ESRI Federal User Conference
February 20 - 22, 2008, Washington, D.C.

FedUC-463

GIS FOR WILDERNESS SEARCH AND RESCUE

Don Ferguson
Mountaineer Area Rescue Group

Abstract

The objective of any search and rescue mission is to locate the missing subject and return them to a stable and safe environment. To do this, search managers must employ tactics that are efficient and do not pose unnecessary risk to rescue personnel. Modern search strategies involve the use of behavioral profiling, probability theory, terrain interpretation and resource management. Geographic information systems provide a platform to integrate these various elements into an effective tool for managing search operations.

This paper discusses the application of GIS to manage the search for a missing autistic youth in the Dolly Sods Wilderness area of West Virginia. Through this example, details are provided for segmenting the designated search area into probability regions based on statistical analysis and a behavioral profile of the missing subject. An operational basemap was developed by integrating digital raster graphics, elevation datasets, and aerial imagery with various shapefiles in order to further segment the probability regions into searchable areas. Attribute tables provided a database to track resources, clue logs and area coverage as well as performing basic probability estimates. Recommendations for the use of GIS during search operations focus on improving search efficiency and effectiveness, as well as reducing operational costs and response times with the goal of finding the missing subject as quickly as possible.

1. Introduction

The basic primus of search and rescue (SAR) can be broken down into its two defining disciplines: search and rescue. Locating a missing subject or object is the first element of any SAR mission and must take place before “rescue” can occur. The second phase of the SAR incident beings once the subject of the search is located. This consists of first accessing the subject, providing initial care to prevent further distress and finally returning the subject to a more stable environment. When considered on a whole, it is often the rescue element that receives primary attention in both news media and SAR training. However, as witnessed by a number of recent high profile SAR incidents within the United States[1,2] it is the “search” element that has frequently proven to be the most difficult.

The basic concept of searching for a missing object can be considered human nature and is often driven by need, desire or curiosity. Because of this innate relationship, searching as part of a SAR incident is commonly misrepresented as putting a lot of people in the field to look around for the missing subject or object. However, when a human life is at risk this simplistic approach is inappropriate as modern search theory has provided more effective methodologies[3].

Modern search theory has stemmed from work first introduced during World War II to assist with the detection of enemy submarines[4,5]. This early work provided a mathematical framework with which resource could be used in such a way as to increase the likelihood of locating the object of the search. Stated more formally, the objective of applied search theory is to maximize the probability of success (POS) by utilizing the available resources in the minimal amount of time[3]. This is accomplished by through a systematic approach of defining the areas to search as well as providing a mechanism for optimizing the probability of detection (POD), or likelihood of a resource detecting the object of the search, for a given method of detection and environment.

Aeronautical and Maritime SAR has embraced the concept of modern search theory with application of SARPlan[6] in Canada and programs such as CASP[7] and SAROPS[8] by the US Coast Guard. Through the use of such tools, statistics have indicated a significant increase in the number of lives preserved[9]. While some in land SAR planning have championed modern search theory and attempt to progress its usage[3,10,11,12], actual mangers in the field have been slow to deploy these techniques. This may in part be due to the lack of understanding of the application of modern search theory to land search and rescue. However, distinct differences between maritime and land based searches, particularly the difference between searching on water where regular grid patterns are possible and in forested areas that demand the use of irregular grids, has limited their application. Even aeronautical searches that occur in forested areas permit the use of regular grids as aircraft, for the most part, are not limited by topography and vegetation. Land SAR managers and field teams are limited by the terrain of the search area as natural and man-made barriers prevent the use of regular grids. Outdated maps and a disconnect between documented and planned search efforts also reduce the efficiency in SAR operations.

Geographical information system (GIS) software provides a dynamic platform capable of integrating spatially referenced data to assist with decision making and resource management. The combination of current aerial and satellite imaginary and elevation models with digital topographical maps provides a significant improvement in search area assignments compared to historical methods. A GIS can assist with establishing on-scene communications and improve searcher safety, as well as refine field operations and mission reporting through the use of handheld Global Positioning System (GPS) units.

