EVALUATING THE UTILITY OF A GEOGRAPHIC INFORMATION SYSTEMS-BASED MOBILITY MODEL IN SEARCH AND RESCUE OPERATIONS

by

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I dedicate this to my family and my friends for their patience as I invested many nights and weekends to follow my passion in geographic information science and technology. I write this for those that volunteer so many hours to search for and rescue those in need, hoping to make their efforts even more effective.

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Abbreviations

ABM	Agent-based models
BYU	Brigham Young University
CART	Classification and regression tree
DEM	Digital elevation model
FEMA	Federal Emergency Management Agency
GDB	Geodatabase
GIS	Geographic information systems
GISci	Geographic information science
GIST	Geographic information science and technology
GMU	George Mason University
GNSS	Global navigation satellite systems
GPS	Geospatial positioning system
IC	Incident command
ICS	Incident command system
IGT4SAR	Integrated Geospatial Tools for Search and Rescue
IHOG	Interagency Helicopter Operations Guide
IPP	Initial planning point
ISRID	International Search and Rescue Incident Database
LKP	Last known point
LPB	Lost person behavior
LZ	Landing zone
MRA	Mountain Rescue Association

MXD	Map file
NAD	North American datum
NAPSG	National Alliance for Public Safety GIS
NASAR	National Association for Search and Rescue
NHD	National Hydrological Dataset
NHTSA	National Highway Traffic Safety Administration
NLCD	National Land Cover Dataset
PDF	Portable document format
PLBs	Personal locating beacons
PLS	Point last seen
POA	Probability of area
POC	Probability of containment
POD	Probability of detection
POS	Probability of success
PSR	Probability of success rate
ROW	Rest of the world
SAR	Search and rescue
SSARCC	State Search and Rescue Coordinators Council
SSI	Spatial Sciences Institute
TIGER	Topologically integrated geographic encoding and referencing
TNP	Terrain Navigator Pro
UAS	Unmanned aerial systems
USC	University of Southern California

USGS	United States Geological Survey
USNG	United States National Grid
UTM	Universal Transverse Mercator
WiSAR	Wilderness search and rescue
YOSAR	Yosemite Search and Rescue

Abstract

Every year thousands of people become lost or injured to the extent that a search and rescue (SAR) unit needs to step in and help. Through the ages, we have needed to look for people and things yet the theory behind searching goes back less than 75 years to World War II. The main idea is that to be successful, searchers need to search the right area, and be able to detect the person or thing. This research explored the utility of using a GIS-based mobility model to assist search planners in developing their search areas. A mobility model incorporates consideration of the speed with which a person can move across the landscape. The tool used here is an Esri ArcGIS template called Integrated Geospatial Tools for Search and Rescue (IGT4SAR). While it includes many SAR tools, this research focused on the mobility analysis component. This study specifically assessed IGT4SAR's ease of use, speed, and success rate at determining how far a person can travel in a given time. Nevada County provided detailed information on a few incidents used to gain familiarization with IGT4SAR and the state of Oregon provided a large database of historical and diverse SAR events that allowed for broader testing of the model. Ultimately, 44 incidents were used to test the model. The model itself is easy to use, but the template is complex. With preloaded data, the model creates a product in less than 15 minutes. Starting with an unrealistic assumption that the incident start time recorded in the database represented the time when the subject left the last known location, test runs resulted in a 30% success rate where the found location fell in a time band that was less than the amount of time between the start time and the found time recorded in the database. After adding a estimated three-hour delay in reporting time to the SAR notification times the model had a 75% success rate. These results suggest that IGT4SAR can assist in defining a containment area to limit a search radius and is worthy of continued development.

Chapter 1 Introduction

"I cannot begin to tell you how grateful I am that Chris is alive because of you. The response to my call was phenomenal … thank you for all that you do to help people in trouble. I cannot picture a braver set of people … nothing can ever repay what you have done. Thank you, Sara Ray" (Ray 2015).

The Deschutes County Search and Rescue Team received this note in 2015 after a successful search and rescue. It provides a brief example of the importance of effective search and rescue operations. This research strives to make a small contribution to further develop search and rescue (SAR) operations and its use of geographic information science and technology (GIST). A number of organizations in the SAR community currently use geographic information systems (GIS) but primarily as a tool to produce simple maps. Further leveraging GIS data and analysis in order to find missing persons provides endless opportunities for growth in the field. This paper specifically looks at the effectiveness of using a mobility model that considers travel cost path analysis techniques.

1.1 Why Choose Search and Rescue?

SAR is naturally a geospatial problem (Doherty et al. 2014). People can become lost, hurt, trapped, despondent, or even abducted. Something along these lines happens daily across the world, totaling in the thousands as evidenced by the International Search and Rescue Incident Database (ISRID) (Koester 2008). These people need help, and as illustrated in Figure 1, they need it fast (Adams et al. 2007). Even with our advanced technologies such as global navigation satellite systems (GNSS), personal locating beacons (PLBs), and mobile phones, this is still simply the reality we live in. There are hundreds of SAR units across the United States and many others across the world that are there to help. Volunteers usually staff these units, regularly investing their time-off to support others. Reducing the time spent searching for these people in need of aid is to the benefit of both the lost and the searching. Techniques that assist the planners in defining the search area will likely lead to finding the lost subject in less time, which dramatically increases chances for survival (Cooper, Frost, and Robe 2003). GIS in SAR is not a replacement for other SAR tools, such as paper maps and expert planners, but can be an enhancement working to supplement and validate other capabilities.

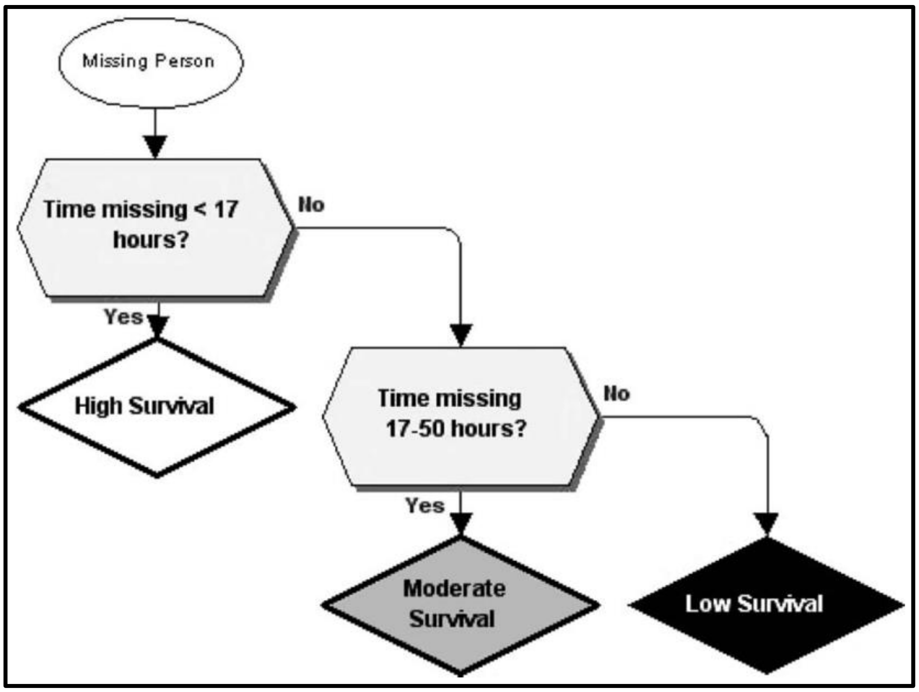

Figure 1 Model produced by a classification and regression tree (CART)
(Source: Adams et al. 2007)

Search and rescue teams often organize at the county level and can vary greatly from one jurisdiction to another. In California there is typically one Sheriff's Deputy assigned to the SAR team. The team has a SAR Volunteer Coordinator that works issues often at the strategic level and various team leaders working at the tactical level. The broad structural goal is for the group to organize according to the Federal Emergency Management Agency's (FEMA) Incident Command System (ICS) as shown in Figure 2. This system allows for command and control, is familiar to the emergency management community, and can scale from a small incident to one that requires aid from other nearby teams or potentially those from across the state.

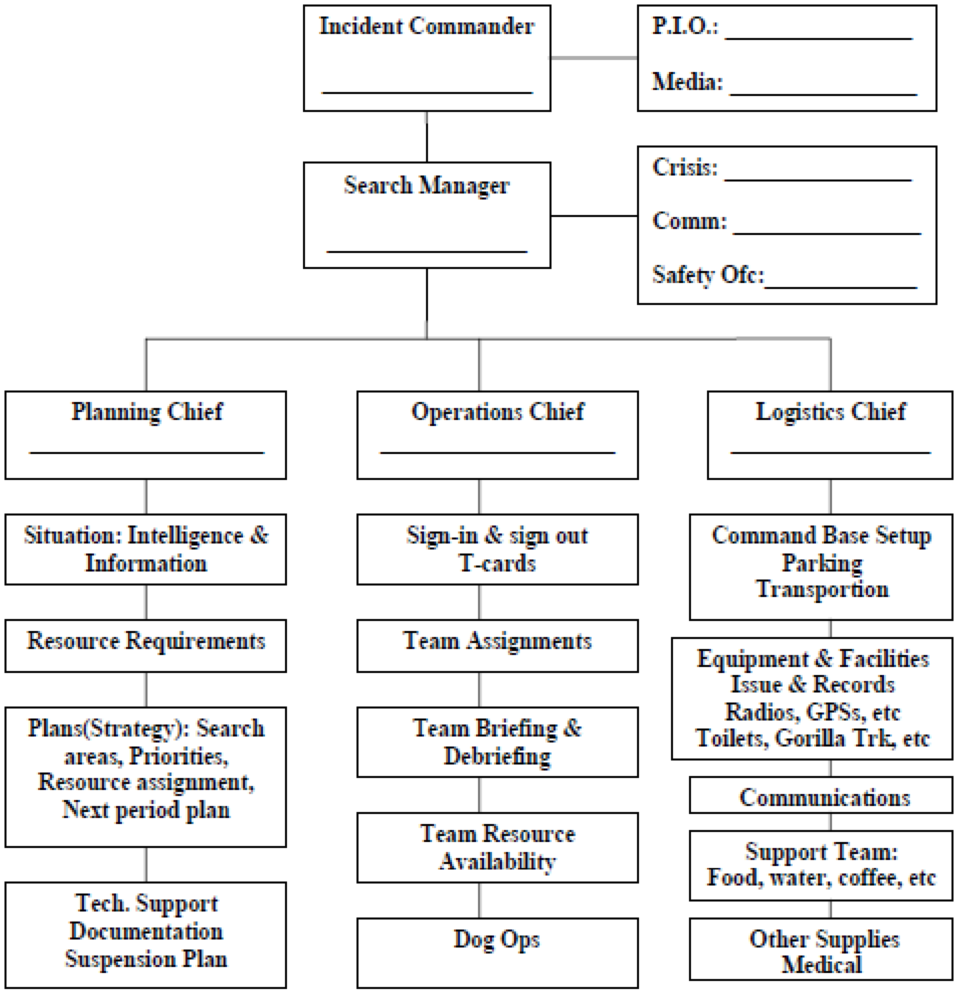

Figure 2 Example ICS-based organizational chart for a SAR team

Often volunteers arrive ready to search yet the planning team has not had enough time to divide the area into efficient search segments for the three to five person search teams. Getting the search teams out initially can be a bottleneck. Being able to use a mobility model to assist in the decision process may help speed the process. Thankfully, 50% of searches end with the subject found in three hours or less (Koester 2008). When the subject remains missing after a number of hours, using the search teams effectively becomes a major concern because the area that a missing person may possibly be located in becomes exponentially larger as time continues. Having a good estimation of how far a person potentially could travel in the various directions, given the relevant information, would be valuable. With this information, the planners would be less apt to send search teams out into areas where the subject is unlikely to be. This is where a GIS mobility model with the capability to adjust different variables may prove useful.

1.2 Why Study a Mobility Model?

GIS has been somewhat involved in the search and rescue field for many years and even more so today as technologies in software, hardware, and data acquisition advance. To address the administrative aspects of a SAR incident, developers created a few GIS software solutions, such as MapSAR and Terrain Navigator Pro that focus on facilitating operations rather than informing operations. Over the last few years, analyzing the potential of GIS to identify a missing person's location more effectively and efficiently is receiving more attention (Doherty et al. 2014). While there has been a fair amount of study on mobility models in general, also referred to as a motion or cost-distance model (Vogt, Nikolaidis, and Gburzynski 2012), Sava points out that very few researchers write with regard to search and rescue operations (Sava et al. 2015; Doherty 2013).

With today's remote sensing, digital storage, and computer processing capabilities, coupled with the accumulating historical SAR incidence data, geographic information science (GISci) should be able to contribute to search and rescue endeavors to a greater degree. A GIS can accurately and efficiently evaluate geographic data such as streams and watersheds, elevation, vegetation, geology, transportation routes, etcetera, to develop a travel cost layer. This layer, combined with information regarding the mental and physical characteristics of the lost person, then can calculate and illustrate the areas a person could likely travel to in a given amount of time. This method will not lead the searchers directly to the missing person, but if it can more accurately determine the search area, it is a step in the right direction.

Lately, a few people active in the SAR community started rigorously examining what more GISci can bring to the search and rescue field (Doherty et al. 2014; Durkee and Glynn-Linaris 2012; Ferguson 2008). Each paper contributes in its unique way, with some addressing the methodology and others looking more at the data collection and its conditioning. While working with data is a foundational part of any project, the focus of this research is evaluating the usefulness of a GIS-based mobility model in search and rescue operations. As our society encourages people to get out and enjoy the outdoors, equipping SAR teams with better tools such as mobility models may be significant, especially to those that have been lost and found or injured and rescued.

1.3 Research Objectives

The main objective that this research addressed was to evaluate whether a GIS-based mobility model tool can be useful in search and rescue operations. Three underlying sub-objectives support this overall objective. The first is assessing if using a mobility model GIS tool is feasible without having extensive training. The second is considering if the process is executable in a short timeframe with limited computing resources. The last underlying objective is determining if the model can reliably give the incident command (IC) planners an effective outer limit for their search areas. Ultimately, checking this tool in real-world situations will decide its true utility. In order to arrive at the overall research objective, various areas were investigated including GIS analysis techniques currently used in SAR, search theory, lost person behavior, search operations, wilderness search and rescue, and travel cost modeling. These subjects either led to the current line of study or supported the investigation into the utility of mobility models in the search and rescue context.

1.4 Research Overview and Stages

This research took a number of different turns following the discoveries of work already completed coupled with a better understanding of the data. Initially, the thought was to create a model that would display the greatest likely distance that a lost subject would travel in a given amount of time. Both static and dynamic environmental conditions would have been the basis for the calculations as well as the subject's particular relevant characteristics. During the research for this approach, a tool that executed some of these very tasks was discovered. Ferguson developed a model in an Esri ArcGIS template called Integrated Geospatial Tools for Search and Rescue (IGT4SAR), which also includes many other SAR tools (Ferguson 2012). Exploration of different avenues occurred upon that discovery. Examining the impacts of using different land cover data sets, or using different resolution elevation data sets were considered as potential points of focus. Ultimately, determining the usefulness of the existing mobility model became the main goal. This effort broadly included completing initial research to define the appropriate research objectives, deciding on a methodology, searching for applicable data sets of actual SAR incidents, executing the method, and evaluating the results.

The specific study area, illustrated in Figure 3, consists of two Oregon counties, Lane and Deschutes. The decision on the area came following an evaluation of availability and characteristics of a number of different SAR incident data sources. Balancing the number of incidents, computational time required, and diversity of subjects and topography, all were part of the decision process.

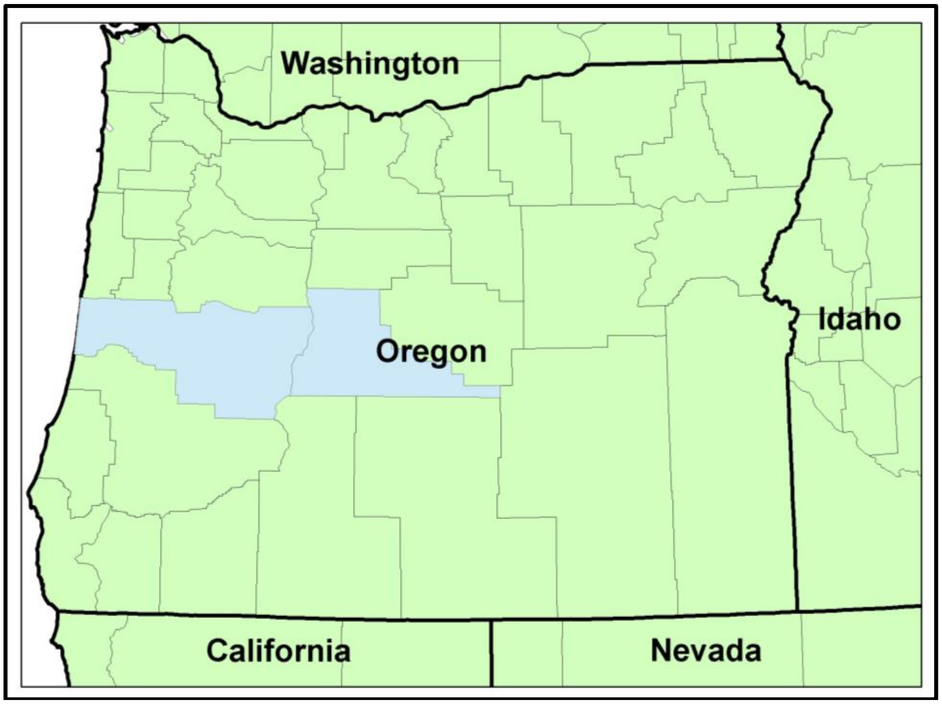

Figure 3 Study area in blue (Lane and Deschutes Counties)

1.5 Expected Outcomes

Expected outcomes developed from the beginning of the study and continued throughout the rest of the process. Before learning of IGT4SAR, there was an expectation that a GIS-based SAR mobility model could be learned rather easily. Another was that the anticipated calculation time for developing a furthest extent search area or containment distance would take 10 to 20 minutes with a reasonably capable computer. Having had discussions with experienced SAR personnel and initially working with IGT4SAR on two SAR incidents, the major expected outcome was that 100% of the lost subjects would be found within the model's containment distance assessment. There was also an expectation that the model would greatly overestimate the furthest point a subject could travel in a given amount of time.

