 calls, Emergency Locator Transmitters), as well as new sources such as the SPOT locator beacons and social media data (e.g. Facebook and Twitter).

Several electronic mapping programs, such as Maptech Terrain Navigator, National Geographic Topo and Delorme Topo North America, are frequently utilized by SAR teams over and above GIS software packages. Although, these mapping packages do not have the full analytical capabilities offered by a full desktop GIS software package (e.g. create data, analyze data, perform complex spatial operations such as spatial queries and layer merges), they are able to integrate data captured in the field (e.g. GPS tracks and waypoints (including attribute information collected)) and display multiple layers (e.g. topographic maps and aerial imagery) as well as perform analytical tasks such as provide 3D views and measurements of distances and areas.

The fact that teams are able to conduct successful operations using these mapping packages indicates that the functionalities common in many full GIS packages is not a necessity for all search and rescue missions. Since most SAR missions are completed within a single operational period ((75% completed within 6 hours, 92% within 10 hours and 100% within 24 hours) as found in this study and other studies (81% in less than 12 hours, 94% in less than 24) (Koester 2008)it may not be feasible to use a full GIS package at all times, as demonstrated in this study (e.g. use of on-line maps to view a variety of information to find the lost mountain biker versus more complex adhoc analysis performed in a full GIS package). Instead a combination of geospatial tools with varying levels of analytical capabilities can be used ranging from basic through to advanced (Figure 7) depending on the level of expertise and complexity of missions within the different SAR teams and mission areas. Even when a full GIS solution is available the nature of the SAR mission will dictate the appropriate tools to be employed. So as a mission becomes more complex, and/or teams become more sophisticated in their use of geospatial tools, there can be a move to the use of more complicated tools. These may be ad hoc analyses, such as viewshed analysis of cellphone coverage, to the adoption of a full SAR mission management ArcGIS-based package such as MapSAR.

Different data are needed as search and rescue missions progress (see Figure 1). Having easily accessible geographic information, either through on-line maps or tablets, to aid during the initial trigger and search decision stages is essential for planning (basic level, Figure 7). As the search is conducted the need for additional data and sources may vary depending on the complexity of the search and may require basic to advanced level of information and analysis (Figure 7). Finally, once the mission has been completed, during the post analysis and debriefing having the ability to view and analyze the outcome of the mission (e.g. PLS and Found Location with tracks of the team) are useful.

Since SAR are highly geospatial having access to a comprehensive set of up-to-date geographic information, sometimes referred as Minimum Essential Data (MED) is key. The data that make up the MED (see (Durkee and Glynn-Linaris 2012) for suggestions) may vary between SAR groups, however, some of the key components, such as up-to-date imagery, topographic maps are available through ArcGIS Online. To create the additional MEDs for a SAR group will require some intermediate to advanced level (figure 7) GIS capabilities. Additional key datasets may include, avalanche risk maps created using avalanche danger forecasts coupled with slope, aspect and elevation information of the area in question (see (Scott 2009)), mobile phone coverage maps to show coverage by each tower (see (Ferguson 2008, Maiti et al. 2012)), accessibility maps based on modelling remoteness (see (Fritz and Carver 1998, Fritz and Carver 2000)) to allow teams to assess time-to PLS and a "hotspot" risk map illustrating key areas of lost-persons (see figure 5c and (Field and Demaj 2012)).

Key barriers to the uptake of GIS were found to be associated with costs, lack of expertise and difficult to use. During this study several of these barriers changed and may encourage increased use of complex GIS packages, such as ESRI ArcGIS. Firstly, the cost of using this software which normally is in excess of $2000 for a single-use license was reduced to $50-$100 for non-profit organizations and/or personal use. Secondly, MapSAR, an add-on for ESRI ArcGIS, was released late during 2012, provides a rich set of analytical tools to aid SAR. To improve the adoption of MapSAR, ESRI and the SAR community have provided useful training tools and documentation. Although training is being provided, lack of expertise and difficult to use may still exist as barriers. In contrast the use of ArcGIS Online, once set up, are easy to use (see Table 3 for comparison of technologies) and should allow for SAR teams to start to integrate GIS-based technologies into different stages of missions as needed.

Through this study and the experience of the ART, the following changes are being made to improve SAR efforts.

1- **Digitalizing mission data to enable historical analysis of missions**. Historical mission data becomes valuable only if it is available for analysis. Unfortunately much of this data is only available in a paper format. Since this study, the Alpine Rescue Team has continued capturing essential mission data in a spreadsheet (see Table 1) that is easily transferable into GIS sytems (e.g. ArcGIS and ArcGIS Online). A current short-coming is standardization of the essential data to capture. Using the modified Koester spreadsheet, SAR teams, at a minimum can capture the attributes listed in Table 1. Future considerations should include the method in which to capture this data – through an electronic form via the web or some form of document sharing environment (e.g. google documents) to provide central access that maintains integrity of the data and minimizes duplication and redundancy. Although, such a system may be developed and implemented at a team level it may be fruitful to explore the implementation of such a system at the state or national level to enhance data consistency, provide data sharing between teams (when necessary), encourage centralized reporting and improve feedback mechanisms into systems such as ISRID. In Colorado such a system could be developed under the auspices of the Colorado Search and Rescue Board at the state level, and the Mountain Rescue Association, at a national level.