The objective of this paper is to present a discussion on the further use of GIS software for managing SAR operations. This is done through a firsthand account of using ArcGIS[13] as a SAR planning tool for the search of a missing autistic youth in the Dolly Sods wilderness area of West Virginia. We begin in Section 2 by providing relevant background information regarding the missing subject. Section 3 provides a brief discussion of SAR planning process. In Section 4 the application of ArcGIS to the Dolly Sods search is presented with a discussion of the greater potential of GIS for wilderness search and rescue given in Section 5.

2. SAR Incident Background Information

On a sunny Sunday afternoon in October of 2007 a father and mother had planned to take their 18 year old son (referred to as "subject") on a day hike along the Boar's Nest Trail in the Dolly Sods Wilderness Area located within the Monongalia National Forest near the border of Randolph and Tucker Counties in West Virginia. The family also consists of two additional children that were not present at the time of the excursion. The subject was severely autistic possessing the mentality of a toddler (as described by the parents) and was non-verbal however was as physically capable as any typical 18 year old male. Outings such as this were commonplace for the family as they would often hike and bicycle together.

The Boar's Nest trail begins with a steep uphill climb containing several switchbacks followed by a long flat section. Figure 1 is a section of the USGS topographical map that contains the Boar's Nest Trail. Note that the trail switchbacks are not depicted on the original map. Although the family typically stays together during outings, the initial climb allowed the subject to get ahead of his parents and was soon out of view. It should be noted that the family reported making every effort to keep pace with the subject, however on previous excursions in which the subject got ahead of the family he would turn around after some time and return. The "X" indicated on the map in Figure 1 is the location of the point last seen (PLS) by the parents. After loosing sight of the subject the father did a cursory search of the trail and the area while the mother proceeded out of the area in order to notify authorities (there is no cell phone coverage in the area). The time was approximately 15:30 hours.

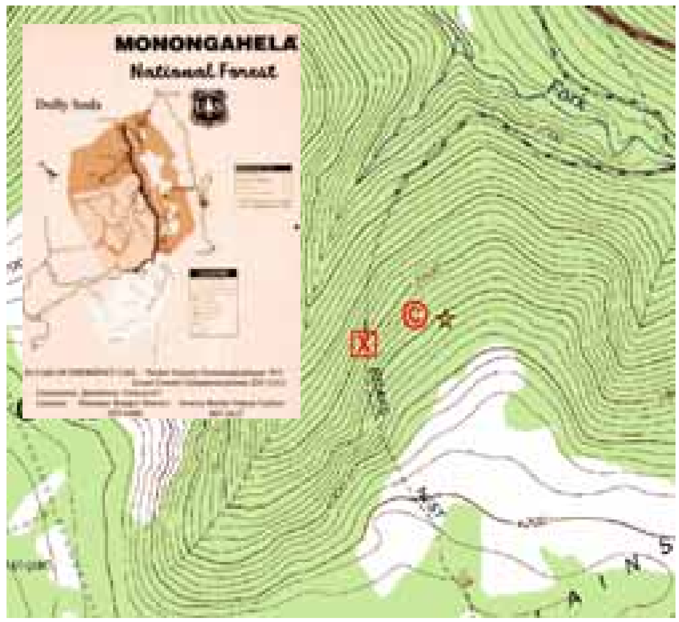

Figure 1: Section of the USGS 1:24000 topographical map that contains the search area. PLS is indicated by the "X" shown on the map.

Local authorities arrived on scene and began hasty search operations along the trail and in the region of the PLS. This area is composed of steep difficult terrain with extremely thick laurel thickets thus significantly hampering their search efforts. A hat that was identified as belonging to the subject was located 50 meters off the trail to the east of the southern most switchback on the trail (shown as the "C" Fig 1) and 200 meters east of the PLS. The search continued until dark (approximately 19:00) at which time the incident commander suspended the operation until morning. Searching resumed at 0630 the next day with efforts on the east and west areas around the PLS and along the main trail. At 13:30 SAR teams trained in search management began arriving on scene. Until this point all planning and field operations were being conducted from a single posted map located some distance down the road to the northwest from the PLS and was similar to that shown in the insert in Figure 1.