Chapter 2 Existing Research Relating to Search and Rescue

This chapter is based on an extensive literature review coupled with discussions with experienced SAR volunteers. Those contacted included people from both the west and east coast. Some came from an academic perspective but all were actively serving in the SAR community. The literature review was ongoing and included sources written specifically for SAR as well as those that examined associated or supporting topics. Much of the related research was located in journals although a number of books and websites were found to be relevant.

In November 2015, the National Alliance for Public Safety GIS (NAPSG) Foundation sponsored an excellent workshop held near Yosemite National Park called SARGIS7 that drew more than 50 people with interests in SAR, GIS, or both fields to discuss advancing the connection between the two (Doherty 2015). This provided an opportunity for some important dialogues with leaders in this area of study. At the workshop, Donald Ferguson, PhD traveled from the east coast and presented his extensive work on the only publically known GIS-based mobility model for SAR (Doherty et al. 2014). The model is one tool among a multitude that are part of an impressive template for ArcMap called Integrated Geospatial Tools for Search and Rescue (IGT4SAR).

2.1 Search and Rescue Science

It is crucial to remember that a rescue cannot happen without first finding the subject. Many people become lost each year, and this has been the case for countless years. On the other side of these situations is that fact that, usually, there are people out there searching for these people. Beyond just lost subjects there are also other things people search for, such as animals, plants, gold, and even one’s military enemies. Surprisingly, the task of searching for people and things had not been scientifically addressed until World War II.

2.1.1. Early Research

Bernard Koopman was the first to address search theory in literature after working for the US Navy during the Second World War (Koopman 1946). He worked on a team that was assembled to conduct research that could help military operations improve, it was called operations research. This discipline is still alive and well although it is applied to much more than just military operations today. Koopman's original charge was to locate enemy ships and submarines. As promise was seen in the work, it was also applied to searching for friendly pilots that had been shot down over the Pacific Ocean. While there are vast differences between searching on land and searching on the water, which has no slope to speak of, roads, or surface differences, the general theory is still quite applicable. It was somewhat unanticipated to see how much high-level math is involved in what appears to be a relatively simple concept.

In search theory there are basically two costs that need to be considered. The most obvious is the cost of the search, which can be measured in terms of time, money, effort, etcetera. The other is the cost of the subject being searched for, which can also be measured in a number of different ways including money, inconvenience, or even lives. These two costs need to be balanced. For example, if a person loses a pencil between their home and a destination five miles away, the cost of the search would far outweigh the cost of the pencil. The opposite is also true and in the case of searching for a missing person, it is likely the only cost considered too high would be if someone on the SAR team had his or her life placed in grave danger or if the subject cannot be found and the exposure time overwhelmingly indicates death.

2.1.2. Search Theory Applied to SAR

Put simply, the search theory idea is that in order to find something, searchers need to be looking in the right area and be observant enough to detect the object when the correct area is searched. The right area is represented by the term probability of area (POA) and is calculated partly from the subject's point last seen (PLS) or their last known point (LKP). Either of these points can be used by the team as their initial planning point (IPP). The likelihood that the searcher would detect the object being looked for is referred to as the probability of detection (POD). Both the POA and POD are expressed as percentages. The POA is the percentage chance that what is being looked for is in the area being searched. There can be some confusion here as some in the SAR community, primarily in the maritime environment, refer to the probability of area concept as the probability of containment (POC) (Koester 2008; Lovelock 2008).

In SAR operations, one team cannot search the entire area in which the person is likely to be found, so the search manager divides the area into smaller segments as seen in Figure 4. The whole search area's POA should approach a value of 100% when adding all the search segments together but some portion should be allocated to the area outside the designated search area. This area outside the search area is termed the rest of the world (ROW) (Phillips et al. 2014). The larger the planners draw the search area or POA, the smaller the ROW percentage will be. The goal is to get the POA to be as small a geographical area as possible while keeping the ROW percentage as small as possible. Each team's smaller search segment will potentially be in the 5-25% range.

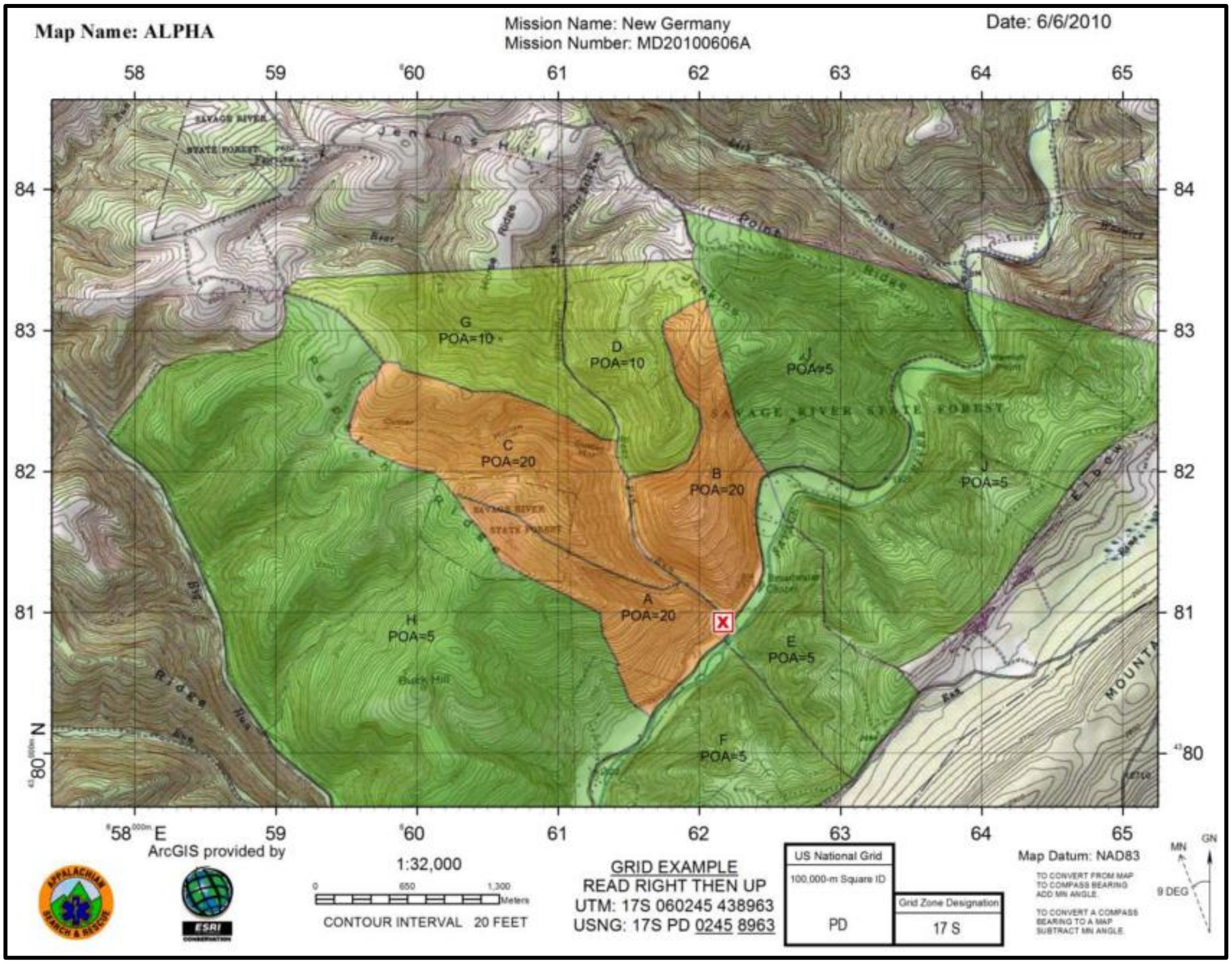

Figure 4 Example probability of area (POA) map divided into search segments with red indicating a higher POA and dark green a lower POA (Source: Ferguson 2008)

The POD is how well the search team searches their segment. It is considered physically impossible to search any area to 100% coverage so, on extended searches, a segment may be searched more than once in order to increase the percentage covered for that segment. Key variables influencing POD are the team's competence, speed, spacing, as well as the conditions such as vegetation, topography, lighting, and so forth (Phillips et al. 2014). There are different ways this variable is determined. One of the simplest is when a team returns from searching their assigned segment, they are asked something along the lines of "if 10 subjects were lost in your segment, how many would you have found?" A more technical means is downloading the track log from their global positioning system (GPS) device and then buffering the track to the distance the team was spaced, also called an effective sweep width (ESW), and then finally calculating the percentage of their search area that is intersected by the buffered area. Combining both answers to establish a number is also used. The result expressed as a percentage, using whichever method, is the POD.

The probability of success (POS) in finding the subject equates to the probability of area multiplied by the probability of detection. This is illustrated in Equation (1).

$$POS = POA \times POD \tag{1}$$

Lost person behavior (LPB) is studying what people do when they become disoriented in the wilderness in order to try to better estimate where a lost person might be. This is helpful because a typical person can walk three miles in an hour, which quickly makes for a large search area. Syrotuck completed seminal work in this area in his examination of 229 incidents, mainly from the states of Washington and New York (Syrotuck 1976). He divided lost people into six categories: small children, children, hunters, hikers, miscellaneous outdoors, and elderly people. He calculated and averaged the distances they traveled in flat and hilly terrain. He then determined the distance ranges these people, by quartile, were found from the place they were last seen. This information assists in keeping the search area to a more manageable size.

Combined with these statistical aids, decision by consensus is often used either informally or formally. This is done by having experts evaluate the possible distance and direction the subject would take, ranking their choices privately so as to reduce bias, and then combining the evaluations to determine the group's decision. The associated output can be seen in Table 1 (Mattson 1980).

Table 1 Simple consensus matrix (Source: Mattson 1980)

Person	"A"	"B"	"X"	"Y"	TOTAL	CONSENSUS
Route I	40	50	50	40	180/4=	45%
Route II	30	30	20	40	120/4=	30%
Pos. A	20	10	20	10	60/4=	15%
Pos. B	10	10	10	10	40/4=	10%
Total	100%	100%	100%	100%		100%

2.1.3. Recent Research

More in depth LPB research has recently been done by Koester. Through a USDA grant, his dbS Productions LLC has gathered data sets from across the United States and around the world accumulating more than 50,000 SAR incidents. The International Search and Rescue Incident Database (ISRID) has allowed Koester to further divide lost people into 41 categories and the incidents into multiple ecoregions. The larger sample sizes provide greater confidence in his statistical analysis, which considers distances from their point last seen, track offset, and mobility hours, among others. Koester's book, *Lost Person Behavior*, is known throughout the SAR community and seen as an essential resource by those that study search and rescue operations (Koester 2008). Work has also been done on developing a Bayesian approach to modeling LPB with the ability to incorporate SAR planners' expert opinion and terrain data (Lin and Goodrich 2010)

More recent advances in SAR science have come from Doherty's work in Yosemite National Park (Doherty 2013). He looked at a number of search and rescue tasks and connected them with GIS capabilities. The three broad areas investigated were prevention, search, and rescue. The preventative search and rescue (PSAR) aspect discussed georeferencing text-based data from previously written reports into a format appropriate for analysis. The searching section investigated ways GIScience can assist the established statistical models to better determine a search area. This work was done in conjunction with Ferguson (Doherty et al. 2014).

The rescue component compared two models, one expert-based and one GIS-based, that were used to select subject extraction points that are accessible by helicopters (Doherty, Guo, and Alvarez 2011). Jacobs has also recently contributed to the field in his report for the National Association for Search and Rescue (NASAR) which identifies what geographic features lost subjects are often found by and their frequency (Jacobs 2015). This analysis was done independent of the person's last known point partly because those points are of limited number and quality.

2.1.4. Current Use of SAR Science

Even with the work done in search and rescue science, the adoption of new ideas is slow. Syrotuck (1976) and Koester (2008) are frequently referred to in SAR trainings, more often with training for incident command team members rather than the searchers themselves. Rose found in her 2015 study that while GIS had some of the most advantages of the mapping technologies used by SAR personnel, it is not used as often as other traditional methods because it is considered difficult to learn (Rose 2015). Many training courses are still using Syrotuck's probability zones and probability tables from the 1970s, which come from a much smaller set of data than the ISRID.

A large part of SAR science uptake involves the collection and storing of incident data. The ISRID is the largest database as it compiles data from around the world. A challenge there is the consistency of the data with some groups tracking all fields with a great deal of accuracy to groups at the other end of the spectrum reporting very little information. Access to data is another limiting factor to the adoption of the science. The case is likely that most of the SAR teams are not recording their search data and uploading it to a larger collection effort. States like Oregon, New York, Washington, and a few others are collecting data but many are not. California, often an environmental and technical leader, is just starting to revive theirs. The 2015 State Search and Rescue Coordinators Council (SSARCC), which is where those state employees that oversee their state's SAR operation meet, had 11 states attend. Between this number, which is an indicator of the level of many states' engagement, and the fact that there is no standardized data collection tool or mechanism listed at their website, highlights the lack of collective effort at establishing a larger SAR data gathering mechanism (SSARCC 2016).

Even with the somewhat slow uptake, the future of SAR science with its use of GIScience is bright. More people are conducting research in the field and data is becoming easier to collect, share, and analyze. Other areas that are specifically being investigated that have a GIS connection at the practical level are the use of unmanned aerial systems (UAS) and mobile phone triangulation (Durkee and Glynn-Linaris 2012; Goodrich et al. 2008). Areas that have promise of being practical but are more theoretical are agent-based models (ABM) and Bayesian models (Doherty et al. 2014; Lin and Goodrich 2010).

2.2 Mobility Models

Mobility models have been used for a number of years and look at how animals, vehicles, people, etcetera move over time. These models primarily look at nodes within a network and as of late, particularly wireless devices on a network (Vogt, Nikolaidis, and Gburzynski 2012). This work deals with advanced math and is moving forward as data from wireless networks become more available. Mobility models can be generic or they can be developed for specific situations such as visitors at theme parks (Solmaz, Akbaş, and Turgut 2015). These models are often evaluated by comparing their results to GPS track data. Mobility models have been used in urban planning, anthropology, and wildlife studies (Doherty 2013). In these models, costs are calculated by applying a least-cost path algorithm to a source raster and a resistance raster (Adriaensen et al. 2003).

Often times, in search and rescue events, the subject either has no phone or there is not a sufficient network signal. It would be an interesting study to see how many GPS tracks could be accumulated from lost subjects that actually had connected devices. This would further connect mobility models and search and rescue operations.

Tobler's Hiking Function is foundational to mobility modeling in search and rescue (Pingel 2010). It is an exponential function that determines hiker’s speeds. The function estimates how fast a hiker will travel based on the slope angles encountered. This function should be an important component in calculating potential distance covered.

A joint study between George Mason University (GMU) and Brigham Young University (BYU) produced an online tool called MapScore that can be used to evaluate models using the ISRID although at this point, it appears MapScore is not capable of evaluating a full GIS-based mobility model (Twardy et al. 2011). In Ferguson’s IGT4SAR template, he has incorporated multiple variables in his Theoretical Search Area model. This particular model receives more attention below.

2.3 Mapping Tools Used in Search and Rescue

Some SAR units have been using GIS extensively yet it is not commonly applied to search theory (Rose 2015). A few teams use ArcGIS for Desktop but of those that use some sort of GIS tool, more use a software package designed specifically for search and rescue operations. There are several mapping tools available that cover tasks search and rescue teams frequently execute (Pfau 2013; Rose 2015). The oldest and most often used is the paper map and a pencil.

This tool is low cost, uses no batteries, and is familiar to most people. Although, as the next generation moves to a greater extent into SAR operations, fewer people may have a history with paper maps, having relied on digital devices for their navigation.

There are a few different options for digital mapping available to planners. Google Earth is an intuitive tool used by many organizations that gives more up-to-date information than paper maps, can show imagery, can store location information, and has many other strengths. SARsoft, also referred to as SARtopo, is a tool that is browser-based that can also be used offline. The offline version can be operated off a team's own remote server so multiple users can work with the same data on the same event. It has many excellent tools to assist in the administration of the search.

MapSAR is an ArcGIS template and was a seminal project that made using a fully capable GIS more accessible to the SAR community (Pedder 2012). An updated version is currently being developed using ArcGIS Pro and its expanded capabilities. Terrain Navigator Pro (TNP), OziExplorer, Mission Manager, and National Geographic Topo! offer other SAR mapping solutions (Rose 2015). Of the various offerings, IGT4SAR has the most advanced collection of analysis tools available and is further detailed in the next section.

2.4 Integrated Geospatial Tools for Search and Rescue

Integrated Geospatial Tools for Search and Rescue (IGT4SAR) is an ArcGIS template that had its beginnings in MapSAR. It is a free, open-source template licensed under the terms of the GNU General Public License as published by the Free Software Foundation and is available on GitHub (https://github.com/dferguso/MapSAR_Ex). This is the most advanced GIS analysis package for SAR operations. It offers not only multiple tools supporting administrative functions but also may be the only one that offers multiple analysis tools. Specifically, IGT4SAR incorporates a mobility model called the Theoretical Search Area model.

2.4.1. Available Tools

To work with the IGT4SAR, a new incident must be created based off the original downloaded template. This will bring into ArcMap a customized IGT4SAR toolbar and in the catalog window a home folder including an Esri geodatabase (GDB) and map file (MXD). In the toolbar, there is a palette with six groups of tools as seen in Figure 5. Having a palette is helpful considering the number of tools available. These tools are viewable in the Catalog under the SAR_Toolbox10b toolbox and are typically well explained in the help section. All but two of the tools are written in Python and the others were created using Esri's ModelBuilder. One important point is that most of these tools require input or uploading of other supporting data sets in order to be effective. The template does help with team effectiveness and efficiency but it does not magically create the inputs.

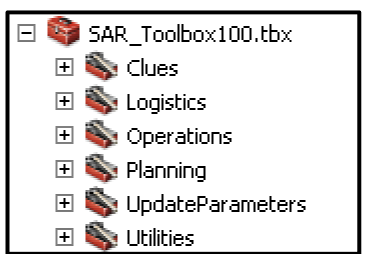

Figure 5 IGT4SAR's main toolbox

The Utilities group has six tools within it. This is where the user finds the Create New Incident tool. Here, a user finds tools to export both the feature layers in to Esri or Google Earth formats, as well as exporting table data to Microsoft Excel. Other tools include Plot Point Locations for adding points and Select Features by Distance from IPP (Initial Planning Point) which is the primary point a SAR team uses to plan their activities. As can been observed in Figure 6, printing maps using a Map Book is the sixth tool available.

