

# **Development of a Spatial Decision Support System for Emergency Medical Service Facility Siting**

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## **Abstract**

Improved strategic location of an Emergency Medical Service (EMS) facility can significantly increase EMS efficiency. Urban planners need to consider a location that satisfies multiple criteria in order to make an informed decision about a future EMS facility site. Apart from basic criteria such as parcel value and size, decision-makers need to consider area and population coverage from potential parcels. Geographic Information Systems (GIS) provide an adequate analysis environment for EMS facility siting as many considered criteria are of a spatial nature. However, urban planners making decisions about an EMS facility site often lack the necessary expertise to make full use of challenging GIS tools.

In order to help urban planners in the analysis process, this research developed a Spatial Decision Support System (SDSS) for EMS facility siting. The system was developed in ESRI ArcGIS (9.3) using the Visual Basic for Applications (VBA) programming environment. The objective of the system was to integrate spatial data, analysis, and visualization in a single system to help users evaluate a facility siting problem. The system's performance was tested using data for the Town of Blacksburg, VA. In addition, the system was evaluated by local planners and GIS staff with experience in EMS facility siting. Planners agreed the system enables more comprehensive and straightforward use of GIS for EMS facility siting analysis than other available siting tools. Potential improvements include a simpler user interface, synthesis of geoprocessing techniques, reduction of analysis time through automation, and better decision-making by improved visualization of results.

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# **Chapter 1: Introduction**

## **1.1 Problem Statement**

Organized emergency medical care has been present in human societies for a long time. Introduction of new technologies such as telecommunications and automotive transportation has led to efforts in increasing Emergency Medical Services (EMS) efficiency. As an example of those efforts, the U.S. government's 1973 EMS Act requires that 95% of emergency calls are tended to within 10 and 30 minutes for urban and rural areas, respectively (Rajagopanal and Saydam 2009). In essence, determining the optimal location of an EMS facility can greatly enhance EMS efficiency and thus enhance the well-being of a community. Even though location is considered an important factor for many phenomena, in the case of ambulance facilities there is a heightened significance. Previous studies have shown that putting the effort into finding an optimal location for EMS facilities can significantly improve emergency medical service performance and essentially lead to saving lives.

The process of locating an EMS facility can be a sensitive issue, considering that decision-makers need to analyze multiple, and often conflicting factors. Some measure of population coverage, such as average emergency call time-response estimates of ambulance vehicles, can be a crucial factor in EMS facility location analysis. However, in order to make a reasonable decision, planners need to consider other factors such as economic and infrastructure constraints. These constraints can include characteristics such as parcel value, size, and availability. Geographic Information Systems (GIS) create an appropriate environment for analyzing complex location problems such as ambulance facility siting, since they enable the modeler to synthesize many criteria of interest. Criteria used in this research were determined through correspondence with the Town of Blacksburg planners regarding the general

requirements for an EMS facility. Urban planners responsible for EMS facility siting are increasingly recognizing the benefits of GIS to location based projects. However, many municipalities do not have resources for such projects and could benefit from a more comprehensive system that synthesizes GIS tools for specific analyses.

To provide a more comprehensive way for planners to analyze EMS siting options, this research developed a Spatial Decision Support System (SDSS) within the ESRI ArcGIS software. The SDSS helps users perform a multiple criteria analysis for a single potential EMS facility. The system was tested using data for the Town of Blacksburg, Virginia, but is also applicable to other locations considering similar projects. The parameters evaluated by this application were adopted from an actual project conducted by the Town of Blacksburg. Blacksburg's GIS staff was assigned to use GIS analysis to narrow down the number of possible locations for a single EMS facility. Consequently, one of the methods of evaluating the SDSS was to enable local (including Town of Blacksburg) planners to use and provide feedback on the system.