Over the next couple of days efforts continued to expand including night searches conducted by train searchers. At the height of the operation more than 400 searchers (combination of trained and untrained searchers) were involved and after fours days of searching, the subject was located in relatively good health (dehydrated and hungry) at a location approximately 350 meters east of the PLS in an area of dense vegetation (the "Star" symbol in Fig 1). It is believed a combination of difficult terrain, extremely dense vegetation and searching for a non-verbal, non-interactive subject delayed locating the individual. However an additional factor that may have hampered the search, and will be addressed below, is an issue that is present in most land SAR operations: the inability of searchers to search in the assigned area or to inaccurately represent the area that was searched.

3. SAR Planning Process

The goal of search planning is to maximize the POS as quickly as possible with the available resources. What follows is not intended to be a comprehensive discussion of SAR mission planning as could be found in a number of texts (for example Ref 7, 10, 11 and 12). The objective here is to provide a general background so that the non-SAR reader may have an appreciation of how the application of GIS to SAR can be greatly beneficial.

Every search must begin somewhere. The initial location that is used to begin planning the search efforts is referred to as the Initial Planning Point, or IPP. This location may be a point where the missing subject was physically seen by someone and is referred to as the Point Last Seen or PLS (symbolized by the “X” in Figure 1) or it may be a location in which enough conclusive or substantial evidence exists that it can be determined to be the last “known” position of the missing subject (this would be the “C” in Figure 1).

Once the IPP has been establish it is then possible to define a search area. Although there are a number of methods for establishing the search area, a common approach is to utilize a form of behavioral profiling that not only involves developing specific scenarios regarding the missing subject, but also includes the use of statistical databases that have been derived from thousands of previous incidents[12,14]. In Koester[14], approximately 33 categories are listed with statistics on the distance the subject was found from the IPP, difference in elevation, hours the subject was mobile, survivability, dispersion angle from the IPP, suggested initial tactics and investigative questions, and possible scenarios as well as additional information. Table 1 is from Stoffel[12] and is a list of the “Probability Zones” (distant from the IPP in which the given percentage of the missing subjects were found) for mentally retarded individuals of all ages. The Probability Zones provide a mechanism to identify a basis for the search area and often times rings are drawn on the map at these distances from the IPP.

Table 1: Lost person behavior for mentally retarded (distance found from the IPP)[12]

For all terrain Types (Mountainous, Flat and Urban)				
Median Distance	25%	50%	75%	Max (95%)
0.8 km	0.2 km	0.8 km	1.6 km	4.0 km

* May not be aware of becoming lost, being lost or the consequences
* They generally will not respond to their spoken name
* Most often will be hidden from view as a result of fright or shelter
* Many times will stay in one place for days
* They will penetrate well into brush/briars and forests to seek shelter

The next step is to prioritize regions within the search area as to their likelihood of containing the missing subject. Finally the Probability Regions are broken down into segments that can be covered in 4 – 6 hours by the assigned resource. Although this will vary based on the difficulty of the terrain and the nature of the ground cover, experience has found segments size as 80 – 160 US acres to be realistic. The choice of segment boundaries must be based on what can be seen and readily identified in the field by all searchers such as manmade (roadways, trails, fence lines, etc) and natural features (water, topography, steep vegetation gradients, etc). If appropriate features are not readily available improvised boundaries may be created by utilizing compass bearing from easily recognizable locations, GPS waypoints or specified contours. However, improvised segment boundaries pose a significant challenge to field teams and should be avoided if possible. As an additional point, the search managers that are preparing the segmented maps a typically not familiar with the search area and in addition, as the command post may be some distance from the actual search area, it is often the case that the planners never actually physically see the terrain and thus base their decisions on available information from the maps being used and input from teams returning from the field.

Documentation is obvious important during any SAR mission: noting the position of pertinent clues, location and type of resources in the field, areas that have been planned and areas that have been searched. Necessary information obtained from teams returning from the field: where did they actually search and how well it was searched. A measure of the resource search ability is referred to as the Probability of Detection (POD). POD for a given segment is variable (resource, weather, etc) and depends heavily on the amount of the segment that was search (coverage). As stated previously the goal of the search is to maximize the probability of success, where POS = POA x POD. Thus obtaining an accurate measure of where and how well a team searched is critical. Unfortunately teams often times mis-represent their actual search area and POD especially in areas composed of difficult terrain and thick vegetation thus hampering the search efforts.