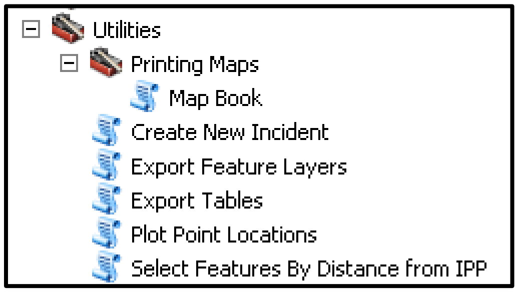

Figure 6 IGT4SAR's Utilities toolbox

The next group of tools is called UpdateParameters as seen in Figure 7. This is also a grouping of utility-like tools. Search Area Names and Update Domains updates the respective items in the user-defined folder. Update Map Layout refreshes the Universal Transverse Mercator (UTM) zone, United States National Grid (USNG), and magnetic declination based on the Incident Information Layer.

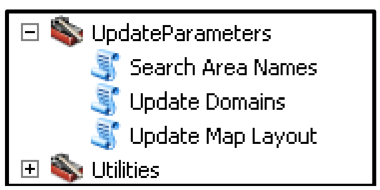

Figure 7 IGT4SAR's UpdateParameters toolbox

In the Clues group, there are two tools. Both tools use ModelBuilder, Esri's internal graphical modeling tool. Figure 8 shows the first is a ClueHotSpot tool that uses Getis-Ord G statistic to help planners assess the clustering of clues. The second is Hot Spot with Rendering.

Figure 8 IGT4SAR's UpdateParameters toolbox

Logistics is another grouping in the SAR toolbox, and is shown in Figure 9. The Estimated Radio Coverage tool uses a Digital Elevation Model (DEM) and the radio's sensitivity to provide an estimate of signal strength for the team's radios. It considers tower power, transmitter and receiver gain, and other factors specified in the user-entered radio tower feature class. If coverage is not complete in the search area, the Repeater Locations tool will analyze the optimal locations to place radio repeater stations. To facilitate the extraction of the subject after they have been found, there is a Helicopter LZ (landing zone) tool. This tool uses Interagency Helicopter Operations Guide (IHOG) standards to select safe landing areas. This tool uses a given extent, DEM, National Land Cover Database (NLCD), LZ size, and slope to determine potential areas. A machine learning LZ model has been examined against expert opinion in the Yosemite National Park and the two methods matched 90% of the time with the model correctly identifying 95% of the points in the test location data set (Doherty, Guo, and Alvarez 2011).

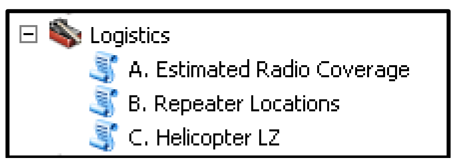

Figure 9 IGT4SAR's Logistics toolbox

The Operations group of tools includes eight different options. Two create forms for the missing person and the search team's assignment as can be seen in Figure 10. There is a Coverage tool that analyzes the search team's global position system (GPS) device data to determine their POD. The GPXtoFeatures tool uploads information such as clues from a GPS into the GDB. Two tools are available to create a pre-defined search pattern for piloted aircraft or UAS given the pattern type and sweep width. If an internet connection is available, there is a tool that will retrieve the weather forecast. The last tool exports the post-incident data into a file that can be shared using the ISRID data format.

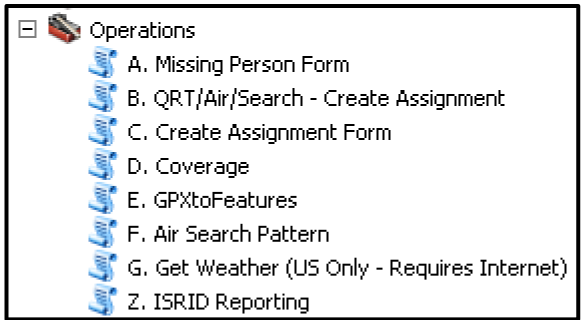

Figure 10 IGT4SAR's Operations toolbox

The final group in the SAR_Toolbox10b is Planning. This group contains 18 unique tools. Seven of the tools use some method to assist planners in approximating the subject's location. These include Koester's Statistical Search Area, Track Offset Model, Find Locations, and Elevation Model (Koester 2008). One is from Doke's Watershed Model (Doke 2012) and another is Jacob's Stream Interface finding (Jacobs 2015). The last model is Ferguson's Theoretical Search Area, which uses two tools. The first is a Cost Distance model that creates an impedance or friction surface. This surface is then used by the Theoretical Search Area tool to develop a least cost path distance surface from a given point grouped by time units. Other tools include the Segment Search Speed tool, which estimates the team's speed based on the friction surface, a PSR (Probability of Success Rate) Estimate, Slope Analysis, Cell Coverage based on entered cell tower data, and a Resource Estimation tool that approximates how many searchers will be needed. Other features include QR code generation, many other forms, multiple pre-established map formats, radio log, and personnel tracker to list some as captured in Figure 11 below.

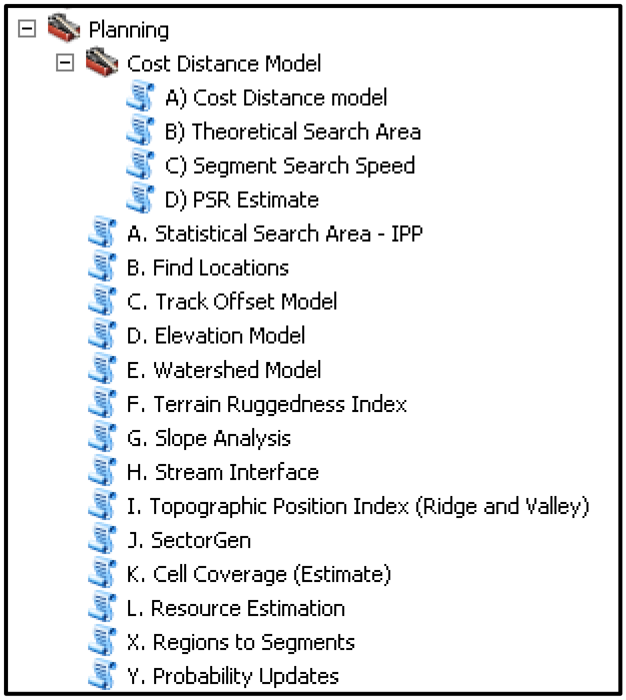

Figure 11 IGT4SAR's Planning toolbox

2.4.2. Mobility Model

The Cost Distance model and resulting Theoretical Search Area model are of primary interest here. The Cost Distance model is basically an impedance layer calculated using multiple underlying layers and map algebra. The map algebra adds overlapping cell values from input layers to determine a cumulative impedance score. Cell values range from zero to 99, which indicates no friction or impedance like a level road (0) to something that is impassable such as a lake (99). The elevation surface is calculated by applying Tobler's Hiking Function (Tobler 1991) to the DEM created slopes, both uphill and downhill, in order to obtain the raster's impedance values. Excessive slope is determined when it is greater than 60% and the impedance is then valued at 99 or impassable. As seen in Table 2, a land cover impedance value is attributed to each of the land cover types in the NLCD with open water deemed impassable at 99. Table 3 lists some examples of the federal codes for roads but the walking impedance is at zero for each, although there could be impedance associated with a road due to its slope. The values for trails are seen in Table 4. Streams and rivers are given a value based on the specified or calculated size of the feature.

Table 2 Land cover impedance values

LAND COVER CODE	DESCRIPTION	IMPEDANCE
11	Open Water	99
12	Perennial Ice/Snow	80
21	Developed, Open Space	20
22	Developed, Low Intensity	20
23	Developed, Medium Intensity	30
24	Developed, High Intensity	40
31	Barren Land (Rock/Sand/Clay)	60
32	Unconsolidated Shore	70
41	Deciduous Forest	50
42	Evergreen Forest	50
43	Mixed Forest	50
51	Dwarf Scrub	75
52	Shrub/Scrub	75
71	Grassland/Herbaceous	50
72	Sedge/Herbaceous	50
73	Lichens	20
74	Moss	20
81	Pasture/Hay	20
82	Cultivated Crops	30
90	Woody Wetlands	80
91	Palustrine Forested Wetland	80
92	Palustrine Scrub/Shrub Wetland	80
93	Estuarine Forested Wetland	80
94	Estuarine Scrub/Shrub Wetland	80
95	Emergent Herbaceous Wetlands	80
96	Palustrine Emergent Wetland (Persistent)	80
97	Estuarine Emergent Wetland	80
98	Palustrine Aquatic Bed	99
99	Estuarine Aquatic Bed	99

Table 3 Examples of the federal codes for roads. CFCC is a Census Feature Class Code, MTFCC is a 5-digit code assigned by the Census Bureau intended to classify and describe geographic objects or features

CFCC	MTFCC	MTFCC_FC	SPEED_LIMIT	Walk_Imped
A00	S1100	Primary Road	40	0
A01	S1100	Primary Road	40	0
A02	S1100	Primary Road	40	0
A03	S1100	Primary Road	40	0
A04	S1100	Primary Road	40	0
A05	S1100	Primary Road	40	0
A06	S1100	Primary Road	40	0
A07	S1100	Primary Road	40	0
A08	S1100	Primary Road	40	0
A09	S1100	Primary Road	0	0
A10	S1100	Primary Road	65	0
A11	S1100	Primary Road	65	0
A12	S1100	Primary Road	65	0

Table 4 Example trails impedance values

TRAIL_CLASS	DESCRIPTION	IMPED
1	Minimal/Undeveloped Trail	25
2	Simple/Minor Development Trail	20
3	Developed/Improved Trail	15
4	Highly Developed Trail	5
5	Fully Developed Trail	0

The next step is creating the mobility model, specifically the Theoretical Search Area model. The new piece of information needed here is the estimate of the subject's expected nominal walking speed. This is assuming the subject is walking across a flat surface with no slope. The default Walking Speed entry is approximately three miles per hour. The number can be adjusted for the environmental situation and the subject's characteristics. The harsher the conditions and less mobile the person is, the lower the Walking Speed entry. The estimate entered will be the maximum speed used by the model with impeding terrain lowering the speed.

Part of the output from this model is a set of continuous points that all take the same amount of travel time from the IPP. These points create a line, also known as isochrone rings, surrounding the initial planning point (IPP). These rings are the polygon boundaries of what are termed isochrone polygons. When visualizing the results, the impact on the isochrone polygons of roads, streams, water bodies, and slope is evident, ultimately enlarging or reducing the potential search area such as is shown in Figure 12. In the northwest portion of this map the influence is demonstrated by the isochrones extending along roads and generally shrinking back from increased slopes.

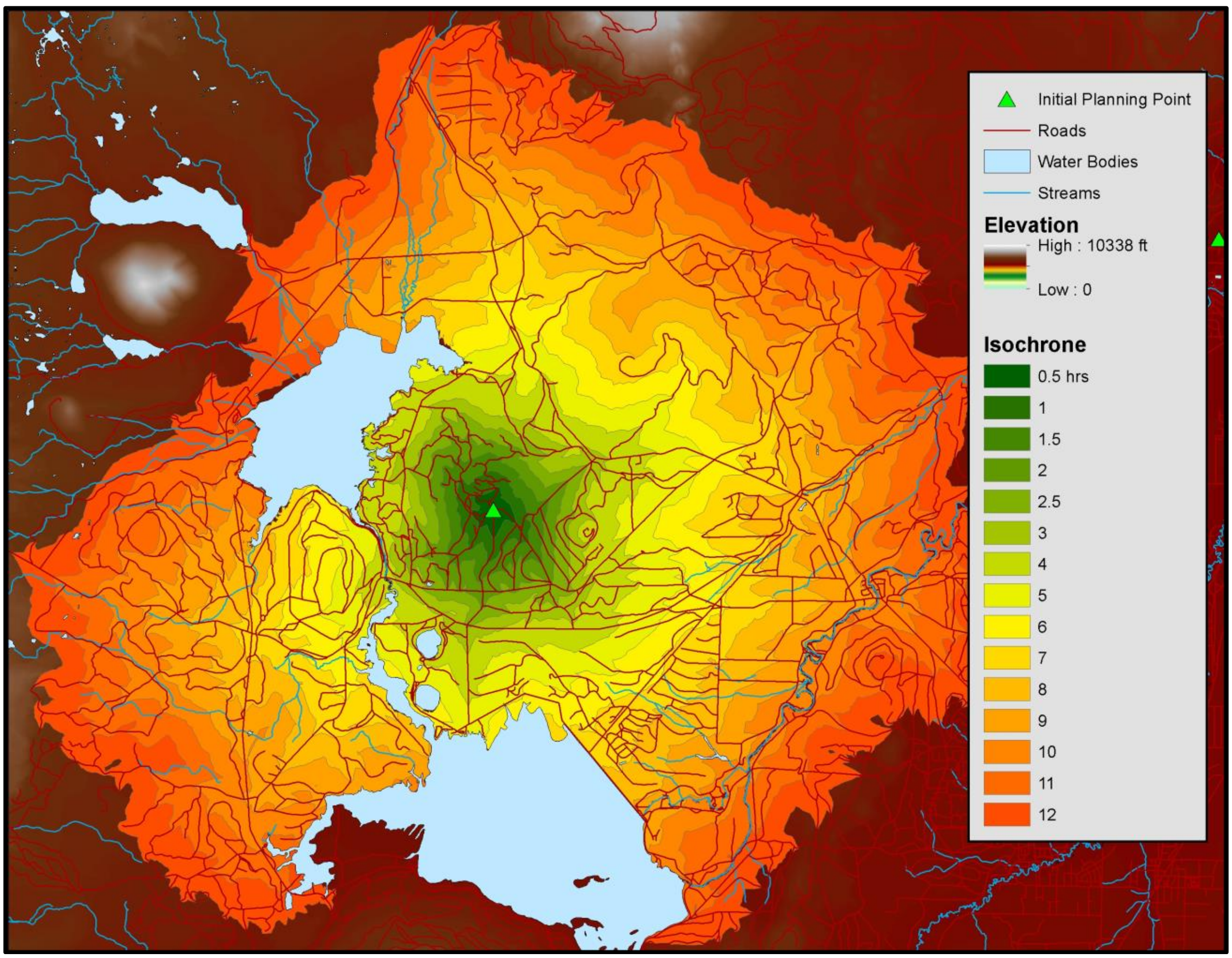

Figure 12 Example of terrain’s effect on isochrones and the Theoretical Search Area

2.4.3. Documentation

Although there has been substantial effort into documenting IGT4SAR, the template still has room for improvement. Most tools have comments in the help area that are helpful. Ferguson also attends major SAR events and offers free training where people can ask specific questions and really see how the tools work although only so many trainings can be given each year. There are 17 different portable document format (PDF) files and one README file that are included in a documentation folder that is created when IGT4SAR is initially copied. These documents cover detailed installation, administration, and explanation of various tools and workflows. There are also six YouTube videos created by Ferguson totaling approximately one and one-half hours (https://www.youtube.com/channel/UCrWNjhnpNOiEAATDzNw3lFg).

Even with all this information, the complexity of IGT4SAR is such that more references would be helpful. An example of help information that is missing is how to save the initial base data for a team's area of responsibility into IGT4SAR. Simply having the information that is currently available, systematically organized in one file, or at least linked would help in understanding IGT4SAR.

2.5 Summary

This chapter reviewed the previous research related to search and rescue operations. Koopman's early work in search theory as well as the research by Syrotuck, Koester, and Doherty have made major contributions to SAR operations. Search theory has been applied to SAR operations although adoption is slow and data collection needs to be improved. While there have been a number of studies done on mobility models in general, more work needs to be done specific to SAR. A few mapping applications have been developed for search and rescue but IGT4SAR really uses the power of GIS with its multitude of tools, specifically analysis tools.

The mobility model in IGT4SAR appears to be the first of its kind. The next chapter examines the research process, different aspects of the data, and the procedures used in this research.

Chapter 3 Data and Methods

This chapter has four sections. Discussing the research process for the project is first. The second part is an exploration of the data requirements. Data sourcing and condition is next with the final section being about the project procedures and expected outcomes.

3.1 Research Process

As stated in the first chapter, the main objective of this research was to evaluate whether a GIS-based mobility model tool is useful in search and rescue operations. In order to address this, three sub-objectives were identified. Stated as questions, these are:

- Is using a GIS-based SAR mobility model tool possible without having extensive training in both GIS and SAR? This was designed to be a qualitative assessment. The availability and usefulness of in-person training, tutorial videos, documentation, and hands-on time with the tools were all part of this assessment.
- Is the modeling process executable in a short timeframe with limited computing resources? This was assessed throughout the process, noting the time the various tools took to set up and execute.
- Is the output from the mobility model accurate enough that it can assist the search manager or incident command (IC) planners in determining an effective outer limit for their search areas? Most of the work was involved in addressing this question.

The research strategy began in the extensive literature review coupled with discussions with experienced SAR volunteers. It was at this stage that the first draft of the research objective and questions formed. More detailed consultations with local search and rescue experts took place following the initial literature review. Local SAR team members provided specific incident information for evaluation. Familiarity with the developed SAR mobility model started during the examination of these local incidents and gave an opportunity to begin to assess the level of knowledge needed to operate such a model. Collection of a good deal of local GIS data sets began as well as the conditioning of the data. After executing the initial runs of the model, the results were reviewed. During this time, larger data sets were being researched and requested in order to run the model on a larger sampling of incidents.

Following the investigation of the local incident data, a larger data set was chosen for the main project. For computational reasons, reduction of its number of incidents occurred. Once this paring down was complete, the next step was collecting the additional data sets required by the IGT4SAR mobility model such as elevation, land cover, hydrology, and transportation lines. More clipping and conditioning of the data occurred. To reduce the computational time, much effort was put into the editing of Python scripts used in IGT4SAR tools. The model processed through the selected incidents. Formatting and examination followed the exporting of the results from the ArcMap table into Microsoft Excel. Figure 13 illustrates the overall project process.