2- **Minimum Essential Datasets –** The MEDs should include a range of data that depict physical geographies (e.g. up-to-date imagery, digital elevation model, rivers, watershed boundaries), socio-economic data (e.g. roads, tracks, hiking trails, access points (e.g. parking areas, picnic areas, points of interest)), mission data (e.g. PLS and Found Locations) as well as processed information (e.g. mobile phone coverage areas, potential avalanche risk areas, remoteness and high risk areas (or "hotspots") based on historical missions). Once a team has identified the MEDs required for their location, these datasets can be compiled and created by a GIS expert therefore minimizing the need for a full GIS. An element of MEDs creation should be a frequent assessment of new data sources for possible inclusion and a periodic review of existing data to determine which requires updates.

3- **Adoption of new technologies alongside current methods.**
Teams are able to conduct successful operations using electronic mapping packages such as Terrain Navigator and OziExplorer, suggests that the functionalities common in many GIS packages is not a necessity for all search and rescue missions. Key requirements for missions include the ability to access geospatial data quickly to visualize the search area (e.g. through ArcGIS online and tablets), manage resources and keep up-to-date of mission progression while in the field where connections to the internet are limited (e.g. APRS Radio). Having the ability to cache data, such as the USGS maps on tablets and other such mobile devices is important. For missions where connectivity is limited, missions can be directed by a team individual from their home or office (or through satellite phone) via cellphone or radio, thus managing and sharing geospatial information and providing recommendations based on views of the terrain.

The use of a full GIS by a SAR team requires a considerable investment in computers, software and training of personnel to be competent in its operation. And as discussed it is not always necessary. The relatively new technologies such as tablets or online mapping capabilities all have possible uses in SAR and can in fact coexist and complement one another. For instance the use of tablets by several Alpine Rescue Team mission leaders helps in the early stages of mission planning but does not remove or reduce the need for electronic mapping packages as missions progress over time, when the tablets limitations would become a hindrance to effectiveness.

4- **Development of training materials and procedures.**
The visual presentation and analyses of historical mission data can highlight a number of avenues to enhance team efficiency by (a) providing team members, especially new members, with a visual tool to help them understand where missions frequently occur; (b) allow the team to plan trainings in the form of mock missions and familiarization hikes in key mission/"hotspot" areas to improve understanding of access and egress points, communications (radio coverage) challenges, and the physical environment; and (c) improve lost person behavior profiles by analyzing LSP, Found Location and direction and route of travel of lost person.

Some future key challenges include the use and integration of new technology and increasing amounts of data from disparate sources. New devices like personal locators and services, such as social media sites Facebook and Twitter, are becoming increasingly location-aware. No single person or team can possibly keep current on all of these developments, yet they may at some point in the future be key to a successful SAR mission. The SAR and GIS communities need to develop methods for dealing with new technologies and the ability to share skilled expertise. A community effort may avoid reinventing the wheel – multiple teams going through the effort to develop their own procedures.

Along with the new sources and volume of data is the challenge of keeping data up-to-date. Increasing frequency of the collection of satellite, aerial and LiDAR data, the 3-year update cycle of the new USGS topographic maps (REF), and availability of crowd-sourced data such as OpenStreetMap all will create challenges to those tasked with developing and maintaining a SAR MEDs. This has important implications relative to data sources and mission operations as the use of an incorrect datum or coordinate system will result in dispatching teams to an incorrect location (REF – there was a recent article) so care must be exercised in the acquisition, formatting and use of disparate data.

In conclusion, even when a full GIS solution is available and the necessary resources are available to operate the system, the nature of the SAR mission will dictate the appropriate tools to be employed. A key challenges facing SAR teams lie in understanding what information is available and its accuracy as well as how to access, utilize, manage and integrate different data sources (both new and existing) during time-sensitive missions. New data sources that may be challenge now will likely become routinely used in the future, and as GIS technologies progress and become easier to use they will likely play larger roles in SAR missions. This area of study is promising for both the GIS and SAR communities and it is the author's hope it is vigorously pursued in the future.

References

Brewin, B. (2011) Fire fighters battling blazes in the Southwest are relying on high-tech tools. http://www.nextgov.com/nextgov/ng_20110620_4710.php (last accessed Aug 3 2011).

Bruninga, B. (2011) Automated Packet Reporting System. http://www.aprs.org/ (last accessed 22 April, 2013).

Cooper, D. C., J. R. Frost & R. Q. Robe (2003) Compatibility of Land SAR Procedures with Search Theory. . 177. http://www.uscg.mil/hq/cg5/cg534/nsarc/LandSearchMethodsReview.pdf (last accessed 24 July 2011).

Cova, T. J. 1999. GIS in emergency management. In *Geographical Information Systems: Principles, Techniques, Applications, and Management,* eds. P. A. Longley, M. F. Goodchild, D. J. Maguire & D. W. Rhind, 845-858. New York: John Wiley & Sons.

dbs_Production. 2011. International Search & Rescue Incident Database.