Design and complexity of a SDSS are often indicators of success of the system in terms of its ability to improve decision-making. Decision-makers who evaluate problems such as EMS facility location often come from areas of expertise other than GIS. These decision-makers could benefit from a comprehensive GIS system, even if they have existing GIS resources or consult with GIS experts. Development of a SDSS for this type of project can add another dimension to the analysis process by giving decision-makers control over the modeling factors through a sequence of comprehensive steps. The user interface of the SDSS enables the user to enter the criteria preferences, and then background analysis of the system produces a set of results which are displayed for comparison of the most suitable alternatives. Consequently, decision-makers

can easily iterate the process and observe the tradeoffs and different outputs associated with modifying criteria.

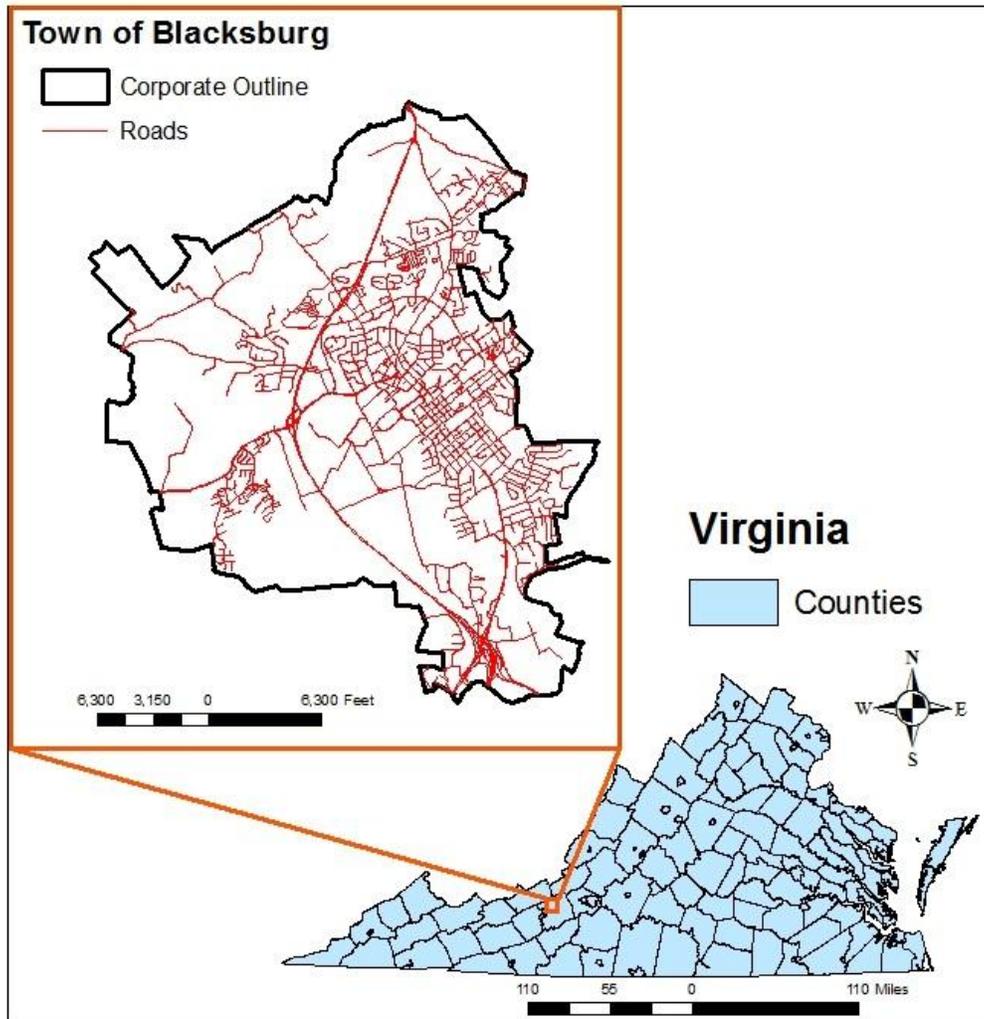
Perhaps the biggest contribution of most Decision Support Systems is their capability to easily replicate the analysis and enable the observation of impacts of various scenarios and change in criteria. Two case studies employing significantly different criteria were performed and described in the results section to portray the value of serious consideration of criteria. With that in mind, the objective of this research was to develop a SDSS that helps potential town planners faced with an EMS siting problem and that is applicable at many locations (dependent on available data).