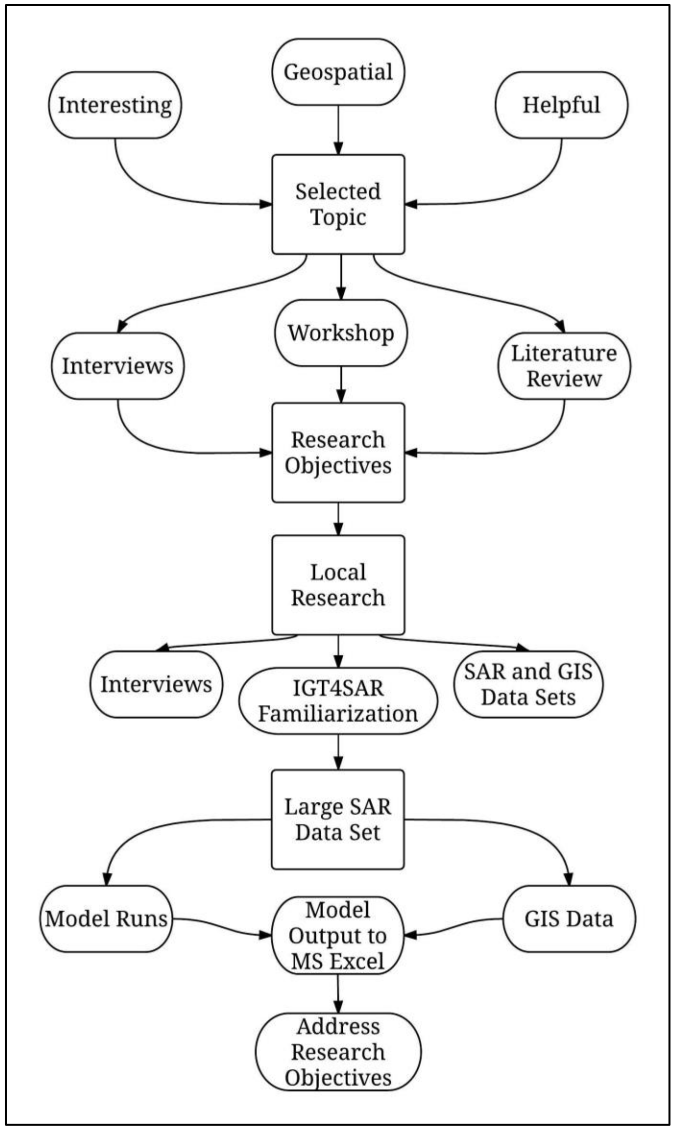

Figure 13 Overall Research Process

3.2 Software Used

The software primarily used in this thesis was Esri's ArcGIS 10.4 for Desktop, Microsoft Excel, and PyScripter. Within the ArcGIS platform, ArcMap and its Spatial Analyst extension, received the lion's share of the work. The IGT4SAR template, built using Python scripting, was used extensively. The more common tools used were the clip, project, merge, select by attribute and location, some mosaicking, and XY to line. There was much less spreadsheet work done compared to the amount done in ArcGIS as Microsoft Excel was mainly used to organize, sort, format, and otherwise manipulate and evaluate the finished model output data. A few very basic averaging and summing formulas were also used. The free PyScripter was used to edit IGT4SAR to save processing time during the actual process of running the model on multiple incidents.

3.3 Data Required

The data used in this research fall into two major categories. The first is the underlying environmental or base data sets that are used in the model. The other major data set was the compilation of actual search and rescue incidents to be used to test the accuracy of the model. Without either one of these data sets, the model cannot be properly evaluated. The more base data sets that are incorporated, the more accurate the model will be, assuming the data sets are accurate.

The foundational or base data sets that a comprehensive GIS-based mobility model for SAR should heavily rely on are elevation, land cover, lines of travel, streams, and bodies of water. Not only do these data need to be accurate but they also need to be available for large areas in order to complete an analysis that covers a variety of topography. Lastly, for the purposes of this study, the data sets need to be consistent, allowing comparison of an incident in one area to another incident a great distance away. Information on administrative boundaries, power lines, fence lines, and watersheds are also useful in IGT4SAR although only the power and fence lines are used in its Theoretical Search model.

The SAR incident data sets are not well developed but they are starting to move in that direction with low cost online portal solutions. Many other fields such as demography have a strong coordinating body at the federal level and they appear to conduct more studies that examine the field as a whole compared to SAR that has little research with unconsolidated data. The US Census Bureau, an authoritative source, collects, conditions, and distributes key data that demography and many other fields study. Those interested in traffic safety can search the National Highway Traffic Safety Administration (NHTSA) or the Insurance Institute for Highway Safety and find statistics. At this point, the SAR community does not have that sort of national aggregator of data except for Koester's ISRID, which is not publically available. The Mountain Rescue Association (MRA) is also collecting data from their teams in a standardized way at the national level. SAR data sets often rely on a volunteer entering the information about each incident. This volunteer may not have been involved in the search and may not understand the relevance of the data. These data sets can advance the science behind search and rescue and provide justification for the continued and expanded resourcing of SAR efforts.

3.4 Data Used in the Model

Sourcing the data for the environmental side of the process went fairly well whereas the search and rescue data set was somewhat more challenging. All the data used in this research was free. All were available online except the SAR data set, which required a special request.

3.4.1. SAR Data Sets

Choosing the SAR incident data set was required before any base data could be collected. Although there are not many different databases that could be researched, there are some. The three sources considered were Yosemite Search and Rescue (YOSAR) data, Oregon's Office of Emergency Management (OEM) SAR database, and the ISRID as listed in Table 5. Four criteria were used to select the data set were whether there was a sufficient number of incidents, diversity in terrain, variety of subjects, and if it was previously studied.

Table 5 Comparison of SAR data sets

Data Set	Number of Incidents	Diverse Terrain	Diverse Subjects	Other Academic Studies
Oregon state	4,447	Yes	Yes	Some
ISRID	>50,000	Yes	Yes	Many
Yosemite National Park	2,308	Somewhat	Somewhat	Multiple

The YOSAR information was recently used in at least two graduate course projects and the custodians of the data were very open to sharing their information. There is a good amount of variety in the terrain although the extreme landscape of the Yosemite area made it less attractive. Also, the park attracts more active users which led to less diversity in the subjects. The ISRID, which is the largest consolidated SAR database of them all and has been the subject of a number of studies, was developed and is owned by dbs Productions LLC and, while it is certainly shared, it is not as accessible as other governmental or non-profit databases. In the end, the Oregon database was chosen for further research since it best met the criteria. Incident points from this database can be seen in Figure 14. It appears to have been studied in Jacobs' work but otherwise it has not been used as much as the ISRID or Yosemite data.

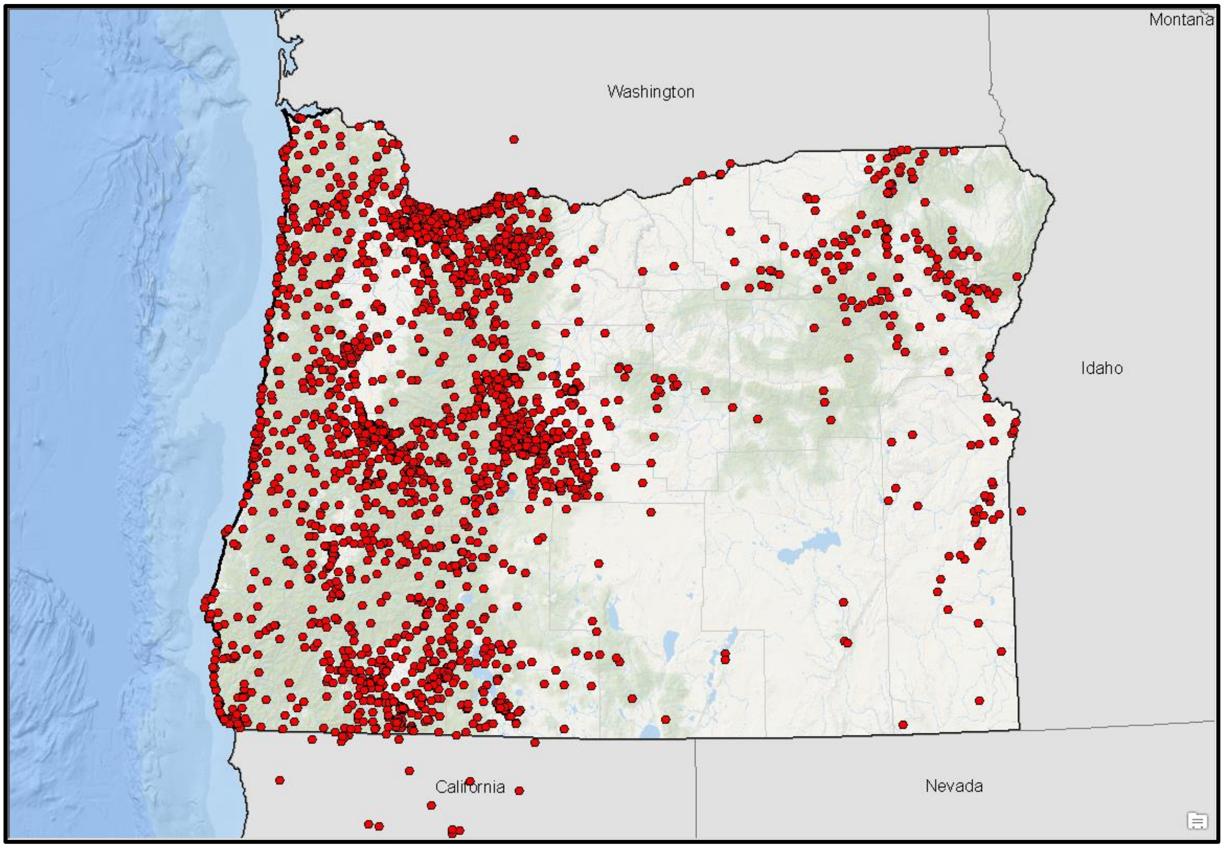

Figure 14 Oregon SAR Find Points, including out-of-state mutual aid operations

The Oregon database is extensive. It has a very large number of incidents recorded from 1998 to 2015 with most incidents recorded after 2010. There are a total of 4,477 subjects recorded although multiple subjects can be associated with one SAR event. There are 52 different fields stored in their database as seen in Table 6. Oregon has a form that SAR teams are required to fill out and it can be viewed in Appendix A.

Table 6 Oregon database fields and example data

Field Name	Field Value	Field Name	Field Value
OEMNumber	2014-2267	HuntingGame	No
IPPLat	45.6542	HuntingBirds	No
IPPLong	-121.64105	NordicSkier	No
IPPAlt	2395	OtherSkier	No
FindLat	45.6636072	Snowboarder	No
FindLong	-121.6458139	HorseRiding	No
FindAlt	2633	Swimming	No
IPPDist	3640	Powerboat	No
MissingLand	YES	OtherWaterAct	No
MissingWater	No	NonPowerboat	No
RescueLand	No	MotorVehicle	No
RescueWater	No	OtherAct	No
Water	No	Suicide	No
FalseInc	No	Wandering	No
BodyRecovery	No	Criminal	No
Other	No	VehicleTravel	No
Snowmobile	No	Recovered	Alive
Bicycle	No	Condition	Well
Climbing	No	Sex	Female
Hiking	No	Age	22
OtherWork	No	Group	Female solo
Unknown	No	AdultChild	No
MushroomPicker	No	ReportedDate	10/19/14 18:19
OtherPicker	No	FoundDate	10/19/14 18:52
OtherForestAct	No	Duration	0:33:00
Fishing	No	Narrative	[See report for details.]

3.4.2. Base data

Following the SAR database selection, collection of base data sets began. Because the data needed at least to span multiple counties, so that a large sampling was possible, sourcing was somewhat limited to the state and federal levels in order to ensure compatibility throughout. An important element is the quality of environmental GIS data covering the area of interest. The USGS was the source for the elevation, which is a complete and accurate data set at the 10-meter resolution. USGS also provided the land cover and hydrology layers. Both of these are the best, freely available data sets for this area and are considered complete and accurate. The lines of transportation, which run the range from major highways and unnamed dirt roads, was obtained from the GIS Unit in the Oregon Department of Transportation. They compile files from the many entities responsible for the roads in their particular jurisdiction. US Census Topologically Integrated Geographic Encoding and Referencing (TIGER) data was considered as a source for the transportation lines but it had much less detail. These data sets can be seen in Figure 15. All datasets were projected to NAD 1983 Oregon Statewide Lambert Feet Intl and clipped to the administrative boundaries of the two counties.

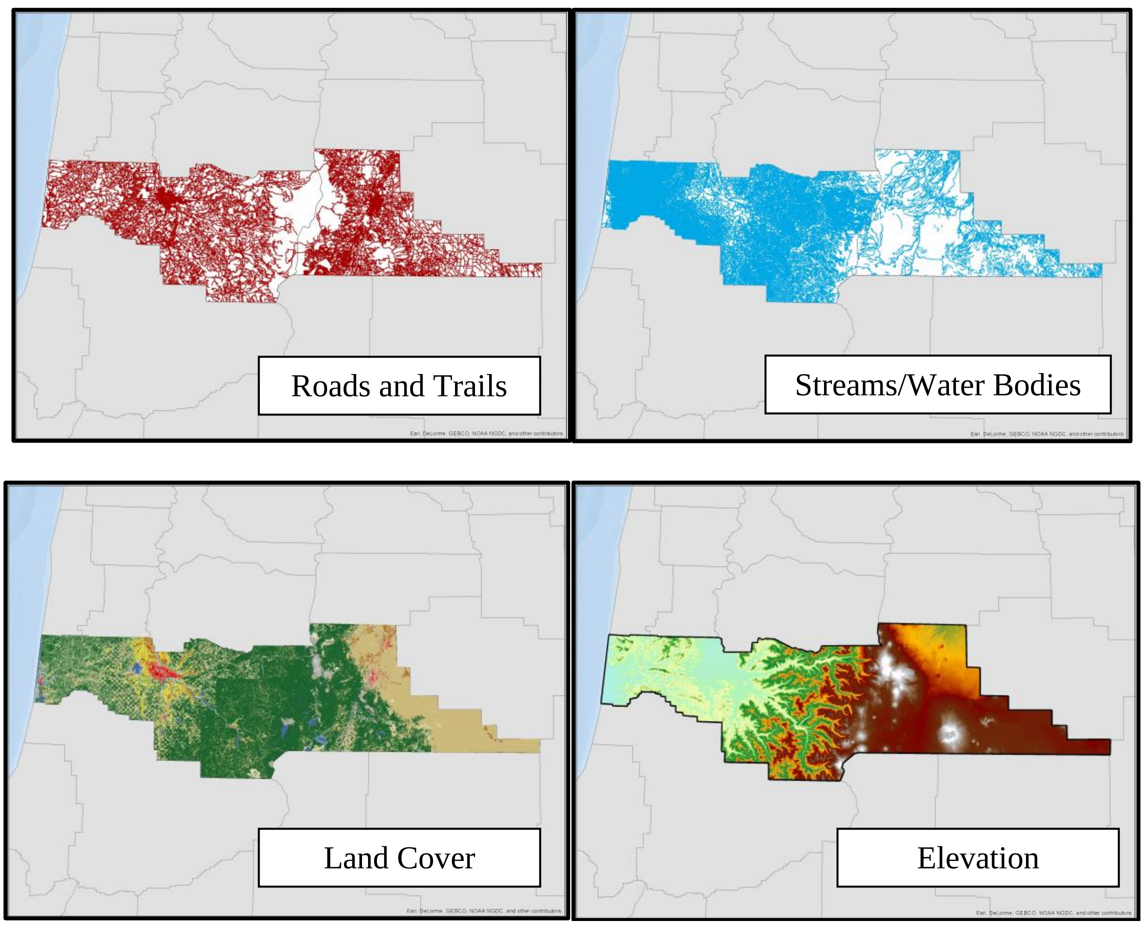

Figure 15 Base data for Lane and Deschutes Counties including roads and trails, streams and water bodies, land cover, and elevation

Considerable conditioning of the base data took place. In order for IGT4SAR to function properly, GIS data needed to be loaded into existing templated files so the model would know where to pull its data from, exactly which fields would be there, and the fields' names. This required field matching. When the attributes or their data types did not match, creating new columns and dictating attribute values using the field calculator occurred.

3.4.3. Conditioning the SAR Data

Conditioning of the Oregon SAR database took some more effort. Oregon OEM collects their data in Microsoft Access. They exported the information to Microsoft Excel and emailed it with the OEMNumber being the unique ID, or key, for each row of information. There were 4,447 rows of data, each representing one lost person. Not all of these rows contained the needed data points so some sorting and cleaning was needed. The first sort removed all rows that did not each have a value for IPP, Find Points, or recorded time. Also removed were incidents that were not land-based and those that were marked as being vehicle travel. That brought the number of rows down to 656. Further sorting led to selection of only incidents that had a time of 10 hours or less. This was done in order to keep the extent of computed search areas from becoming too large. Another deletion included removing multiple subjects involved in a single SAR incident.

This reduced group of incidents of 657 was then loaded into ArcMap to examine them with regard to concentrations and diversity of topography. Two contiguous counties in western and central Oregon contained a large number of incidents and have varying terrain. The Select by Location geoprocessing tool was used to choose SAR incidents in Lane and Deschutes Counties, creating a data set of 102. Finally, and importantly, to test the limits of the mobility model, the incidents were sorted by distance from the IPP to the Find Points. The 51 incidents with the greatest distance were then selected to challenge the model. The group was quickly reviewed to ensure there was still diversity in terrain and subjects.

3.5 Variables Required for SAR Mobility Model Analysis

There were three major variables and a number of other significant variables involved in the testing of the model in this thesis. The first major variable is the initial planning point (IPP) which is the primary point the SAR team uses to plan their activities. The IPP is usually either the last known point (LKP) of the subject or their point last seen (PLS). During an actual SAR incident, only the IPP is required for the model to produce an output.