Doherty, P. 2011. The Investigation of GIScience & Search and Rescue in Yosemite National Park. In *ESRI Users Conference*. San Diego, CA. USA.

Doherty, P., Q. H. Guo, Y. Liu, J. Wieczorek & J. Doke (2011) Georeferencing Incidents from Locality Descriptions and its Applications: a Case Study from Yosemite National Park Search and Rescue. *Transactions in GIS,* 15**,** 775-793.

Doherty, P. & P. Rudol (2007) A UAV search and rescue scenario with human body detection and geolocalization. *Ai 2007: Advances in Artificial Intelligence, Proceedings,* 4830**,** 1-13.

Durkee, G. & V. Glynn-Linaris. 2012. *Using GIS for Wildland Search and Rescue*. ESRI.

Ferguson, D. 2008. GIS for wilderness search and rescue. In *ESRI Federal User Conference*. Washington, D.C.

Field, K. & D. Demaj. 2012. Over the Edge 3D: Death in Grand Canyon.

Fritz, S. & S. Carver. 1998. Accessibility as an important wilderness indicator: modelling Naismith's Rule. In *GISRUK 98*. Edinburgh, Scotland.

---. 2000. Modelling remoteness in roadless areas using GIS. . In *4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospects and Research Needs.* . Banff, Alberta, Canada.

Frost, J. R. (2000) Principles of search theory. 38. http://coloradosarboard.org/csrb-documents/Principles%20of%20Search%20Theory.pdf (last accessed September 2011).

Gupta, S. & C. Knoblock. 2010. Building Geospatial Mashups to Visualize Information for Crisis Management. . In *7th International ISCRAM Conference*. Seattle, USA.

Heggie, T. W. & M. E. Amundson (2009) Dead Men Walking: Search and Rescue in US National Parks. *Wilderness & Environmental Medicine,* 20**,** 244-249.

Johnson, L. (2004) An introduction to mountain search and rescue. *Emergency Medicine Clinics of North America,* 22**,** 511-+.

Johnson, R. (2000) GIS Technology for Disasters and Emergency Management. www.esri.com/library/whitepapers/pdfs/disastermgmt.pdf (last accessed 15 July 2011).

Keech, S. (2007) Who's to blame for James Kim's death? http://www.salon.com/news/opinion/feature/2007/01/11/kim (last accessed.

Kelley, D. E. 1973. *Mountain Search for the Lost Victim*. Montrose, CA: Dennis E. Kelley.

Koester, R. J. 1998. The Lost Alzheimer's and Related Disorders. In *National Association of Search and Rescue*, 165–181. Chantilly, VA

--- (2008) Lost Person Behavior: A search and rescue guide on where to look - for land, air and water.

Koester, R. J. & D. E. Stooksbury (1995) Behavioral Profile of Possible Alzheimers-Disease Patients in Virginia Search and Rescue Incidents. *Wilderness & Environmental Medicine,* 6**,** 34-43.

Maiti, S., N. Paul & T. Pagging (2012) Spatial analysis of mobile signals in Himalayan hill cities. *Current Science,* 103**,** 478-480.
McCollister, C. & K. Birkeland (2010) Using Geographic Information Systems for Avalanche Work. *The Avalanche Review,* 24**,** 10-11.
Medred, C. (2011) The Alaska search and rescue thin line. http://www.alaskadispatch.com/article/alaska-search-and-rescue-thin-line?page=0,0. (last accessed September 14, 2011).
Meier, P. (2012) How Crisis Mapping Saved Lives in Haiti. *Explorers Journal*. http://newswatch.nationalgeographic.com/2012/07/02/crisis-mapping-haiti/ (last accessed.
Netsch, R. 2008. Search and Rescue Optimal Planning System. In *Esri Federal User Conference*. Washington, D.C: ESRI.
Nortel (2008) White Paper: 911 — Where's your emergency? **,** 8. https://confluence.slac.stanford.edu/download/attachments/87691498/Nortel_E911.pdf?version=1&modificationDate=1283206307000 (last accessed 7 September 2011).
Pedder, J. (2011a) MapSAR Briefing Map HD. http://vimeo.com/27446670 (last accessed.
--- (2011b) MapSAR Incident Setup HD. http://vimeo.com/27446697 (last accessed.
--- (2011c) MapSAR Initial Incident Data HD. http://vimeo.com/27446733 (last accessed 12 September 2011).
--- (2011d) MapSAR Overview HD. http://vimeo.com/27446759 (last accessed.
Perkins, D., P. Roberts & G. Feeney (2011) The U.K. Missing Person Behaviour Study. http://www.isaralliance.com/www/library/ (last accessed 7 September 2011).
Ramsay, A. (2010) Social Media Helps with the Boulder Fire. http://www.examiner.com/online-media-in-denver/social-media-helps-with-the-boulder-fire (last accessed 31 July 2010).
Roche, S., -. Z. Propeck, E. & B. Mericskay (2011) GeoWeb and crisis management: issues and perspectives of volunteered geographic information. *GeoJournal*.
Rosenshein, L. & L. Scott (2011) Spatial Statistics Best Practices. . http://video.esri.com/watch/903/spatial-statistics-best-practices (last accessed.
Russo, T. (2004) Using GRASS GIS to analyze cell phone information from mission 080103. http://pages.swcp.com/~russo/080103/ (last accessed 13 September 2011).
Scott, D. D. (2009) Avalanche Mapping: GIS for Avalanche Studies and Snow Science. *The Avalanche Review,* 27**,** 20-21.
Stoffel, R. 2005. *The Handbook for Managing Land Search Operations*. Cashmere: ERI Publications & Training.
Sutter, J. D. (2010) Ushahidi: How to 'crowdmap' a disaster. http://edition.cnn.com/2010/TECH/innovation/10/25/crowdmap.disaster.internet/ (last accessed 10 August 2010).
Theodore, J. (2009) Critical Geographies of Global Systems. *ArcUser*.
Twardy, C. R., R. Koester & R. Gatt (2006) Missing Person Behaviour. An Australian Study. . *Final Report to the Australian National SAR Council***,** 72. http://www.esf.com.au/documents/reports/RobertGatt2002VicPol.pdf (last accessed September 2011).
Vermes, J. (2006) Is Web Technology Disrupting Traditional GIS? . http://www.gpsworld.com/gis/integration-and-standards/is-web-technology-disrupting-traditional-gis-7460 (last accessed August 2010).