Most often parameters such as the POD, POA and POS are not recorded directly onto the planning map as these values change with each search of a segment and the current approach would quickly become cluttered. However, a graphical display of these quantities would be useful. The conventional approach of maintaining an operational map is to overlay transparencies onto the map. Each transparency layer represents a different phase of the operation. One layer may contain the boundaries of the probability segments while additional layers may contain search segments that are planned, actively being searched or have already been search. To further complicate the matter for multi-day or complex searchers, transparencies may be periodically replaced as they become cluttered often times resulting in a disconnect between tasks completed in the current operational period and previous ones. The current use of transparencies for SAR planning is one that is often used to describe the function of a GIS. Thus it would seem that this is a "made to order" application for a GIS.

4. GIS for SAR

A GIS system offers distinct advantages over the conventional approach of SAR planning as it provides a platform to integrate spatially referenced data streaming from various sources. Additionally, it provides a mechanism for viewing, querying and analyzing this data, thus creating useful information to assist in decision making and resource management[15]. As noted previously the often used analogy of the layered transparencies is the system that is currently utilized in managing many SAR operations, thus it would seem a logical progress as computer continue to have a larger role in the field. However, unlike most users of GIS, wilderness search and rescue does offer some unique challenges. Most notably is the fact that operators are typically deployed in remote, rural areas without access to computer servers, conventional communication avenues and sometimes reliable power. These difficulties are often addressed by preloading data on portable media and at times creative improvisation.

As in the manual (paper map) method, the foundation for the planning map is still the 1:24000 USGS topographical map as these are the scale and type of maps teams in the field will be using (Figure 2). For the GIS, scanned DRGs of the area were preloaded on a portable hard drive that was deployed along with the computer running ArcGIS. Using the lost person behavior tables and the Multiple Ring Buffer tool in ArcGIS it is possible to identify the statistical search area around the IPP. These rings indicate the percentage of historical subjects that have been found within this distance from the IPP for the given category.

The dynamic capability of GIS permitted the inclusion of updated trail, roadway and drainage locations that was obtained from the US Forest Service and the West Virginia Highland Conservancy (Figure 3). Recall, on the original USGS topo shown in Figure 1 the region around the PLS does not include the trail switchbacks. Experience has shown that exclusion of this type of information has contributed to confusion by teams in the field as to their assigned search areas.

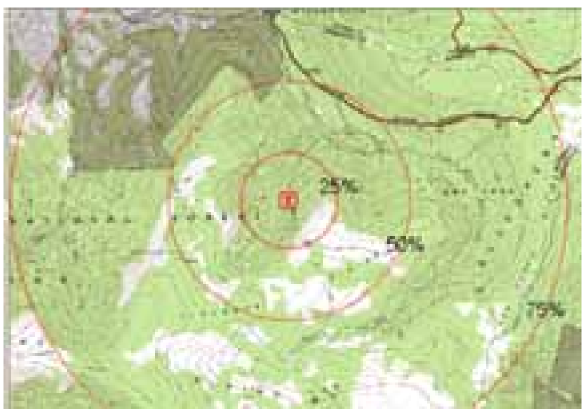

Figure 2: DRG with multiple ring buffer around the IPP to indicate the statistical search area.

Figure 3: DRG with updated trail, road and drainage information obtained from the US Forest Service and the West Virginia Highland Conservancy.

Even without the advantages of GIS, the availability of the aerial photographs (DOQQ) has greatly enhanced planning for wilderness search and rescue. During operations search planners that are preparing the segmented maps are typically not familiar with the search area and in addition, as the command post may be some distance from the actual search area, it is often the case that the planners never actually physically see the terrain and thus base their decisions on available information from the maps being used and input from teams returning from the field. The aerial photographs offer command staff a better representation of the actual search area in many aspects and are typically more current than topo maps. Both these features aid in establishing regional and segment POA.

The addition of the digital elevation model (DEM) processed with the Spatial Analyst hillshade tool adds even more features to the search area (Figure 4). Combining this with the DRG and DOQQ helps to distinguish features useful for search segments boundaries that may have been difficult to interpret or not present on the topo map. This improves the selection of segment boundaries for easier recognition by field teams and reduces the need for “improvised” boundaries.