## **1.2 Study area**

The study area for the pilot application and evaluation of the SDSS is Town of Blacksburg, VA. Blacksburg is an incorporated town located in Montgomery County, Virginia (Figure 1.1). According to the US Census 2008 estimate, Blacksburg has a population of approximately 42,000 citizens, and has experienced above national average population growth in recent decades. Since it is considered one of the faster growing areas in Virginia, the process of locating the EMS facility is critical for the long-term success of the EMS service. The current EMS facility is located on Progress Street in the downtown area. Town officials recognized a need to relocate the facility as it was becoming too small to satisfy the number of operating vehicles it must house. There needed to be a careful consideration of the future facility location as available resources demanded that a single facility covers the entire town.

There are several reasons why the Blacksburg data was used to evaluate the success of the system developed in this research. The EMS facility relocation is currently underway through

cooperation of several different town offices. The Town's project did not involve the development of a SDSS, as different criteria were evaluated by different offices including urban planning, engineering, and GIS experts. Since coordination of different areas of expertise can be costly and time consuming, one of the goals of this research is to synthesize all the geographical criteria used in the Town's project and simplify the analysis process.



**Figure 1.1** Town of Blacksburg, Virginia

In correspondence with the Town of Blacksburg GIS office, the criteria of the actual project undertaken by town officials were identified and used as a guide in design of the SDSS. Using an existing project as a guide helped in development of a more applicable system which satisfies the

current needs of decision-makers. The geographical criteria that the town officials considered included the analysis of the town's parcels attributes (value, size) and respective town coverage of potential parcels. Blacksburg's GIS office maintains data necessary to support this type of analysis and their staff provided the data for the purpose of this research. A detailed database of Town's parcel attributes enables the filtering of potential parcels based on user defined criteria. Furthermore, provided road network data can be used to calculate projected coverage zones and to collect useful coverage measurements (address count, area coverage, census population count) within those zones. More detailed description of the GIS datasets used in this research is provided in the 'Methodology' chapter.

## **Chapter 2: Literature Review**

Facility location problems can be very complex and can be modeled using numerous techniques. There is extensive literature on location problems, which includes approaches from many different disciplines. By their nature, these problems are geographic, but in order to address the problems with adequate complexity, researchers need to utilize techniques from many different fields including mathematics, economics, and operations research. First, this literature review introduces the initial basic approaches to facility location problems, which were developed by scholars from a variety of fields, but mainly stem from the areas of mathematics and economics. Next, this literature review covers the emergence of location studies within the GIS environment, which are often more complex and include the consideration of multiple factors in the analysis process. Lastly, this review discusses the Spatial Decision Support Systems (SDSS) approach to the location problem analysis, where a more applicable modeling environment is used to bridge the gap between the location problems research and the decision-makers.

Although location problems are of interest to many disciplines, their nature is geographic. Robinson (1976) explains that if the discipline of geography was condensed into one word, it would be “place.” Even though Robinson refers mainly to the spatial patterns of places, he states that the location of features within a place is one of the main concerns for geographers. Thus, location problems are a part of a spatial tradition in geography. Additionally, facility location studies contribute to some of the important trends for future research in geography. Cutter and collaborators (2002) discuss some of the big questions for the future trends. Facility location research is contributing to the question of how a geographical skill has played a role in the evolution of human civilization. The efficient placement of emergency medical service facilities

can improve the safety and well-being of our communities and thus has an important role in a community's evolution. Additionally, with reference to some of the geographical methods used in solving location problems, a committee at the recent "Beyond Mapping" convention proposed that the third branch of research in GIScience is the one that incorporates GIS in formulating a policy, using Spatial Decision Support Systems as an example (National Research Council 2006).