Figures and Tables

Table 1: Summary of fields used from the original ISRID DB Excel spreadsheet to the modified version used during this study.

ISRID DB Fields	Modified ISRID DB Fields
County	County
City	City
Mission #	Mission #
Incident Date	Incident Date
Incident Type	Incident Type
Subject Category	Subject Category
# Subjects	# Subjects
Age	Age
Sex	Sex
Total Search Time /hr	Total Search Time /hr
Total Time Lost /hr	Total Time Lost /hr
Distance PLS	PLS_UTM - Easting
	PLS_UTM-Northing
	Found_UTM_Easting
	Found_UTM_Northing
	Distance PLS - meters
Elevation Change	PLS_Altitude
	Found_Altitude
	Elevation Change - meters
Subject found by:	Subject found by:
Subject Found feature	Subject Found feature
Subject Status	Subject Status
Subject found mobility	Subject found mobility
Subject Found responsiveness	Subject Found responsiveness
# Hrs Subject Mobile	# Hrs Subject Mobile
Track Offset	Track Offset
Population Density	Population Density
Find Coordinates	Find Coordinates
Low Temperature	Low Temperature
High Temperature	High Temperature
Precipitation	Precipitation
Mission Contact	Mission Contact

Table 2: Analysis of ART Mission Data

Mission Type	Average of Distance Traveled - meters	Max of Distance PLS - meters	Min of Distance PLS - meters	Average of Elevation Change - meters
missing person	2,649	5,261	173	212
recovery	117	117	117	-56
rescue	3,505	3,505	3,505	-543
rescue, recovery				
Search	5,201	49,288	310	300
SPOT	3,902	3,902	3,902	702
Grand Total	**4,511**	**49,288**	**117**	**265**

Table 3: Summary of the three new technologies (ArcGIS, ArcGIS online, and Tablet) investigated during this study as compared with the existing electronic mapping software currently used by the Alpine Rescue Team in Colorado, USA.

Assessment	**ArcGIS**	**ArcGIS online**	**Tablet**	**Electronic Mapping Software**
Functionality	Full	Limited – ability to browse and retrieve data; ability to import data; some analysis	Very Limited – browse maps and add routes and waypoints	Limited – Ability to import data and conduct some analyses. Package dependent.
Training	Yes	No	No	Yes
Data requirements	Need to develop a geodatabase with region and mission specific data	Data are available and can be integrated Need to develop some region and mission data	Maps and imagery limited to what is available in the particular app	Maps and imagery limited to what is available from the vendor and/or in selected formats that may be imported
Ease of use	Difficult	Easy	Easy	Moderate
Ability to Share map and data	Data sits on a single machine. Create pdf and print maps. Share files between PC's.	All data hosted online. Group members able to log in and view the data.	Limited sharing of waypoints and route information.	Files can be created and shared with others using same SW package. Print paper maps.
Cost	Nonprofit use license $50/year	Free with 2GB OR 2500/year with more functionality for 5 users. 50% discount available to non-profits	Trimble Outdoors Navigator Pro - $4.99	Maptech Terrain Navigator Pro - $299/state OziExplorer - $109 per license

Figure 1: Summary of the progression of a SAR wilderness mission from the initial trigger to completion.