The next variable used in this analysis was the point where the subject was found. In Oregon's database they are stored in latitude and longitude in WGS84. Capturing this point could be done any number of ways from a GPS reading to a post-operation map check so the recorded Find Point is likely accurate to within 5-100 meters. Interestingly, this location does not have a universal name but often is called the Find Point, Find Coordinates, Found Point, etc. In this thesis, Find Point is the terminology used throughout. The IGT4SAR template can incorporate these spatial variables in a variety of different geographic or projected coordinate systems using formats from decimal degrees to military grid reference system.

The last major variable is the amount of time the subject was lost. There is an expectation that the location data is accurate but the recorded time data does not reflect the time lost and can be misleading. For these data sets, usually the clock starts upon notification of the authorities or the SAR team, not when the person initially became lost. This is an important point because this delay gives the subject more time to travel and if it is not accounted for, the search area may not accurately represent the possible distance covered. The amount of time delay will vary greatly depending on the subject's typical pattern of life along with the reporting party's level of concern.

To evaluate the mobility model, the bare minimum attributes for these data sets are the IPP (LKP or PLS), the Find Points, and time lost. If one of these three variables was missing, evaluation of a SAR mobility model would be problematic at best. In addition, having good information about the subject's characteristics that relate to their speed traveled over a level surface will make the model's output more accurate and ultimately will add to the data set's usefulness in SAR research and resourcing.

Before beginning work with the Oregon incident database, two incidents from Nevada County, California using local base data readily available were explored to understand the problem set and gain familiarity with IGT4SAR. These incidents were used in the assessment of required training and the processing time that was required. These were both real situations that had fairly detailed information available. The first involved a person that was camping in an area known to the subject. After entering the variables, the model's outcome successfully gave an outer limit of the search area with the subject found within the distance IGT4SAR modeled.

The second case was a day hiker separated from the group during the return portion. Again, the model was successful as illustrated in Figure 16. The problem with these two incidents was that their circumstances did not challenge the model. The SAR team ultimately found the camper deceased close to the IPP. Nobody heard from the camper for a couple of days so the model created a very large search area since the actual time lost time was unknown. In the second incident the team found the person safe and the times recorded were generally accurate but the distance the subject traveled was quite short. Thankfully, this second situation is frequently the case but again, it did not push the model and, because of the variables in these cases, the model output was much larger than many planners would find useful. These incidents were important in gaining understanding of the data sets needed to run the model and their required conditioning as well as the operation and capabilities of IGT4SAR itself.

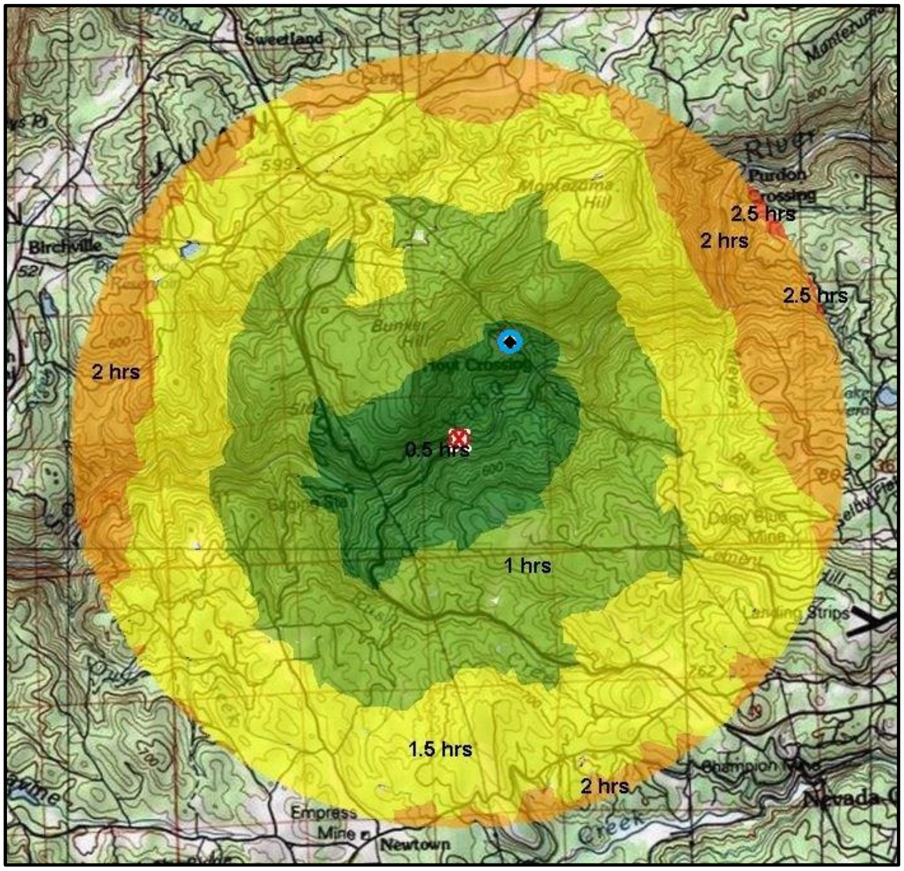

Figure 16 Map showing the mobility model output. The day hiker's IPP is in the center and found location is the black diamond in a blue circle to the northeast. The hiker had been lost for 1.5 hours and the search area generated is about 15,000 acres. The team found him within the 0.5 hour polygon, which is just over 1,700 acres. This was a positive result as the subject was found within the range of the model's estimation.

3.6 IST4SAR Model Processes

After developing the research process, determining data requirements, sourcing the data, and conditioning it, the process of running the model on the Oregon SAR data began. This section describes the model's typical workflow, changes that were made to the model for the research, and the output.

3.6.1. IGT4SAR Mobility Model Workflow

IGT4SAR uses three Python scripted tools to create its mobility model. The first tool, called Create New Incident, generates an incident folder that contains a geodatabase (GDB), map file (MXD), and seven subfolders with various files that IGT4SAR uses to plan for and execute search and rescue operations and administrative procedures. Variables required by this tool are the folder's location and name, coordinate system to use, and the type of form desired for task assignments. Teams plan their search using these forms. Entering other information such as the subject's name, incident's name and number, lead agency, and IPP information is optional. If it were not entered here, it would have needed to be entered before the next tool is run. After running this tool and opening the new MXD, the IGT4SAR template will be in place.

The Cost Distance model is the next tool needed in the procedure. Required fields allow the user to identify the file workspace, choose the subject, choose the IPP, select the distance units, and identify the DEM and NLCD data files. This tool creates an impedance raster, which is the beginning of a least cost path analysis, for the area around the IPP. It takes into account slope, land cover, transportation routes, streams, and water bodies (and fence and power lines if available).

The last tool is the Theoretical Search model. This tool needs the workspace, subject, IPP, distance units, subject's estimated walking speed, and the DEM. The unique variable here is the walking speed. This speed is assuming the subject is walking on unobstructed level ground at their normal pace. The average adult generally walks at three miles per hour (Tobler 1991). This variable is adjustable depending on environmental conditions or subject characteristics. The tool creates polygons that are bounded by isochrones at ½ and one hour steps expanding from the IPP. An isochrone is a line of points all having the same traveling time from a given location. At this point, the model output is complete.

3.6.2. Changes Made to IGT4SAR for Throughput Improvement

With the data sets and variables used in this project, the process of running the three tools and the three associated variable entries took almost 15 minutes to complete analysis for a single incident. This timing is fine for a single incident but the computing time needed to run the large number of sample incidents required for this project would be nontrivial. With this in mind, effort went into combining the mobility model processes using Python coding so that incidents could be run with minimal input. Because Ferguson naturally designed IGT4SAR to work one incident at a time, there were challenges.

The Cost Distance tool had 670 lines of code and the Theoretical Search Area has 275 lines of code. Ultimately, it was possible to combine the two tools by editing the Python to remove duplicate scripting and ensure the variable matched from one tool to the next. Another piece in the process was to write Python script that hard-coded all of the required input variables, except for the IPP. A portion of this revised script for variables is shown in Appendix B.

Working with the data began with an .xlsx file exported from Oregon's OEM Microsoft Access SAR database. This file contained critical incident data such as the IPP, Find Point, and the search duration for multiple subjects. The Create New Incident tool was run once and it produced a home folder containing six subfolders, an .mxd map file, and a .gdb geodatabase to house the model output. This home folder stored all 51 of the model runs. The subject information was loaded into the subject table in the home folder so they could individually be selected to run through the model. Running the model required entering the subject's unique identification number into the newly combined tool in order to generate both Cost Distance and Theoretical Search Area output files for the incident associated with that particular subject. The file names needed to be changed so they were not overwritten during the next model run. By using one incident home folder, combining the Cost Distance and Theoretical Search Area tools, and hard-coding all variables but one, the process went from doing 3-4 incidents per hour and having 9-12 interactions with the machine to processing 7-8 incidents per hour and only having 7-8 interactions.

3.6.3. Model Outputs Combined

After all 51 incident IPPs, Find Points, and mobility model outputs were on the map, one could begin to see the success of the model. Unfortunately, after culling the data set down to 51 incidents and running them through the previously defined procedure, seven incidents needed removal because there were database classification errors or the recorded numbers were very improbable. The final number of incidents used in this analysis is 44.

The result of running all 51 incidents though the combined model tool was 51 impedance rasters and 51 polygon shapefiles saved in the geodatabase. The impedance rasters buffered 10 miles out from the IPP or if not hard-coded, the distance specified by the user. The values range from zero to 99 designating the calculated impedance. This raster was not placed in the map document but was used to calculate the Theoretical Search Area. The shapefile generated by the Theoretical Search Area was named MobilityModel and contained polygons bounded by isochrones measured from the subject's IPP. These isochrones begin in ½-hour increments and increase to one-hour increments extending out to 12 hours. As shown in Figure 17, a number of the events overlap because of people becoming lost in the same area over the more than 10 years that the database has been housing SAR incidents.

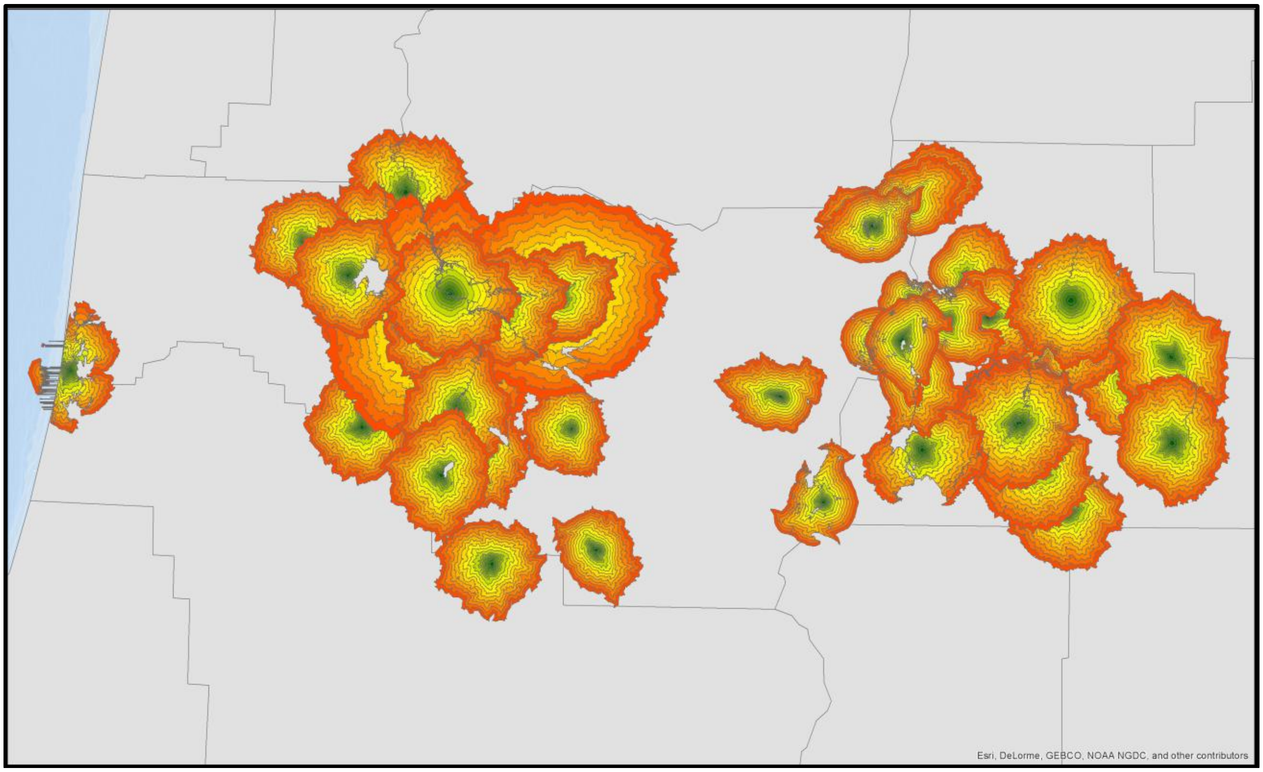

Figure 17 IGT4SAR Theoretical Search Area results for all 51 incidents

One aspect that made visual interpretation of the combined model output difficult was the number of data points in view and the overlapping nature of the paired locations. To improve the visualization, the IPP and Find Points feature classes were used in the XY to Line tool in ArcMap. This associated each IPP, or subject location, with its Find Point, using their OEMNumber as the key. A sample is seen in Figure 18.

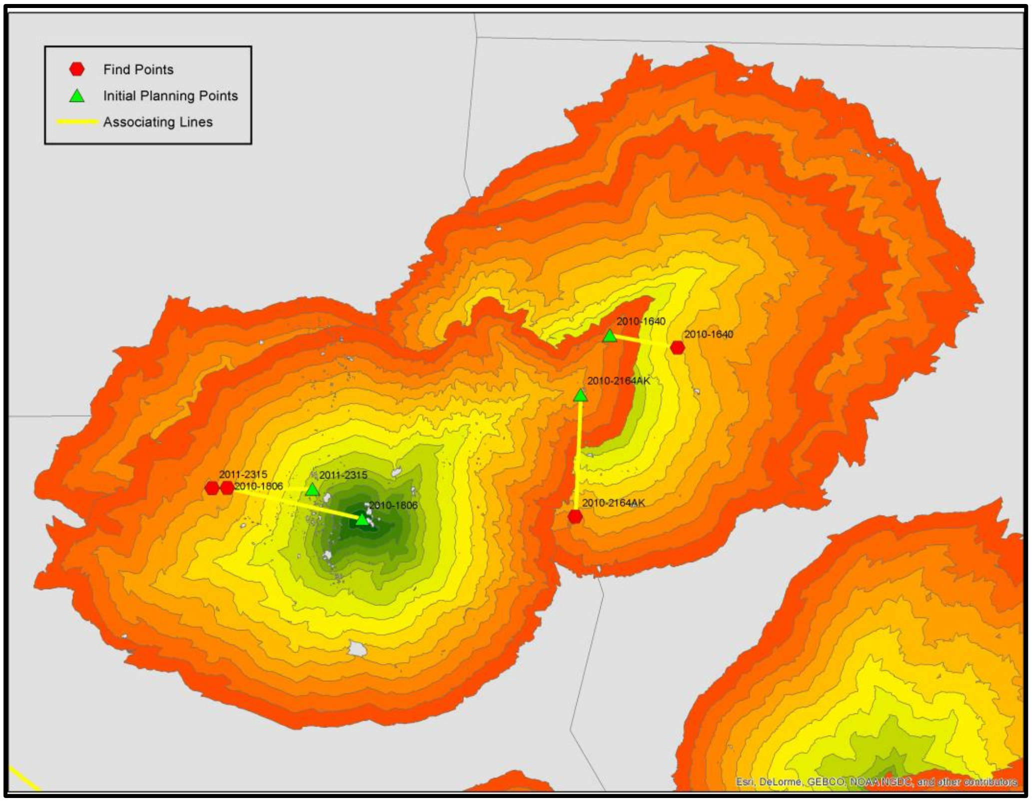

Figure 18 Using the XY to Line tool to associate IPPs with Find Points

Next, since the iterative process of the combined model could not label each set of output isochrone polygons with the related incident number, it was necessary to devise a method to extract the relevant isochrone polygon in which each Find Point fell. While it is possible to conceive of an automated method, given the relatively small number to be extracted and the large number of search area overlaps, it seemed wisest just to examine the map and visually identify which isochrone polygon contained the Find Point for each incident.

The isochrone polygons were grouped in ½ hour bands up to the three-hour point and then into one hour polygons. Because of this level of precision, a Find Point that plotted just inside the polygon labeled five hours would be given the same value as a Find Point that plotted at the outer edge of the five-hour polygon. To address this problem a precision adjustment, subtracting half the polygon's time equivalency, either 15 or 30 minutes, was introduced into the table. The resulting polygon values were recorded in a spreadsheet that was initially populated by exporting the table storing the Find Points feature class data from ArcMap and are seen in Appendix B.

3.7 Model Assumptions and Considerations

While modifying and running the combined model with real incident data, a number of assumptions were required in order to produce effective results. While the more general of these are addressed in the last chapter, it is important at this point to highlight some of the key assumptions and considerations that affect the results of this model and the subsequent analysis.

When people get lost, they usually wait to report their situation so they can try to find their way. Likewise, when someone calls to report a friend or family member lost, there is always some delay either because of lack of awareness or attempting to find the person. The SAR database tracks the time of notification as the beginning of the incident time. To account for this unknown delay time, three hours were added to each of the incidents' time in order to produce an estimate of each subject's actual time of travel. This necessary adjustment will be too long for some and not long enough for others but the expectation is that it will produce results that are generally in the range of the true travel time. In Doke's research on Yosemite SAR incidents, he found that the median time missing was nine hours while the median time searching was two hours (Doke 2012).

Another assumption used is that each of the subjects had an average walking speed of three miles per hour. While this is the average determined by Tobler, IGT4SAR's design allows for variability in this number based on weather and other environmental conditions as well as the age and other subject characteristics when performing the analysis on an individual incident. Since this information was difficult to extract automatically from the source data, in order to process the incidents in batch mode, it was necessary to assume the default speed across the set of samples analyzed.

3.8 Summary

This chapter explained the research process and the overarching research objective of determining whether a GIS-based mobility model could be useful in SAR operations. To carry out this task Esri's ArcGIS 10.4 was used as well as some Microsoft Excel. The data analyzed by this software was divided into two groups, search and rescue incidents and base environmental data. Both groups required conditioning and cleaning. To run an incident through IGT4SAR's mobility model the only incident variable required is the IPP. To assess the model's utility other variables beyond the IPP were needed, namely the Find Point and the time the subject was lost. The template is designed to run at least three tools with different input in order to create the model's output. To reduce processing time for the assessment One incident folder was used to hold all 51 incidents, the second two tools were combined, and most variables were hard-coded. Adding a three-hour reporting delay time and defaulting all subjects to a three miles per hour normal walking speed were two of the biggest assumptions made in the analysis.