The branch of geography that is primarily focused on EMS location problems is medical geography. As discussed by Meade and Emch (2010), medical geography uses concepts and methods from geography and applies them to health-related topics. More specifically, there are numerous locational analyses undertaken by medical geographers, ranging from access to health care resources to EMS efficiency. Apart from physical distance between health care resources and population, medical geographers often focus on social aspects of accessibility such as access to transportation or health insurance (Meade and Emch 2010). In addition, Meade and Emch (2010) explain that the integration of physical and social measures of accessibility enables a holistic approach by these researchers, which shows potential for implementation of policy and planning of comprehensive health care systems.

## **2.1 Basic approaches**

Initially, location problems were studied by mathematicians and economists, using various distance algorithms and formulations to find an optimal facility location. A typical location problem considers a set of customers (demand points), facilities, space, and distance functions (ReVelle and Eiselt 2004; Neebe 1988; Brotcorne et al. 2003). Throughout the literature, the most common way of solving location problems is by using optimization

techniques in order to achieve a certain distance objective. Two of the most common distance objectives involve covering models and p-median models. The covering model involves a problem in which the researcher is concerned with reaching customers within a specified response time; while p-median models consider average weighted response time (Caccetta 2001). Many researchers note that the p-median problem is hard to solve (involves non-linear programming) and is usually solved by a heuristic, a method which is believed to find a close to optimal solution (Dzator and Dzator 2007; ReVelle and Eiselt 2004; Wei et al. 2009). According to Caccetta (2001), the most commonly used heuristics are Teitz and Bart, Densham and Rushton, and the myopic algorithm.

As explained by Caccetta, the Teitz and Bart heuristic starts by considering a feasible facility solution and then relocates the facility to unused sites in an attempt to improve the solution. Caccetta further explains that the Densham and Rushton heuristic considers two different facility relocation (swapping) techniques, local and global, in order to increase the heuristic efficiency in comparison to Teitz and Bart. Lastly, Caccetta summarizes the myopic algorithm which adds facilities one by one based on minimal cost to all customers until a certain covering objective is reached. Although the myopic algorithm adds each subsequent facility based on a minimal cost objective, the final overall placement of facilities is often not optimal. These heuristics provide very intricate optimization models, but are not necessarily directly applicable to the EMS facility location analysis as demand points are not fixed and more comprehensive solutions can be reached by observing multiple coverage measurements such as area coverage along with the population coverage.

One of the major concerns recognized by scholars is the process of defining the objectives. Usually, there are tradeoffs associated with objectives that minimize average distance

(p-median approach), minimize maximum distance, and try to accomplish equitable facility location by striving for a similar response time for all the members of the population. The dominant approach to finding optimal locations is a p-median approach which relies on minimizing the average distance. The p-median approach was first introduced by Hakimi (1964) and has been used intensively in location problems research. However, some researchers argue that solutions acquired by minimizing the average distance often place remote and low-population density areas at a disadvantage in terms of accessibility to public facilities (Ogryczak 1998). Some researchers acknowledge that the models which minimize the maximum distance are more equitable and consistent with the Rawls' general principle of justice (ReVelle and Eiselt 2004; Ogryczak 1998). Additionally, many problems discussed in the literature are defined as multiple objective problems which makes them more difficult for analysts to model. Some researchers note that optimization problems get more complicated with the need to satisfy certain constraints, such as available resources (Dzator and Dzator 2007). In addition, due to the fact that facility locations often involve many stakeholders, the modeling process needs to consider multiple and at times conflicting objectives (Current et al. 2002).