Segment boundaries are built with polygon shapefiles permitting information storage such as name designation and area in data allocation tables. Additional fields can be added to the tables to include POA, POD, tasked resource, status (planned, in progress, completed) and other pertinent information any of which can be used for symbolizing or labeling as shown in Figure 4 and 5.

Figure 4: Combining DRGs, DOQQs and DEMs help to provide a better picture of the search area and improve area segmenting.

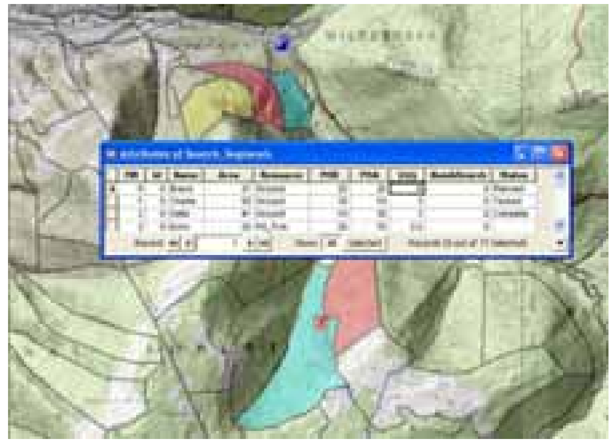

Figure 5: Segments can be color coded as per their status (planned, tasked, complete), based on their POS (POD * POA), resource (ground, K9, air), etc.

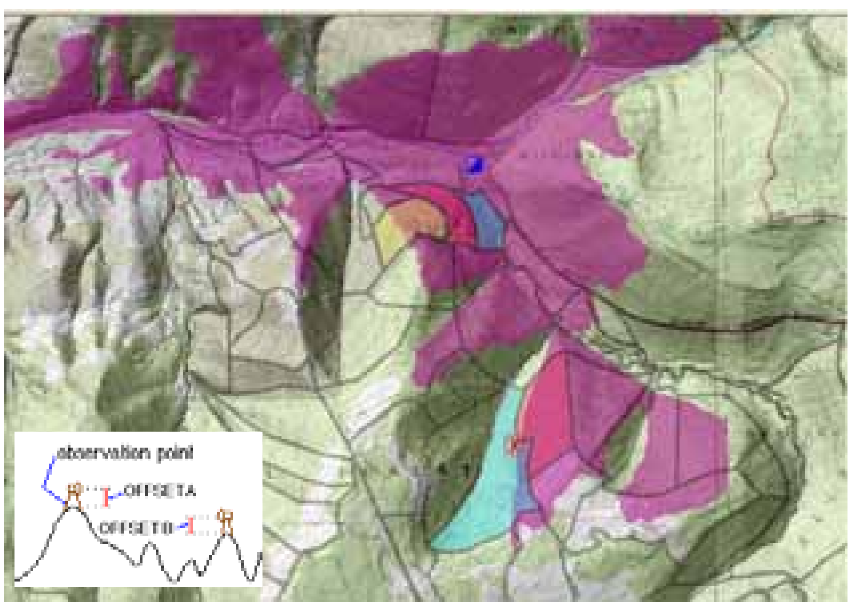

Figure 6: Viewshed analysis of communication originating from the command post indicated by the square in the top center of the figure. Insert illustrates the viewshed tool line-of-sight analysis[13] and does not take into consideration true wave propagation although does illustrate potential gaps in communication coverage.

On scene communications are critical for field team safety as well as mission operations. Although communication equipment may vary, most volunteer SAR organizations take advantage of amateur two meter radio as it is relatively inexpensive, available and easy to use and setup. Operating in West Virginia one quickly realizes that the topography is not particularly conducive for establishing reliable communication unless the command post is located advantageously at the top of a mountain. The viewshed tool of the Spatial Analyst extension provides a rough approximation of the communication capabilities as it only provides a line of sight given the observation point and receiver offset and does not take into consideration true wave propagation. However, it does identify potential gaps in communication to regions in the search area. Communications can be improved with the use of portable field deployable radio repeaters or even the use of human radio relay if necessary.