In the next chapter, the results are explored in light of the expected outcomes and the model's overall success, general findings, and some unusual incidents are discussed.

Chapter 4 Results

This chapter explores the results and findings regarding all three of the sub-objectives. Discussion is also included regarding the lost subjects from the study. Finally, some of the more unusual subjects are addressed. Figure 19 shows the model results for the 51 incidents from the original runs of the combined model.

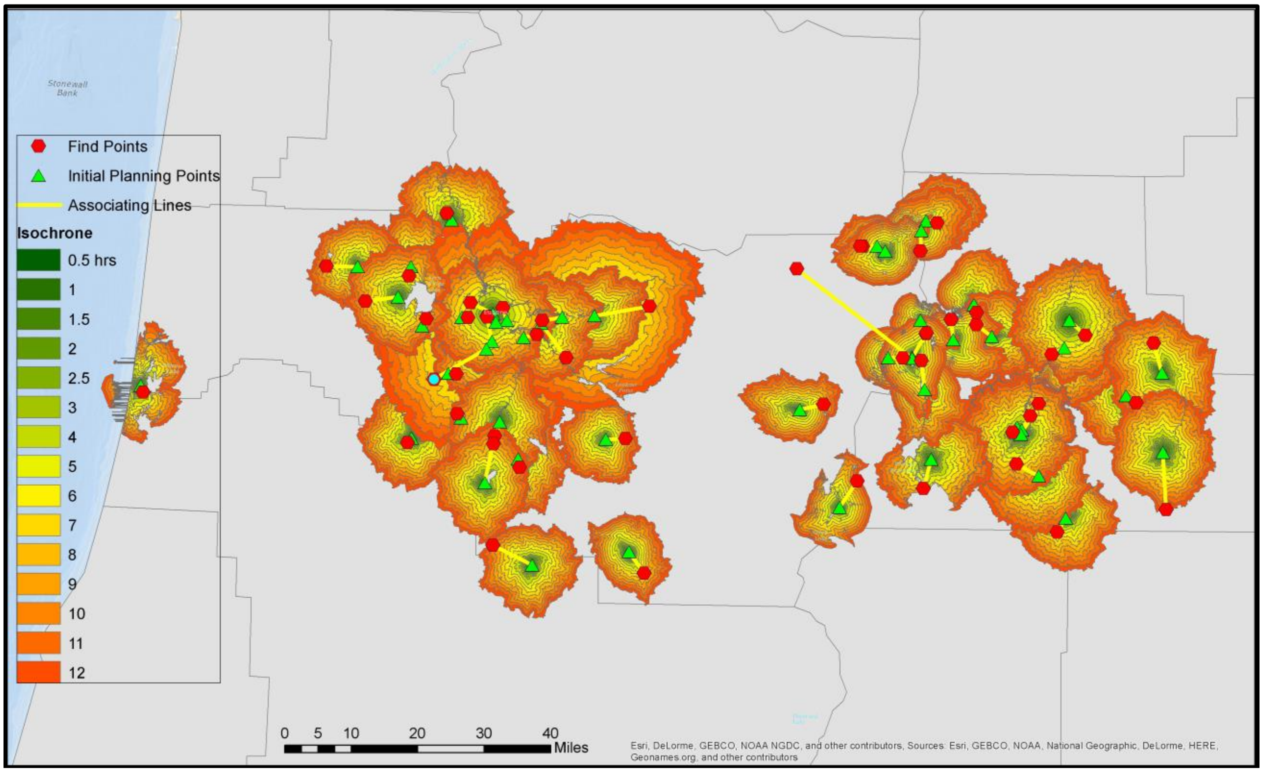

Figure 19 IGT4SAR Theoretical Search Area results, IPPs, and Find Points for all 51 incidents

4.1 Model Results Findings

This section reviews the findings for each of the three sub-objectives. The first was assessing if using a mobility model GIS tool is feasible without having extensive training. The second was considering if the process is executable in a short timeframe with limited computing resources. The last underlying sub-objective was determining if the model can reliably give the incident command (IC) planners an effective outer limit for their search areas.

4.1.1. Training Required

The assessment for training needs was made after working with IGT4SAR on the two Nevada County incidents. This was important because the tool was designed to work through one incident at a time without having the Python script manipulated. The template has many different capabilities beyond that of the mobility model. These other tools often require various other data points which can make a user unsure of what different types of data are needed and where they should be uploaded or input. Because of these types of capabilities and complexities and the fact that it is a template within ArcGIS which is known as a challenging program, IGT4SAR is not a solution that a SAR unit can start using day one. As with most software, getting in and working through a problem is one of the best ways to learn the application. The documentation, while extensive, still could be expanded. The training offered was invaluable as well as the YouTube videos. After one user has learned IGT4SAR, that person would be capable of teaching others.

4.1.2. Computation Time

The typical workflow to generate a mobility model in IGT4SAR included approximately two minutes to create a new incident, four minutes for the impedance layer, and another five minutes for the Theoretical Search Area. That was a total of approximately 11 minutes of computational time with a minute for variable entry and general pause between tool execution. That brought the total average time to about 14 minutes. This is a reasonable computational time, especially considering the laptop used was 2 ½ years old. The planner can also accomplish other tasks while the tools are running. The results dialogue boxes for the tools can be seen in Appendix C.

4.1.3. Success of Modeled Travel Time

The complete table of individual results can be found in Appendix D. A sample of the aggregated results is shown in Table 7. The success of the model is summarized in Table 8. Of the incidents in the sample group and based on the unadjusted SAR response time, 30% were found within the isochrones equaling the search time or less. When the generalized delay time was incorporated, 75% of the Find Points were observed in any polygon whose time is equivalent to or less than the search time.

Table 7 Example results. Green indicates modeled times that are greater than actual search time and pink indicates modeled times that are less than actual.

Calculated results	Subject Number			
	1	2	3	4
Find to IPP Distance (feet)	26,232	20,809	18,098	21,811
Modeled Time Band	9:00:00	7:00:00	9:00:00	5:00:00
Center of Band Offset	0:30:00	0:30:00	0:30:00	0:30:00
Modeled Time (Center of Band)	8:30:00	6:30:00	8:30:00	4:30:00
Recorded Time	6:42:00	6:26:00	2:47:00	1:40:00
(Recorded Time) - (Modeled Time [Center of Band])	-1:48:00	-0:04:00	-5:43:00	-2:50:00
Accounting for Measurement Precision (1/2 of Band Value)	-1:18:00	0:26:00	-5:13:00	-2:20:00
Generalized Delay	3:00:00	3:00:00	3:00:00	3:00:00
(Recorded Time) - (Adjusted Modeled Time) + (Gen Delay Time)	1:42:00	3:26:00	-2:13:00	0:40:00

Table 8 Success of results from the Theoretical Search Area tool

Scenario	Within Model Area	Outside Model Area
Recorded Time	30%	70%
Recorded Time Plus 3 hr Delay	75%	25%

Table 9 shows a summary of the results aggregated into quartiles according to distance traveled. It can be seen that model more successfully covered the lost subjects who traveled shorter distances.

Table 9 Aggregated success of results from the Theoretical Search Area tool. Success measured using times including 3 hour delay.

Quartile of result set ordered by distance traveled	**Within Model Area**	**Outside Model Area**
Quartile with the Longest Distance	45%	55%
Second Quartile	64%	36%
Third Quartile	91%	9%
Quartile with the Shortest Distance	100%	0%

4.2 Lost Subjects

On examination of the detailed information in the full database about these sampled incidents, some interesting facts about the subjects and the performance of the model can be detected. It is important to note that some SAR incident narratives have sensitive information that is not publically released so the narrative column giving specific details and names was not included. Those subjects that traveled five miles or more, the top seven, were quite diverse subjects with ages ranging from 13 to 64, men accounting for 63% of the subjects, activities varying from mushroom picking to running away from home, and different mental states from dementia to intoxicated to suicidal. This variety in subject characteristics is seen throughout the 51 selected incidents. The average distance traveled was 3.3 miles, the average age 45, and 64% of those lost were male. Alzheimer’s or dementia accounted for 18% of the incidents. Data on the subjects can be found in Table 9. Thankfully, no deaths were recorded in the studied set of Oregon data and only one had injuries.

Table 10 Subject characteristics

Age	Average	45
	Range	2 to 88
Gender	Males	61%
	Females	39%
Activity	Hikers	31%
	Pickers (mushroom, antlers)	13%
	Hunters	7%
	Other	9%
	Wanderers	32%
	Suicide	2%
	Not Recorded	6%
Mental State	Dementia, alcohol, suicide	27%
Distance Traveled	Average	3.33 miles
	Range	0.8 - 9.1 miles
Condition Found	Well	98%
Group	Solo	75%
	Single Gender Group	9%
	Mixed Group	16%

4.3 Unusual Incidents

A couple of subjects stood out from the rest. As addressed earlier, the subjects varied greatly, as did their travel, and so is the case for the outliers. The person that moved the second greatest distance of the 51 incidents selected and portrayed in Figure 20 was a trail runner. Because he was a runner instead of someone walking and the time and distance attributed to him were most unusual, he was not part of the final selection. The report stated he had been running to a location about 3.5 miles away. He missed his destination and continued to run the trails through the evergreen forest, as classified by the NLCD. The DEM indicates that he was generally running downhill although there were many streams along his path. His run ended at a bridge approximately 22 miles from his starting point. The 22 miles is a straight-line distance so he likely ran a bit farther. The report stated that it took him four hours to run the distance and while that is fast for most, if this 25-year-old was serious about running it is certainly possible.

Although a marathon is farther, just for reference, the median 2014 time for U.S. men's marathon finishers was 4 hours and 19 minutes (Running USA 2015).

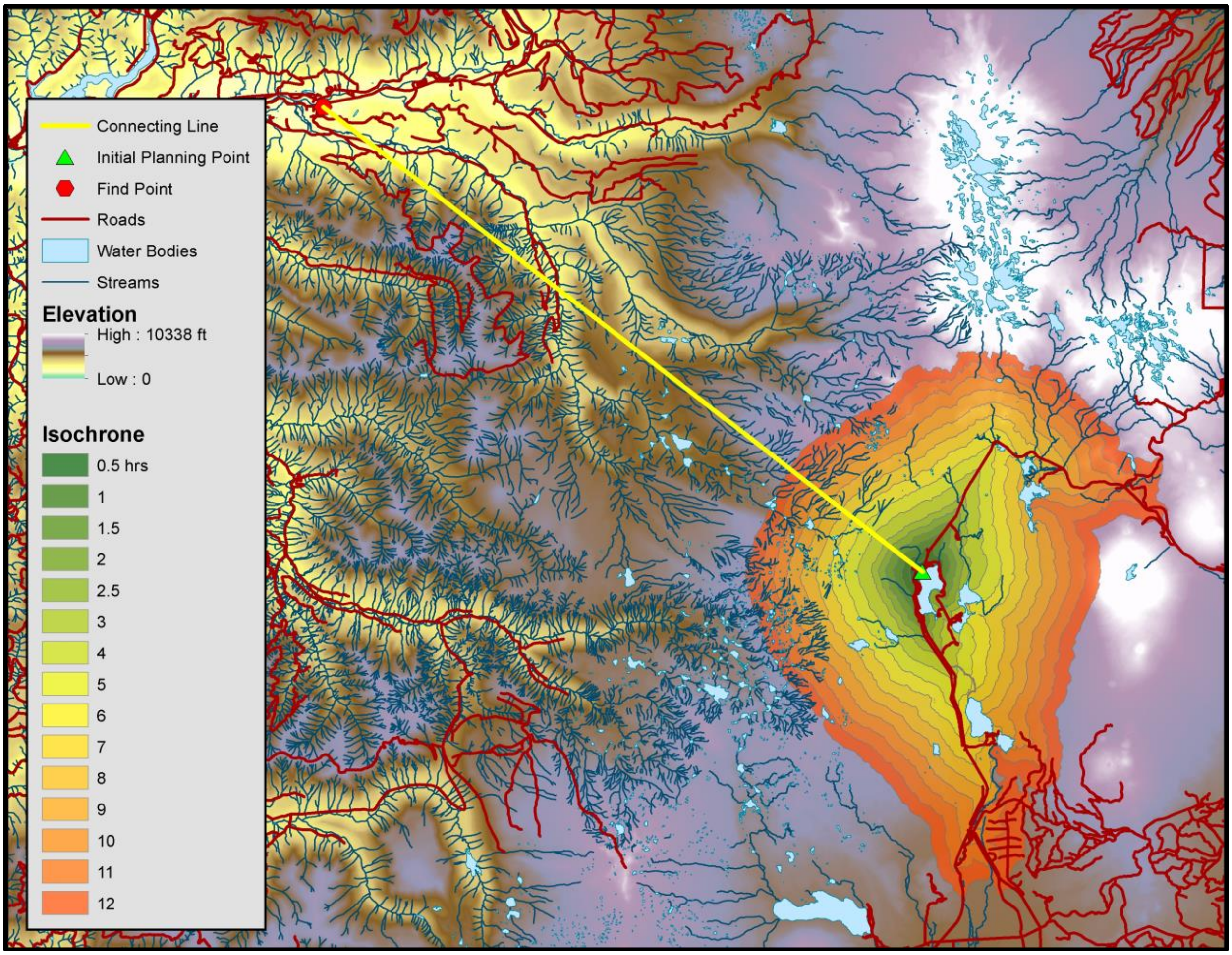

Figure 20 Theoretical Search Area for extraordinary trail runner

Another interesting case was that of the person that went the third farthest in the group, illustrated in Figure 21. This person was hiking, wandered off the trail, and became disoriented. She was found five-and-one-half hours later walking down a road, having crossed at least three other roads to get there. It was in December and she was found at 8:30 pm, 12 miles from her starting point. Being 64 did not seem to slow her down. Fortunately she was found before the colder hours since the temperature dropped down to 35F later that night (Weather Underground 2014).

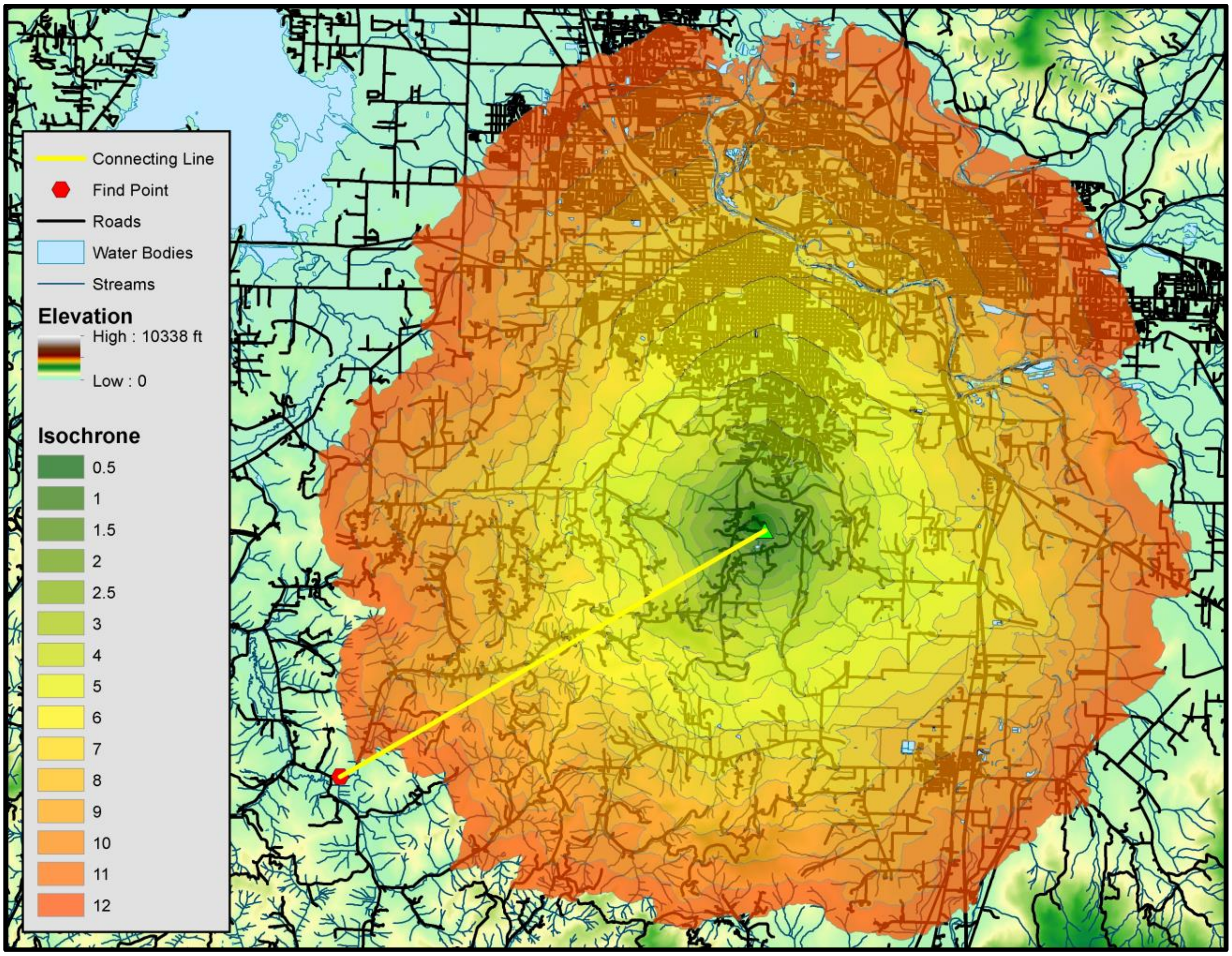

Figure 21 Theoretical Search Area for hiker

4.4 Summary

This chapter covered the assessed results from the analysis and how they fit in with the stated research objectives, information on subjects generally, and information of a few specific unusual cases. It was determined that a fair amount of upfront training was required in order to use the template effectively. The model was able to execute in a short enough time to keep it from being a concern. As computing speed increases, it will be even less of a problem. The finding with regard to the model's success rate was that it performed well with the delay factor included and as time continues, it will be even more successful as it moves down the list to the people that have subjects that did not travel very far.