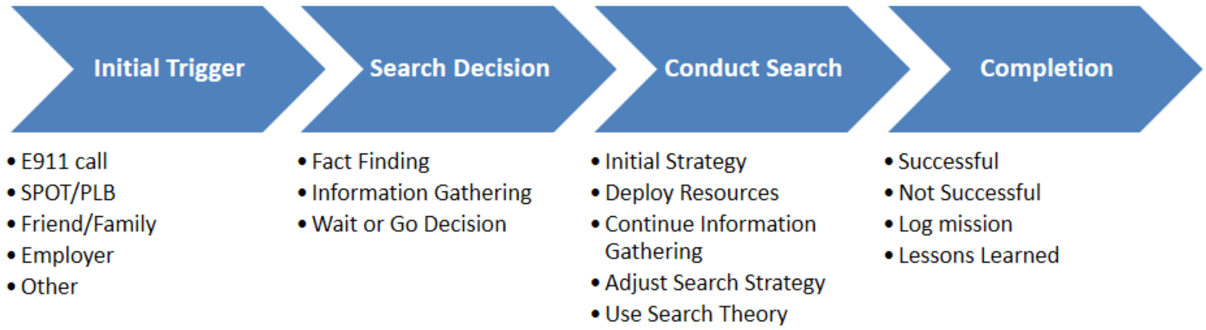

Figure 2: Map illustrating the area covered by Alpine Rescue Team in Colorado.

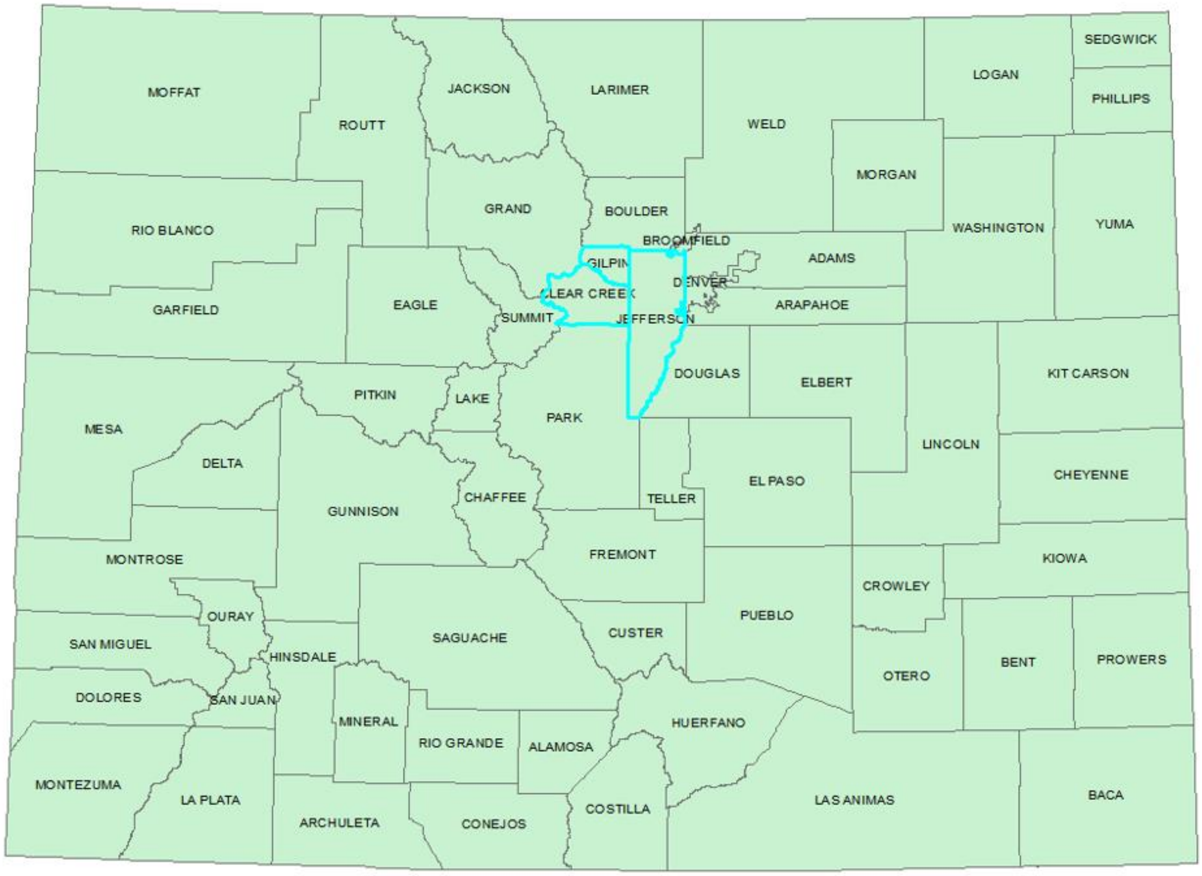

Figure 3: Summary of survey results highlighting the (A) mapping/GIS software, (B) type of information data, and (C) geospatial data currently used during a mission.