As previously noted, an often experienced hindrance to planning is a team not searching the assigned area or mis-representing the area that was searched. This is noted in both trained and untrained searchers. Field teams will commonly find themselves significantly outside the boundaries of their assigned area or overestimate the amount of their assigned area they actually searched. This results in an erroneous report of the POD and may delay search efforts in high probability areas.

The use of GPS navigation has become almost commonplace throughout much of the SAR community as an aid for navigation. Historically, the use of the devices has been limited to merely reporting the location of the team in the field. In the event GPS was used to assist in navigating to the assigned search area or in actually searching the assigned area typically only one or two waypoints would be entered as teams would be required to manually acquire point coordinates from printed maps. Even this may be prone to error as the accuracy of the point would depend on properly obtaining its coordinates which in the past would have been read directly from the printed maps. Given the use of only a few points it would still be difficult to ensure the entire search area was completed. However, managing the search area with a GIS data can quickly and easily be shared with handheld GPS units. MxGPS[16] is an ArcMap extension that was developed to allow users to rapidly transfer data between ArcGIS and a GPS unit. Map features such as points, lines and polygons can be uploaded to the GPS as waypoints or track logs. Having created polygon shapefiles to represent the boundaries of the search segments, it is possible to upload individual polygons as GPS track files using the MxGPS extension (Figure 7a). This now allows field teams to have their entire search boundary displayed on the GPS screen (Figure 7b) are provides them a target area as opposed to relying entirely on geographical references in the field that may be difficult to see as a result of vegetation or during night operations. While searching their assigned areas active GPS units can continue to log the locations that can be used to generate a track log once their task is complete (Figure 7c). Upon returning to the command post, the track log can then be downloaded into back into ArcMap and displayed on the operational map. Assuming a team is utilizing a single GPS, a small buffer along the “searched” track can be created using the ArcMap buffer tool in order to approximate the area that was searched by the entire team. Utilizing GIS and GPS in this manner should greatly reduce the error in reporting the area searched and the estimated POD.