The last chapter concludes this report with a discussion of the model compared to the real world. Limitations of this study as well as future work in the area are considered.

Chapter 5 Discussion and Conclusions

The first research question was whether learning how to effectively use this SAR mobility model would require extensive training. After attending the SARGIS workshop, watching videos, and working with the model, this question's answer is generally no. Extensive training is needed to get the system installed, loaded with base data, and knowing how to use it. Once that is done, training others on a team would not be too difficult. The classroom training and online videos are excellent, but ultimately understanding of both ArcGIS and SAR operations is needed. With all this said, once the organization's base data such as elevation, land cover, transportation lines, streams, water bodies, fence and power lines have been projected and conditioned so they can be loaded into the template, using IGT4SAR is much less difficult. This loading should be a one-time event with information copied to subsequent computers as needed. Although learning how to create the Theoretical Search Area using IGT4SAR is a challenge, learning the procedures is not overly complicated and simply takes time and effort.

The next expected outcome was that the mobility model could be executed in 10 to 20 minutes with adequate computing capability. With the study complete, the finding is that this outcome was met. As long as the area's base data is already loaded and information on the incident is known and available, an output of isochrone polygons can be available in less than 15 minutes. This is assuming the use of a computer with at least a processing speed of 2.5Mhz and 8GB of RAM. With a higher performance computer, times will be faster. Just because the model can be produced that quickly does not mean that it will. The search manager may want the planner to use IGT4SAR for other tasks such as creating quick initial search assignments prior to generating the model. However, assignment of search areas is often the first priority so that search teams can move to their search segment and begin looking for the subject.

An important finding is that time data in SAR is uncertain. It is an important variable to understand in search and rescue. Accurately portraying time is useful in both advancing SAR science as well as justifying resourcing for search and rescue efforts. The results from this study definitely would have a higher degree of certainty if the time lost were recorded along with the time that authorities were involved.

The last finding came from an interview with an experienced SAR planner. The perception is that the mobility model gives too large of a search area for it to be useful, which is connected to the last expected outcome. The intermediate stage of an impedance layer was of interest to the planner though, see Figure 22. This would give the planners some indication of which direction the subject could not go without running into difficult or which direction a subject may find easier to travel. With this information, the team could create search segments accordingly. Some areas are very dense or steep and therefore would be divided into smaller segments as opposed to a flat open area that could be searched quickly allowing the team to be assigned to a larger area. It could also provide potential directions of travel if the impedance layer showed a high value that might channel the lost subject's route choice.

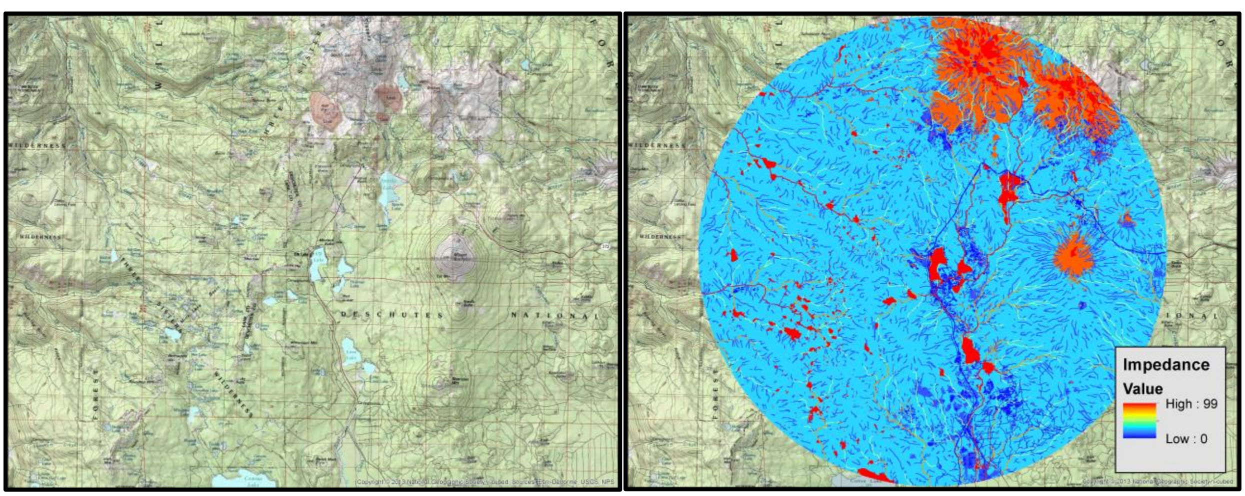

Figure 22 Comparing National Geographic Society topographic map to the IGT4SAR generated impedance layer for a portion of Deschutes County

The major expected outcome is somewhat predicated on the first two. If learning how to work with the model was too difficult or it took too much computing power or time to be useful, knowing whether it was effective or not would not be as important. Although the learning curve was steeper than expected, the process can be mastered and the times are reasonable. The expectation was that all of the search and rescue incidents would be found within the model's appropriate isochrone polygon. This did not turn out to be the finding. Importantly, Ferguson points out that he did not intend the output to dictate where the team should look but that it would be an aid to search manager and planners in the decision-making process. The broader impact discussion takes place in the last chapter. The final expected outcome was not met either. Interestingly, of the three expected outcomes, only one was realized.

5.1 The Model and Reality

Determining what is reality is the biggest cause for uncertainty when comparing the model to real-world events. The biggest question is how long the person has been lost. SAR databases often just record the time authorities were notified and the time the search was successful or suspended. The other important factors in correlating the model and reality are the initial planning point used and the find point. The IPP, point last seen or last known point, may have a greater level of uncertainty because the person reporting them missing may only have a educated guess as to the point to start the search from. The find point typically involves SAR personnel on scene that will record the location while standing there. These locations are generally recorded using a GPS devise but if not, SAR personnel tend to have good recall of their physical surroundings and landmarks.

The model performed differently than expected with regard to reality, even when times were adjusted by a set delay constant. One of the expected outcomes was that the model was going to greatly overestimate the furthest extent of the lost person’s travels. This was not the case as one-quarter of the Find Points fell outside the model’s prediction. This was a positive result. If the model search areas contained all find points, including incidents that were above the median distance travelled, it would simply be estimating a very large area with all points enveloped.

The other expected outcome is that all lost subjects would be found within the model’s estimate. This outcome was not seen, as demonstrated again by the fact that one-quarter of the lost subjects were beyond the model’s estimate. It is important to remember that these SAR incidents were selected to challenge the model when testing whether all incidents would be within the predicted search area. With some of the incidents having greater distances traveled and not falling within the correct isochrones, it could be argued that the model’s output could be useful in the determination of a largest POA scenario. On the other hand, if none fell outside the projected distances, it could not be determined if the model produces a result that was even close to reality since it could grossly be overestimating the furthest point traveled.

When considering the incidents with shorter distances traveled, the model more successfully covered the lost subjects. This can be observed when looking at the group of incidents with the shortest distance traveled listed in Appendix D. This analysis focused on the 44 furthest travelers, 51 original minus misclassified and extreme outliers, in the set of 102 land-based incidents within Lane and Deschutes Counties contained in the original database obtained for this project. Having selected the incidents with the furthest distance traveled, it seems likely that the rest of the land-based Lane and Deschutes Counties incidents would have a much higher rate of being captured in the correct isochrone.

Overall, the assessment is that this model can be helpful to search managers and their planners. For the majority of the cases, the lost person was found within the modeled isochrone. That said, the mobility model does not include all sampled incidents demonstrating that is does not necessarily grossly overestimate a lost person's distance traveled. Importantly, it must be remembered that all assessments are based on the critical assumption that the average delay from when the subject became lost until they were reported lost averaged approximately three hours.

5.2 Limitations and Hindsight

If a model uses poor data, its results will be poor, so the accuracy of data is extremely important. Models do not reflect reality perfectly, but with a good model and accurate data, they are useful. The amount of time the subject was lost before he or she was reported lost is the biggest limitation in assessing the success of this model. As the search and rescue field matures, hopefully accurate and complete data collection will as well.

It was a little surprising to discover that the IGT4SAR mobility model did not use subject characteristic information, such as age and gender, nor what has been learned regarding lost person behavior. These variables are collected and are used in IGT4SAR's tools incorporating Koester's models, but they are not used in the Theoretical Search Area model. Lost person behavior statistics may be worth incorporating into the mobility model somehow or at least giving the user an option for such a hybrid.

From the perspective of a non-profit organization as SAR teams are structured, cost of software might be considered a limitation. Most consider Esri's ArcGIS to be expensive software with commercial starting at $1500. However, nonprofits do not pay for the software but only need to pay a small annual administrative fee (Esri 2016). Microsoft Excel is included on many computers and can be purchased for $110 (Microsoft 2016), although it was required for the evaluation but not the model generation itself and the same operations could have been done free on OpenOffice or Google Sheets.

Looking back there are a number of things that could have been done differently in this study. After doing further research, it appears Syrotuck's statistical research has not been integrated into a GIS. Building a tool that incorporates his work could have been a good project to undertake to advance SAR efforts.

Another option on how this project could have been done differently would be to have limited the incidents not just to land-based events but to hikers exclusively as Doherty did in his Yosemite mobility model research (Doherty et al. 2014). If done at a statewide level, this may have created a more homogeneous data set that may have produced more consistent relationships between Find Point and theoretical search areas. This would have at least controlled one variable to give a more precise assessment of the model although it would have required more data and conditioning.

5.3 Future Work

This area of study is ripe for investigating the connections between search and rescue and geographic information science. Lin and Goodrich developed a model that allows for expert opinion as stated in their 2010 article. Because Ferguson has made his template available on GitHub, someone adding on features that would allow for such input could prove to be very helpful. Another technical point for future work would be to include not just concepts from Lin and Goodrich but also Syrotuck, Jacobson and other models and research into IGT4SAR's mobility model. This could combine the findings from Jacobs, Syrotuck, and/or Doke to potentially reduce the POA while increasing the success rate.

There are two other, less technical and not necessarily GIS related, areas that could be explored in the future. Researching how people's trust of output from computers influence their decision making could have an impact on SAR operations. Some people are inclined to believe an estimate generated by a computer more than their own experience. In these cases, it may be better to have no estimate than a largely incorrect one. A second option would be to work on adding to the existing documentation for IGT4SAR. There is already much work that has been done and a potentially quick improvement would be to simply combine the existing help files.

5.4 Conclusion

IGT4SAR is an extremely capable template, full of a multitude of useful tools to plan for and execute search and rescue operations. The challenge with having so much functionality in an application is that it can often bring an interface that is complex to use. This creates a requirement for a fair amount of training and hands-on practice with the template. Once an individual planner or group of planners have some training and experience with IGT4SAR, the overall SAR operation and administration should run much more effectively and efficiently. The Theoretical Search Area model processing time is short enough that it can be used during actual events. In many situations the mobility model may produce an area too large to be used by itself, but it can serve as an aid to planners as the operation continues. Ferguson did not intend for his tool to dictate search decisions but to be an aid to decision makers. Making an impedance layer covering the entire area the team is responsible for, which is created as an intermediate step, available independently would be helpful as a planning tool so they can assign search segments accordingly. Regarding this study's main objective, IGT4SAR's mobility model can be useful in search and rescue operations but should be used as a support and not as a directive.

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Appendix A: Oregon's Incident Data Collection Form

VER. 7 **OREGON EMERGENCY MANAGEMENT** VER. 7

SEARCH AND RESCUE INCIDENT SUMMARY

OEM Number ____ County Case Number ____ Date of Incident ____
Report prepared by (Name) ____ Phone ____
County ____

WAS ASSISTANCE PROVIDED
☐By another Agency, County, or State to you? Which one(s)? ____
☐By you to another Agency, County, or State? Which one(s)? ____

SAR INCIDENT TYPE - What *type* of incident did this involve?
☐This mission involved more than one type of incident
☐Aviation ☐Beacon searches ☐False - callout reason ____
☐Missing person (land) ☐Evidence search (land) ☐Rescue (land) ☐Body recovery from
☐Missing person (water) ☐Evidence search (water) ☐Rescue (water) ☐land ☐water
☐Training ☐Public event ☐Other water incident
☐Emergency Management (disasters) ☐Other (specify) ____

SUBJECT ACTIVITY - What was the *subject* doing?
☐Helicopter ☐Fixed wing ☐Other aviation ____ ☐Military aircraft?
☐ATV ☐Motor vehicle - Intentions ____
☐Caving ☐Climbing ☐Hiking / camping
☐Government work ☐Other work ☐Bicycling ☐Horseback riding
☐Mushroom picker ☐Other picker ☐Other forest activity ____
☐Fishing ☐Hunting (game) ☐Hunting (bird)
☐Cross country skiing ☐Snowboarding ☐Snowmobile ☐Other snow sports
☐Powered watercraft ☐Non-powered watercraft - What type? ____
☐SCUBA / snorkeling ☐Swimming ☐Other water activity ____
☐Suicide ☐Wandering ☐Criminal ☐Unknown
☐Any other activities ____

SUBJECT DATA AND MISSION RESULTS: List subjects by age
Age(s): Males ____ **Age(s):** Females ____
☐Oregon resident? Home county: ____ **or** Home state: ____

Results:

Recovered	Condition	Found by		Fitness	
Alive: ____	Well: ____	Self-recovered: ____	SAR dogs: ____	Excellent: ____	Good: ____
Deceased: ____	Injured: ____	Family / friends: ____	Air SAR: ____	Fair: ____	Poor: ____
Missing: ____		Ground SAR: ____	Other: ____	Unk: ____	N/A: ____

Distance traveled on foot from IPP: ____ feet ☐Straight line ☐Actual **Track offset:** ____ feet
IPP coordinates: ____ Datum: ____ Altitude: ____ feet
Find coordinates: ____ Datum: ____ Altitude: ____ feet

MENTAL STATE - Describe the mental status of the subject *(if applicable)*
For multiple subjects with different status, identify by age and sex: *subject 1* ____ *subject 2* ____ *subject 3* ____
[1]☐ [2]☐ [3]☐ Alzheimer's [1]☐ [2]☐ [3]☐ Mental illness [1]☐ [2]☐ [3]☐ Autism [1]☐ [2]☐ [3]☐ Mood disorder
[1]☐ [2]☐ [3]☐ Dementia type [1]☐ [2]☐ [3]☐ Mental handicaps [1]☐ [2]☐ [3]☐ Other mental condition ____

[1]☐ [2]☐ [3]☐ Alcohol [1]☐ [2]☐ [3]☐ Methamphetamine [1]☐ [2]☐ [3]☐ Cocaine [1]☐ [2]☐ [3]☐ Opiate [1]☐ [2]☐ [3]☐ Marijuana
[1]☐ [2]☐ [3]☐ Hallucinogen [1]☐ [2]☐ [3]☐ Other drug ____

Last seen date: ____ **Overdue date:** ____ **Reported date:** ____ **Found date:** ____
Last seen time: ____ **Overdue time:** ____ **Reported time:** ____ **Found time:** ____

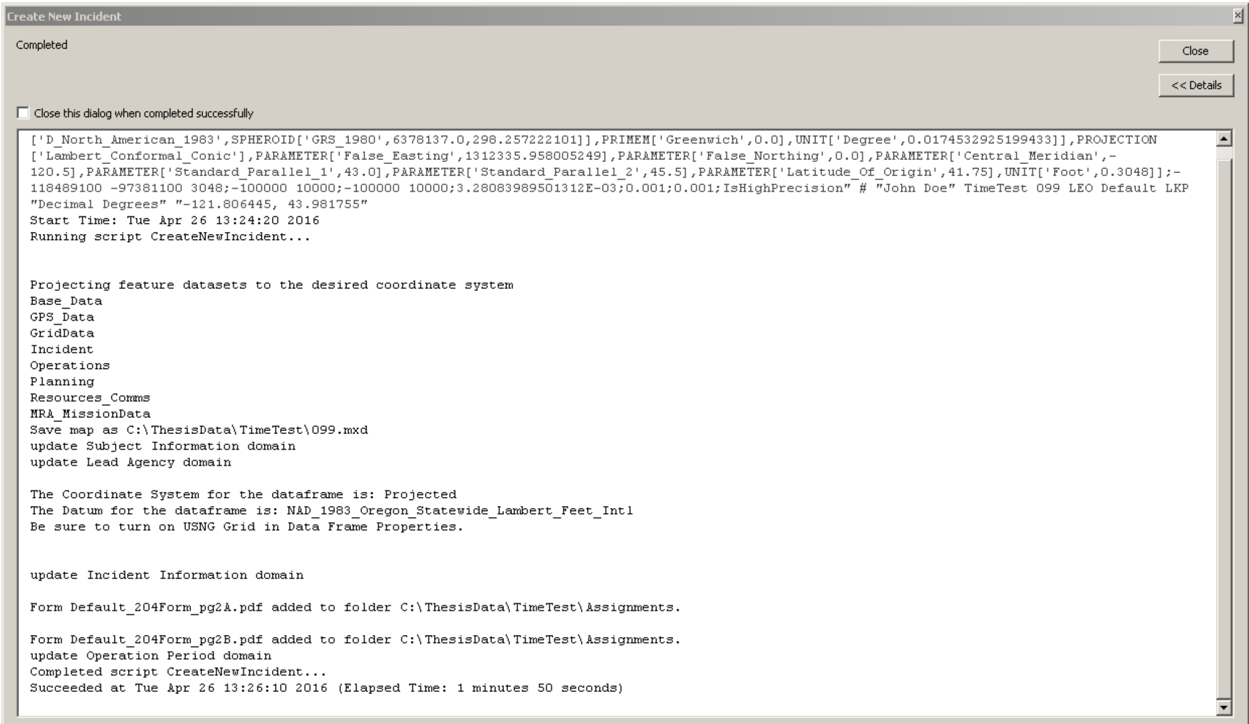
SIGNALING - What did the *subject* use?
☐ELT ☐EPIRB ☐PLB ☐SPOT ☐MLU ☐Cell Phone ☐Radio ☐Mirror
☐Fire/smoke ☐Flare/pyro ☐Sound (gun, whistle) ☐Visual (markers, flags) ☐Project Lifesaver