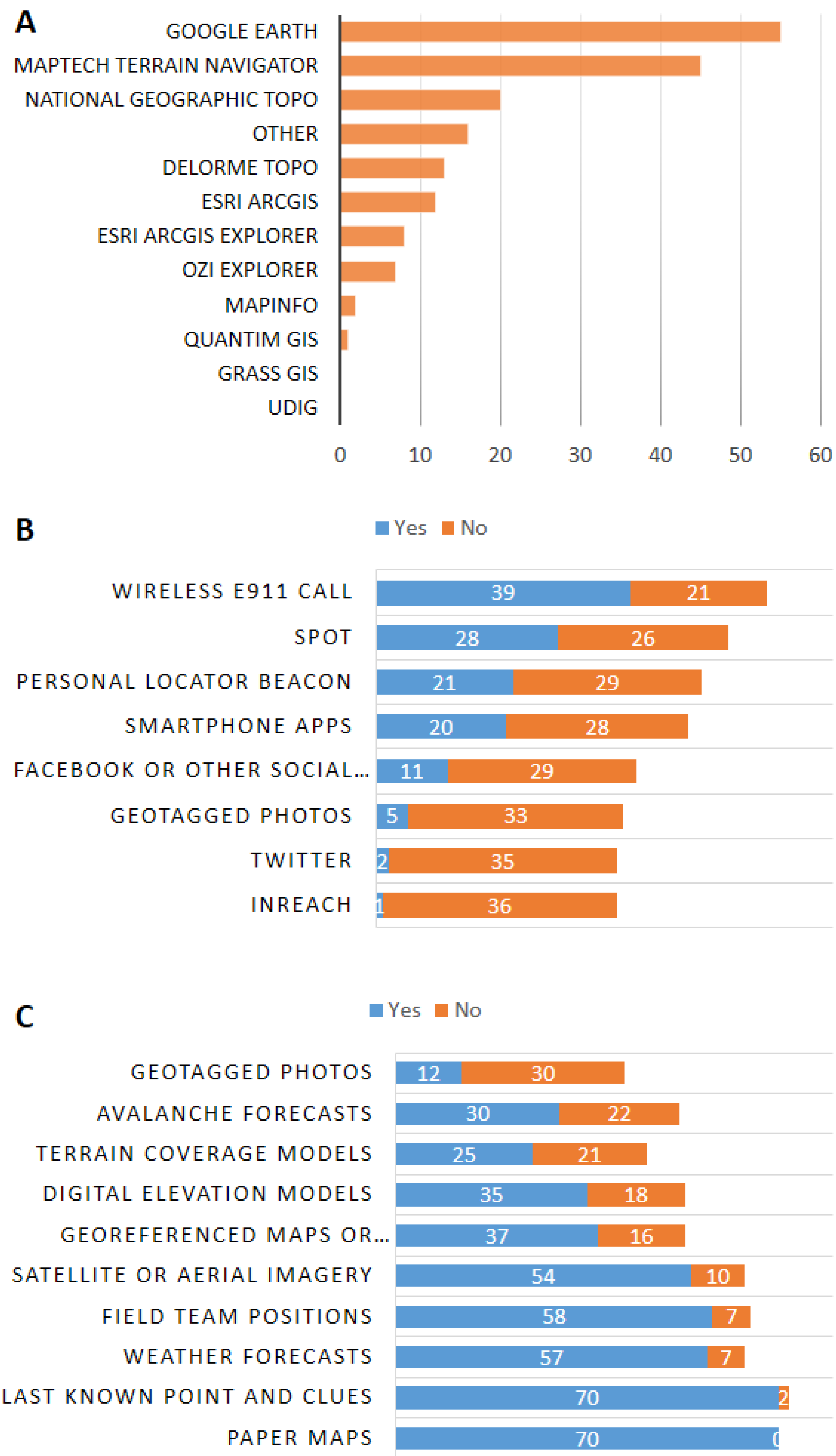

Figure 4: Analysis of Alpine Rescue Team mission data between 2008 and 2011. Graphs provide a summary of (A) condition of lost person, (B) type of mission, (C) number of mission by month and (D) duration of each mission.