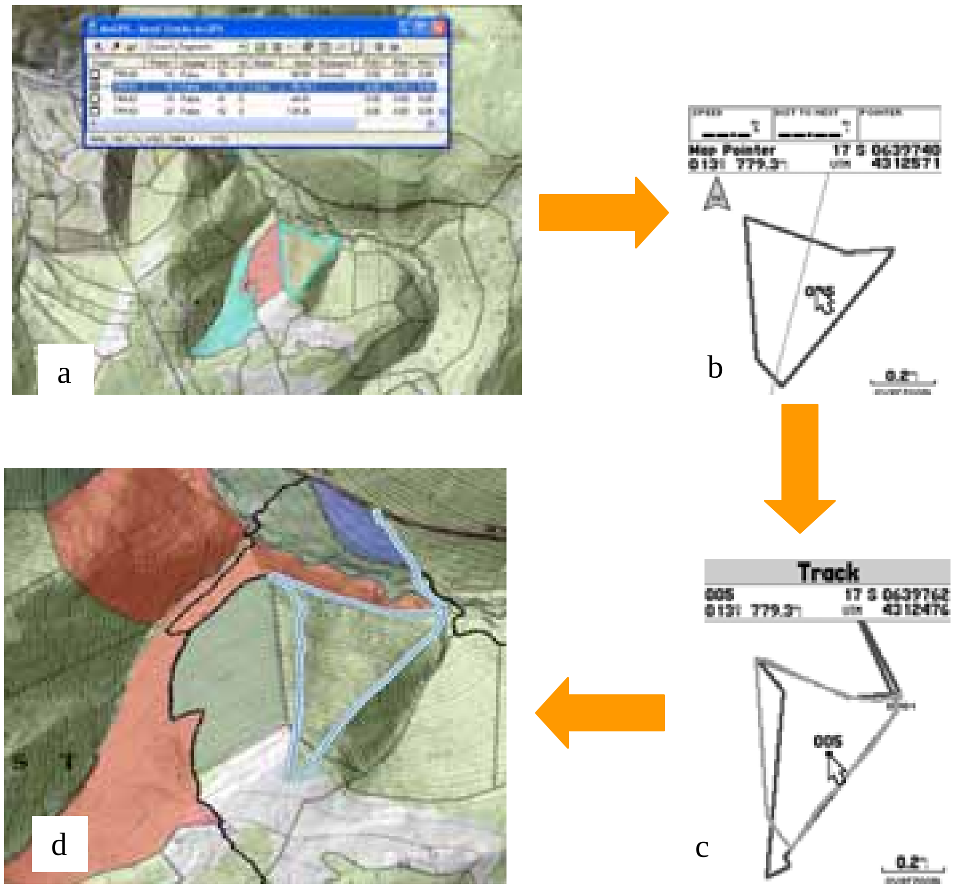

Figure 7: (a) Using the MxGPS extension search area segment boundaries can be uploaded to the GPS as track logs, (b) field teams can use the track log boundary as a guide for their searching efforts, (c) second track log recorded while team is searching in the field, (d) track log in downloaded in ArcGIS and a buffer is greated to represent total track searched by team

5. Conclusion

The goal of search planning is to maximize the probability of success (POS) as quickly as possible with the available resources. Land SAR operations utilizing modern search theory are data intensive. GIS provides a platform to integrate spatially referenced data streaming from various sources. Additionally, it provides a mechanism for viewing, querying and analyzing this data, thus creating useful information to assist in decision making and resource management. Combining DRGs, DOQQs and DEMs improves the selection of segment boundaries for easier recognition in the field by teams reduces confusion and improving searcher POD. Detection capabilities can be further improved by uploading search area segments to GPS as track logs providing target boundaries and track logs from field tasks can be downloaded to better evaluate team performance.

Application of GIS to land based SAR is a relatively new application with great potential. Future work will focus on determining searcher spacing in the field based on vegetation density approximations made from aerial photographs.

6. References

1. Simon, D., "Mount Hood Climbers: What Price Glory?", http://abcnews.go.com/US/ Story?id=2720158&page=1.
2. Johnson, A., Boyle, A., Alexander, P., Tibbles, K., Siravo, S., Grant, T., "Distraught Rescue Crews Come Up Just Short", http://www.msnbc.msn.com/id/16070337/.
3. Cooper, D.C., Frost, J.R., Robe, R.Q., "Compatibility of Land SAR Procedures with Search Theory", NSARC, Task Order DTCG32-02-F-000032, Dec 2003.
4. Koopman, B.O., *Search and screening* (OEG Report No. 56, The Summary Reports Group of the Columbia University Division of War Research). Alexandria, Virginia: Center for Naval Analyses, 1946.
5. Koopman, B.O., *Search and screening: general principles with historical applications,* Revised. New York, NY: Pergamon Press, 1980.
6. Abi-Zeid, I. and Frost, J.R., "SARPlan: A Decision Support System for Canadian Search and Rescue Operations", European Journal of Operational Research, 162, 630-653, 2005.
7. IMSAR Manual
8. Spaulding, M., "SAROPS, The Next Generation Search and Rescue Model; System for the U.S. Coast Guard", *Technologies for Search, Assistance and Rescue*, Brest, France, October 2004.
9. United States Coast Guard, *United States Coast Guard search and rescue summary statistics 1964 through 2006*. Retrieved from www.uscg.mil/hq/g-o/gopr/U_S_%20Coast%20Guard%20SAR%20Statistics%20Introduction.htm, February 2008.
10. LaValla, P., Stoffel, R., & Jones, A.S.G., *Search is an emergency: a text for managing search operations* (4th. revised). Olympia, Washington: Emergency Response Institute, Inc., 1997.
11. Hill, K., *Managing lost person incidents*. Chantilly, Virginia: National Association for Search and Rescue.Inc., 1997.
12. Stoffel, R., *The Handbook for Managing Land Search Operations*. Cashmere, Washington:Emergency Response International, Inc., 2001.
13. ESRI, "ArcGIS", http://www.esri.com.
14. Koester, R.J., "Lost Person Behavior", dbS Productions, Charlottesville, VA, 2008 (*To Be Published).*
15. Heywood, I., Cornelius, S., Carver, S., "An Introduction to Geographical Information Systems", 2nd Ed., Pearson Education, Harlow, England, 2002
16. MxGPS, www.mxgeo.com, December 2007.