Mail to: Oregon Emergency Management, P.O. Box 14370, Salem, OR 97309-5062

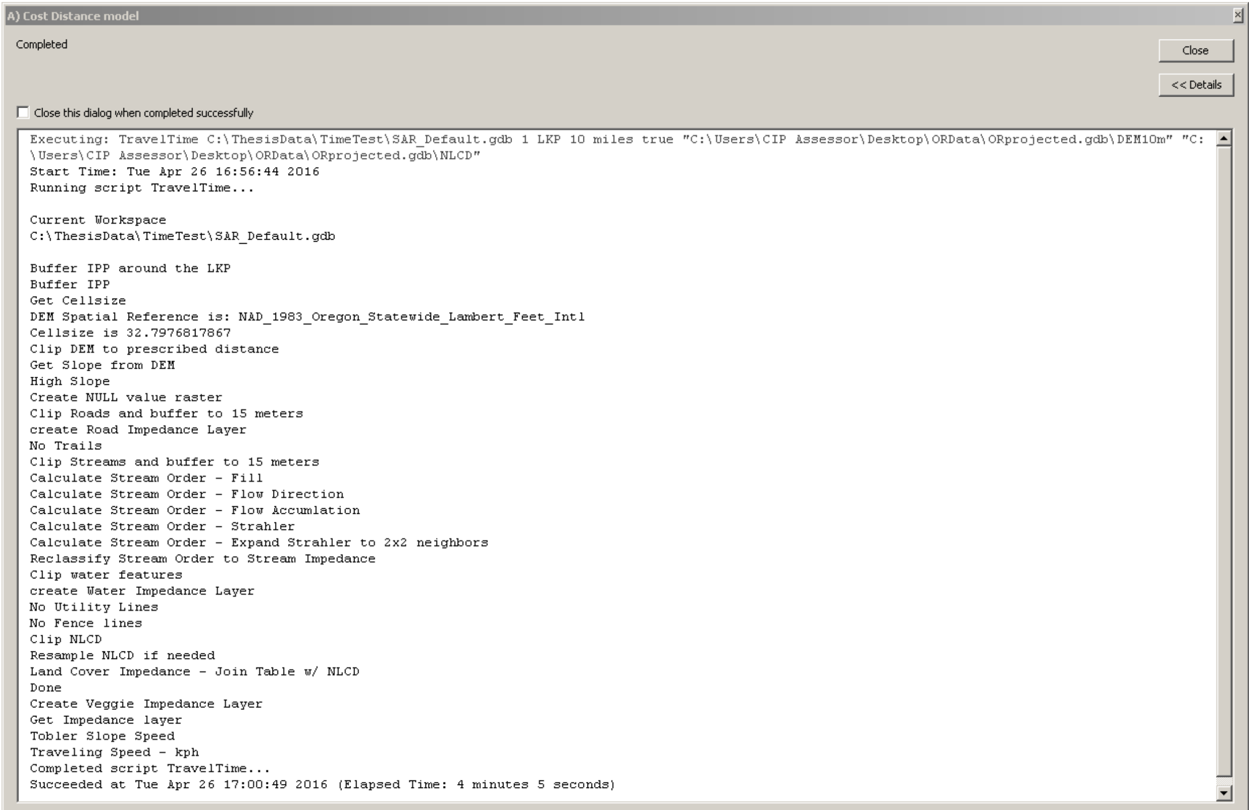
Appendix B: Python editing of IGT4SAR - changing all variables, except SubNum (Subject Number), from arcpy.GetParameterAsText(0) lines to hard-coded values

```
# Main Program starts here

if __name__ == '__main__':
    #in_fc  - this is a point feature used to get the latitude and longitude of point.
    mxd, df = getDataframe()

    SubNum = arcpy.GetParameterAsText(0)  # Get the subject number
    if SubNum == '#' or not SubNum:
        SubNum = "1" # provide a default value if unspecified

    wrkspc = "C:\Users\CIP Assessor\Desktop\ORData\FinalRun\SAR_Default.gdb"
    arcpy.AddMessage("\nCurrent Workspace" + '\n' + wrkspc + '\n')
    env.workspace = wrkspc

    ippType = "LKP"  # Determine to use PLS or LKP

    TheoDist = "10"
    if TheoDist == '#' or not TheoDist:
        TheoDist = "0" # provide a default value if unspecified

    bufferUnit = "miles" # Desired units
    if bufferUnit == '#' or not bufferUnit:
        bufferUnit = "miles" # provide a default value if unspecified

    uSeStr= "true" # Desired units
    if uSeStr == '#' or not uSeStr:
        uSeStr = "true" # provide a default value if unspecified

    DEM2 = "C:\Users\CIP Assessor\Desktop\ORData\ORprojected.gdb\DEM10m"
    if DEM2 == '#' or not DEM2:
#       DEM2 = "DEM" # provide a default value if unspecified
        arcpy.AddMessage("You need to provide a valid DEM")

    NLCD = "C:\Users\CIP Assessor\Desktop\ORData\ORprojected.gdb\NLCD"
    if NLCD == '#' or not NLCD:
#       NLCD = "NLCD" # provide a default value if unspecified
        NLCD = "empty"

    deSiredSpdA = "3" # Nominal walking speed
    if deSiredSpdA == '#' or not deSiredSpdA:
        deSiredSpdA = "3.0" # provide a default value if unspecified
```

Appendix C: Tool Results from Mobility Model Run

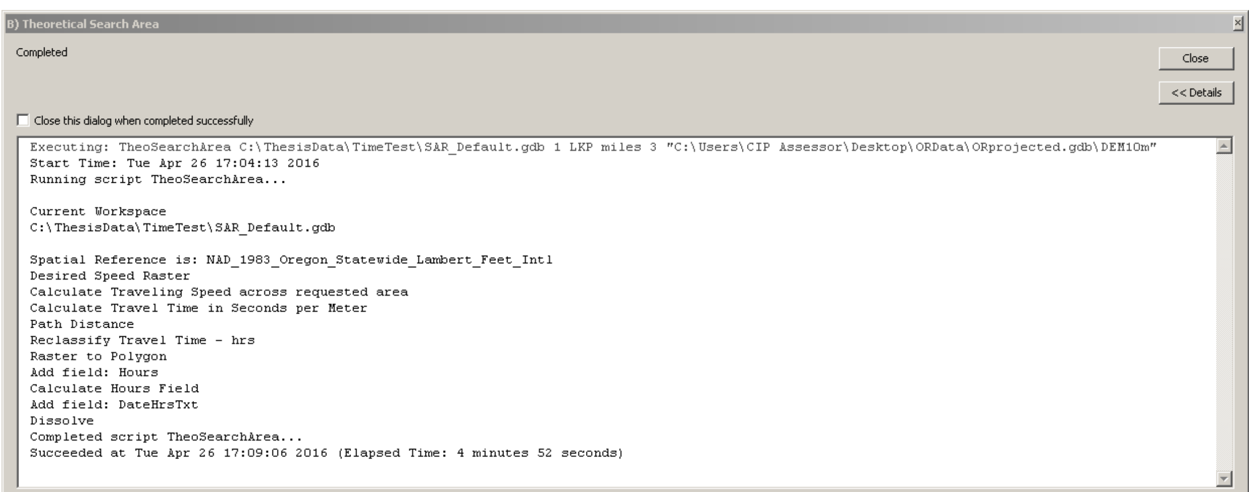


Detailed results window shows 1:50 minutes to process the Create an Incident tool



```
A) Cost Distance model
Completed
Close
<< Details
Close this dialog when completed successfully
Executing: TravelTime C:\ThesisData\TimeTest\SAR_Default.gdb 1 LKP 10 miles true "C:\Users\CIP Assessor\Desktop\ORData\ORprojected.gdb\DEM10m" "C:\Users\CIP Assessor\Desktop\ORData\ORprojected.gdb\NLCD"
Start Time: Tue Apr 26 16:56:44 2016
Running script TravelTime...

Current Workspace
C:\ThesisData\TimeTest\SAR_Default.gdb

Buffer IPP around the LKP
Buffer IPP
Get Cellsize
DEM Spatial Reference is: NAD_1983_Oregon_Statewide_Lambert_Feet_Intl
Cellsize is 32.7976817867
Clip DEM to prescribed distance
Get Slope from DEM
High Slope
Create NULL value raster
Clip Roads and buffer to 15 meters
create Road Impedance Layer
No Trails
Clip Streams and buffer to 15 meters
Calculate Stream Order - Fill
Calculate Stream Order - Flow Direction
Calculate Stream Order - Flow Accumlation
Calculate Stream Order - Strahler
Calculate Stream Order - Expand Strahler to 2x2 neighbors
Reclassify Stream Order to Stream Impedance
Clip water features
create Water Impedance Layer
No Utility Lines
No Fence lines
Clip NLCD
Resample NLCD if needed
Land Cover Impedance - Join Table w/ NLCD
Done
Create Veggie Impedance Layer
Get Impedance layer
Tobler Slope Speed
Traveling Speed - kph
Completed script TravelTime...
Succeeded at Tue Apr 26 17:00:49 2016 (Elapsed Time: 4 minutes 5 seconds)
```

Detailed results window shows 4:05 minutes to process the Cost Distance model tool



```
B) Theoretical Search Area
Completed
Close
<< Details
Close this dialog when completed successfully
Executing: TheoSearchArea C:\ThesisData\TimeTest\SAR_Default.gdb 1 LKP miles 3 "C:\Users\CIP Assessor\Desktop\ORData\ORprojected.gdb\DEM10m"
Start Time: Tue Apr 26 17:04:13 2016
Running script TheoSearchArea...

Current Workspace
C:\ThesisData\TimeTest\SAR_Default.gdb

Spatial Reference is: NAD_1983_Oregon_Statewide_Lambert_Feet_Intl
Desired Speed Raster
Calculate Traveling Speed across requested area
Calculate Travel Time in Seconds per Meter
Path Distance
Reclassify Travel Time - hrs
Raster to Polygon
Add field: Hours
Calculate Hours Field
Add field: DateHrsTxt
Dissolve
Completed script TheoSearchArea...
Succeeded at Tue Apr 26 17:09:06 2016 (Elapsed Time: 4 minutes 52 seconds)
```

Detailed results window shows 4:52 minutes to process the Theoretical Search Area tool

Appendix D: Results Sorted by Distance Traveled **(green indicates modeled correctly and pink indicates an incorrectly modeled incident)**

Subject Number	1	2	3	4	5	6	7	9	11	12	13
Find to IPP Distance (feet)	26,232	20,809	18,098	21,811	38,016	18,101	45,443	25,399	24,782	24,054	34,863
Modeled Time Band	9:00:00	7:00:00	9:00:00	5:00:00	10:00:00	5:00:00	12:00:00	11:00:00	7:00:00	8:00:00	11:00:00
Center of Band Offset	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00
Modeled Time (Center of Band)	8:30:00	6:30:00	8:30:00	4:30:00	9:30:00	4:30:00	11:30:00	10:30:00	6:30:00	7:30:00	10:30:00
Recorded Time	6:42:00	6:26:00	2:47:00	1:40:00	0:50:00	1:08:00	3:15:00	3:16:00	1:58:00	9:41:00	1:49:00
(Recorded Time) - (Modeled Time [Center of Band])	-1:48:00	-0:04:00	-5:43:00	-2:50:00	-8:40:00	-3:22:00	-8:15:00	-7:14:00	-4:32:00	2:11:00	-8:41:00
Accounting for Measurement Precision (1/2 of Band Value)	-1:18:00	0:26:00	-5:13:00	-2:20:00	-8:10:00	-2:52:00	-7:45:00	-6:44:00	-4:02:00	2:41:00	-8:11:00
Generalized Delay	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00
(Recorded Time) - (Adjusted Modeled Time) + (Gen Delay Time)	1:42:00	3:26:00	-2:13:00	0:40:00	-5:10:00	0:08:00	-4:45:00	-3:44:00	-1:02:00	5:41:00	-5:11:00
Subject Recovered	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive
Subject Condition	Well	Well	Well	Well	Well	Well	Well	Well	Well	Well	Well
Gender	Male	Male	Female	Female	Male	Male	Female	Male	Female	Male	Female
Age	80	49	64	50	62	80	47	61	15	67	34
Alcohol											Yes
Dementia-Alzheimer's					Yes	Yes					
Suicide											
Other											

Subject Number	15	16	18	19	20	21	22	23	24	26	27	28
Find to IPP Distance (feet)	19,727	28,170	19,287	17,466	33,875	44,356	48,083	19,762	16,207	16,002	15,662	15,513
Modeled Time Band	5:00:00	7:00:00	8:00:00	4:00:00	9:00:00	14:00:00	13:00:00	5:00:00	7:00:00	10:00:00	9:00:00	6:00:00
Center of Band Offset	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00
Modeled Time (Center of Band)	4:30:00	6:30:00	7:30:00	3:30:00	8:30:00	13:30:00	12:30:00	4:30:00	6:30:00	9:30:00	8:30:00	5:30:00
Recorded Time	3:53:00	6:30:00	8:06:00	3:30:00	2:48:00	4:57:00	5:26:00	9:38:00	4:42:00	8:22:00	3:51:00	3:35:00
(Recorded Time) - (Modeled Time [Center of Band])	-0:37:00	0:00:00	0:36:00	0:00:00	-5:42:00	-8:33:00	-7:04:00	5:08:00	-1:48:00	-1:08:00	-4:39:00	-1:55:00
Accounting for Measurement Precision (1/2 of Band Value)	-0:07:00	0:30:00	1:06:00	0:30:00	-5:12:00	-8:03:00	-6:34:00	5:38:00	-1:18:00	-0:38:00	-4:09:00	-1:25:00
Generalized Delay	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00
(Recorded Time) - (Adjusted Modeled Time) + (Gen Delay Time)	2:53:00	3:30:00	4:06:00	3:30:00	-2:12:00	-5:03:00	-3:34:00	8:38:00	1:42:00	2:22:00	-1:09:00	1:35:00
Subject Recovered	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive
Subject Condition	Well	Injured	Well	Well	Well	Well	Well	Well	Well	Well	Well	Well
Gender	Male	Male	Male	Male	Male	Male	Female	Female	Male	Female	Female	Female
Age	9	57	48	82	13	37	64	64	44	24	58	16
Alcohol												
Dementia-Alzheimer's				Yes				Yes				
Suicide		Yes										
Other												

Subject Number	29	30	31	32	33	34	35	36	37	38	39	40
Find to IPP Distance (feet)	13,209	13,111	13,000	11,744	11,098	11,089	10,923	10,643	9,915	9,049	8,278	7,455
Modeled Time Band	6:00:00	4:00:00	5:00:00	6:00:00	3:00:00	6:00:00	5:00:00	3:00:00	3:00:00	5:00:00	2:00:00	3:00:00
Center of Band Offset	0:30:00	0:30:00	0:30:00	0:30:00	0:15:00	0:30:00	0:30:00	0:15:00	0:15:00	0:30:00	0:15:00	0:15:00
Modeled Time (Center of Band)	5:30:00	3:30:00	4:30:00	5:30:00	2:45:00	5:30:00	4:30:00	2:45:00	2:45:00	4:30:00	1:45:00	2:45:00
Recorded Time	1:00:00	1:04:00	1:45:00	3:45:00	2:00:00	5:42:00	1:58:00	1:45:00	3:03:00	2:44:00	0:49:00	2:06:00
(Recorded Time) - (Modeled Time [Center of Band])	-4:30:00	-2:26:00	-2:45:00	-1:45:00	-0:45:00	0:12:00	-2:32:00	-1:00:00	0:18:00	-1:46:00	-0:56:00	-0:39:00
Accounting for Measurement Precision (1/2 of Band Value)	-4:00:00	-1:56:00	-2:15:00	-1:15:00	-0:30:00	0:42:00	-2:02:00	-0:45:00	0:33:00	-1:16:00	-0:41:00	-0:24:00
Generalized Delay	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00
(Recorded Time) - (Adjusted Modeled Time) + (Gen Delay Time)	-1:00:00	1:04:00	0:45:00	1:45:00	2:30:00	3:42:00	0:58:00	2:15:00	3:33:00	1:44:00	2:19:00	2:36:00
Subject Recovered	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive
Subject Condition	Well	Well	Well	Well	Well	Well	Well	Well	Well	Well	Well	Well
Gender	Female	Female	Male	Female	Male	Female	Male	Male	Female	Male	Male	Male
Age	46	79	72	25	74	36	43	8	13	31	79	88
Alcohol												
Dementia-Alzheimer's		Yes			Yes						Yes	Yes
Suicide												
Other												

Subject Number	41	42	43	44	45	46	47	49	50
Find to IPP Distance (feet)	6,792	6,722	6,621	6,442	6,328	5,484	5,410	4,700	4,662
Modeled Time Band	1:30:00	2:00:00	2:30:00	2:30:00	2:30:00	2:00:00	1:30:00	2:00:00	2:00:00
Center of Band Offset	0:15:00	0:15:00	0:15:00	0:15:00	0:15:00	0:15:00	0:15:00	0:15:00	0:15:00
Modeled Time (Center of Band)	1:15:00	1:45:00	2:15:00	2:15:00	2:15:00	1:45:00	1:15:00	1:45:00	1:45:00
Recorded Time	0:31:00	0:42:00	7:20:00	0:16:00	1:27:00	1:46:00	2:33:00	6:03:00	7:00:00
(Recorded Time) - (Modeled Time [Center of Band])	-0:44:00	-1:03:00	5:05:00	-1:59:00	-0:48:00	0:01:00	1:18:00	4:18:00	5:15:00
Accounting for Measurement Precision (1/2 of Band Value)	-0:29:00	-0:48:00	5:20:00	-1:44:00	-0:33:00	0:16:00	1:33:00	4:33:00	5:30:00
Generalized Delay	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00	3:00:00
(Recorded Time) - (Adjusted Modeled Time) + (Gen Delay Time)	2:31:00	2:12:00	8:20:00	1:16:00	2:27:00	3:16:00	4:33:00	7:33:00	8:30:00
Subject Recovered	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive	Alive
Subject Condition	Well	Well	Well	Well	Well	Well	Well	Well	Well
Gender	Male	Male	Female	Male	Male	Male	Female	Male	Male
Age	9	2	26	76	28	55	7	23	45
Alcohol									
Dementia-Alzheimer's				Yes					
Suicide									
Other	Yes								