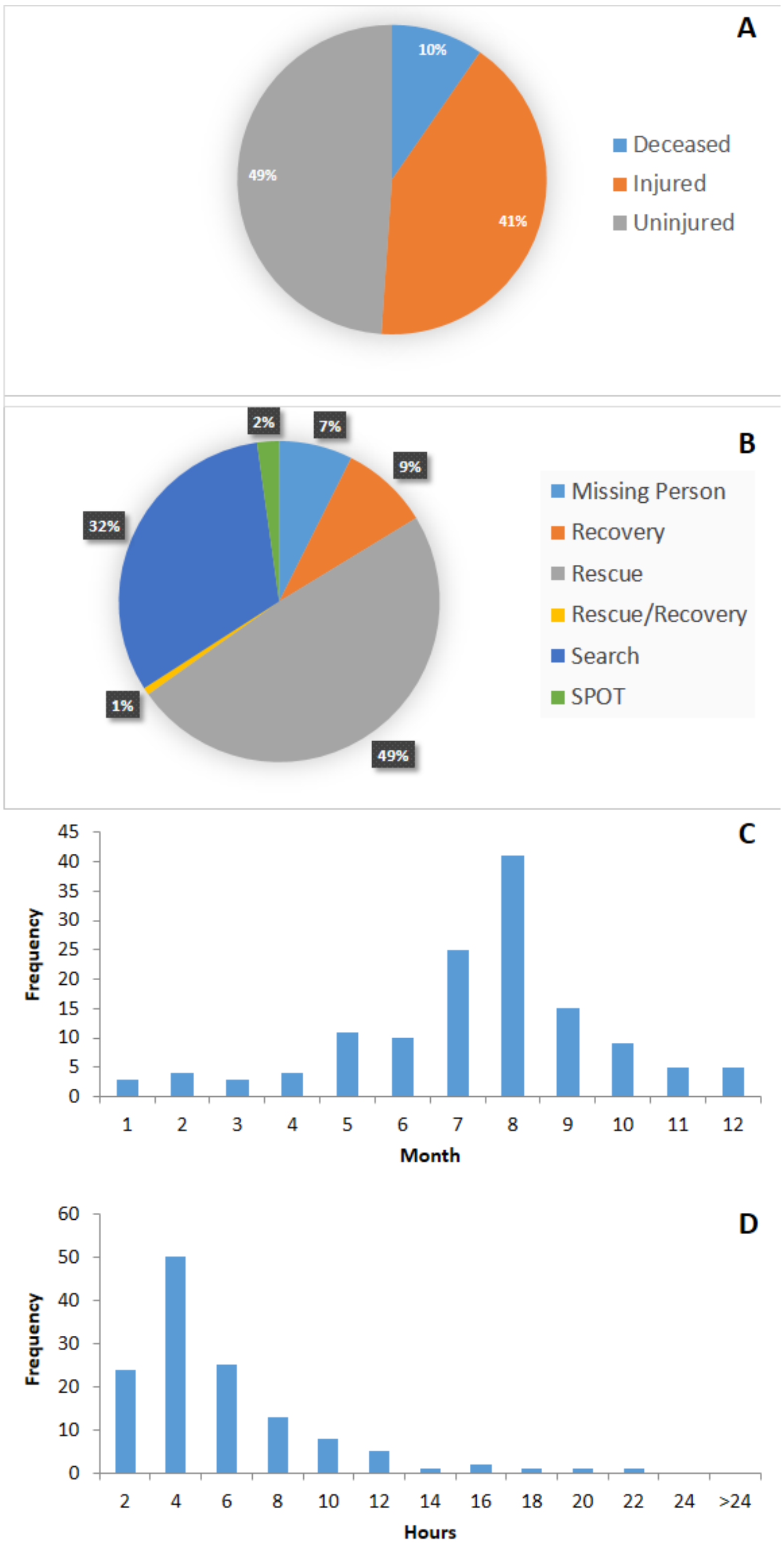

Figure 5: Analysis of (A) difference in elevation, (B) distance between known lost and found person location and (C) a map illustrating the directional movement of lost persons (N= 46) and the spatial distribution of all ART Missions between 2008 and 2011(N=135).

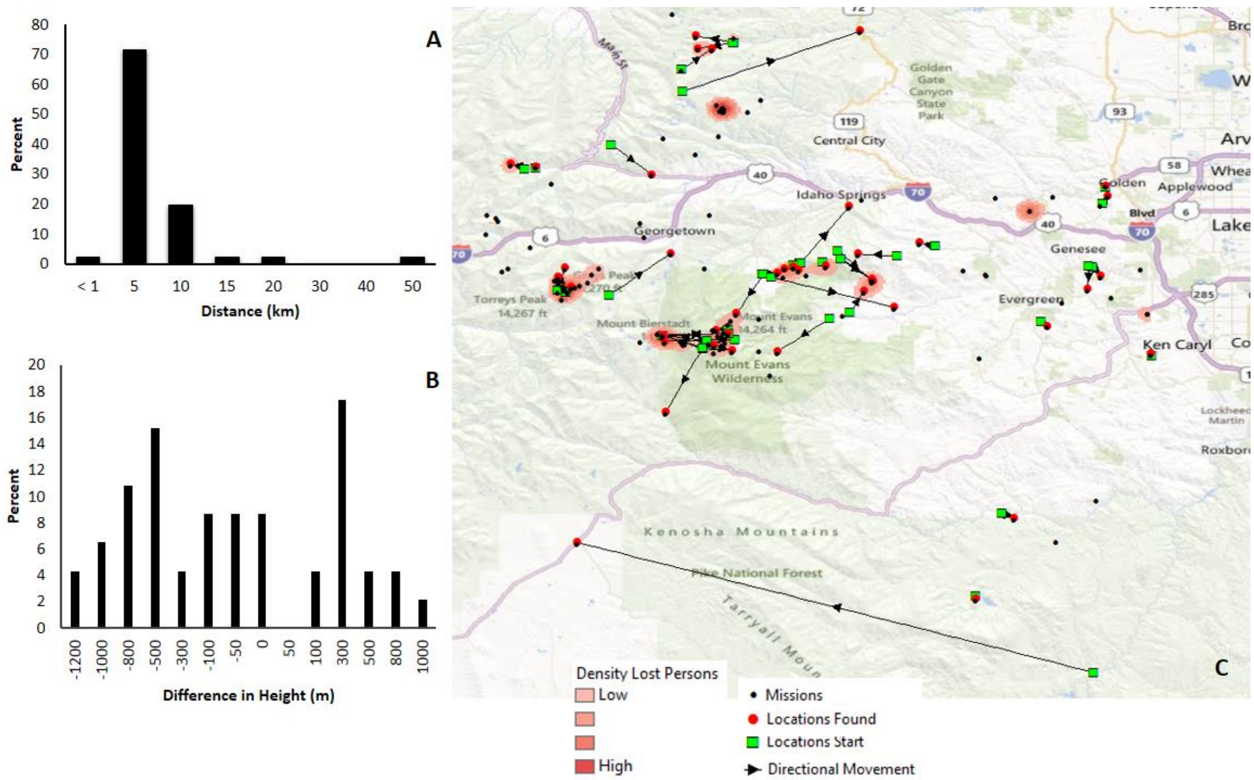

Figure 6: Examples of geospatial technologies applied during this study: (A) shows the viewshed analysis for Mt Evans using desktop ArcGIS; (B) provides an example of locating a lost mountain biker using ArcGIS on-line; (C) shows the tablet in use with access to the USGS topographic maps, and (D) shows the OziExplorer mapping software used by the Alpine Rescue Team.

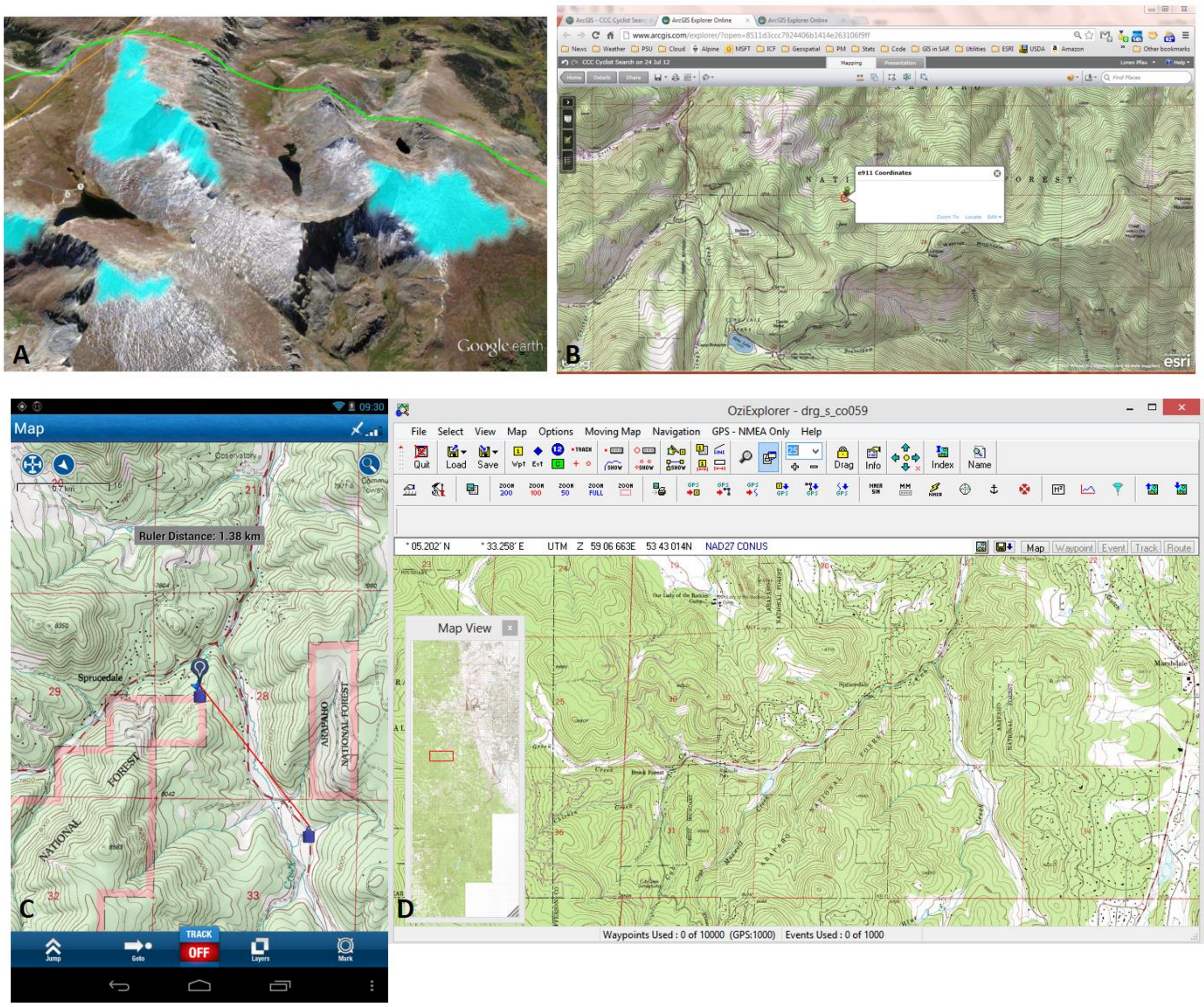

Figure 7: Components of geospatial information that can be used by SAR at different levels.