Many researchers address the issue of location research being mostly theoretical, without much practical application in the industry or public sector. The complex nature of the problems in the literature dictates the presentation of theoretical examples with only few demand points in order to prove a certain algorithm useful, while practical problems often include thousands of demand points. However, by utilizing some of the algorithms from the basic approaches, the recent emergence of Geographic Information Systems (GIS) has enabled researchers to add an applied dimension to location problems. Still, in regards to the analysis of static location problems, it seems that the transition to GIS techniques has been inert. Most recent GIS analyses

consider dynamic location problems, such as the real-time dispatch of emergency vehicles (e.g. Panahi and Delavar 2008).

In comparison to early crow-flight approaches and algorithms used to solve location problems, current GIS software takes a slightly different approach as it mainly considers travel time along road networks in order to calculate distance. In Environmental System Research Institute's (ESRI) ArcGIS software, facility siting analysis is mainly performed using the "Network Analyst" extension. This extension is a collection of tools that operate on a network dataset and can produce outputs such as optimal "routes" and "service areas". The main algorithm behind ArcGIS network analyst is Dijkstra's algorithm, which compares possible travel routes and finds the least cost path depending on a certain impedance attribute (commonly distance or time). For the purpose of EMS facility analysis, road network analysis can be used to create "Service Area" travel-time response polygons by creating polygons which are delineated by lines of equal travel time from the origin (in this application, a potential facility).

## **2.2 GIS location problems literature**

Geographic Information Systems (GIS) tools are progressively being implemented by researchers to help solve location problems. Scholars from other disciplines recognize that GIS spatial tools can help overcome the barrier between location analysts and location decision-makers (ReVelle and Eiselt 2004). Additionally, researchers found that GIS can accurately allocate the facilities in an area if based on variations of mathematical programming techniques proposed by earlier researchers (Wei et al. 2009). It is important to understand the reasons why GIS techniques have led to the analysis of more realistic and applicable location problems. Some of the benefits of GIS include better visualization, easy manipulation of data and models, and the

ability easily to incorporate factors other than distance into the modeling process. In addition, GIS provides a good environment for the use of multiple modeling techniques introduced by the basic mathematical models described earlier.

By having a better visualization, decision-makers gain a better perception of the model and can potentially reach a better solution. Once decision-makers are presented with large volumes of spatially referenced data, GIS technologies can help them understand geographic patterns that would otherwise be hard to determine (Peters and Hall 1999). Furthermore, an important aspect of GIS is the easy manipulation of data and models, such as dynamically changing road network data, which was often a difficult task in the basic algorithmic approaches. Due to the powerful functionality of GIS, most of the literature focuses on highly complex problems in big urban areas. There have not been many studies concerning smaller urban areas, or areas implementing a single ambulance facility to cover the whole community. The study of the Town of Blacksburg EMS location can contribute to closing this gap by identifying the modeling challenges of a single-facility location problem.

Perhaps the biggest contribution of GIS technology to location literature is the ability of the GIS software to incorporate analysis of many factors other than distance without introducing major modeling challenges. The integration of multiple-criteria location problems with GIS is recognized as one of the most important areas for future decision support in spatial planning (Ogryczak 1998). In addition, Ogryczak (1998) explains that the development of solutions in GIS environments is suitable for multiple-criteria location problems as it enables the user to model both the decision and criterion space geographically. In essence, the introduction of factors such as economic, social, and political constraints makes the outputs of the modeling process more reasonable. Some researchers claim that consideration of these economic

constraints should be one of the first steps in the modeling process (Mitropoulos et al. 2006). As an example, researchers in Greece used age, income, and urbanization aspects in order to portray health profiles in certain areas (Mitropoulos et al. 2006). This concern was also present in a case study in Rotterdam, Netherlands, which considered previous emergency demand areas, minimization of overlap, and preference of urban over rural areas for ambulance relocation (Geertman et al. 2004).

Due to the relatively recent application of GIS tools to location problems, as well as the fact that most GIS analyses in the literature are site-specific, it is difficult to make generalizations about any trends in the predominant modeling techniques used. Bender and collaborators (Bender et al. 2001) explain that it is difficult to provide an encompassing set of tools in GIS for location problems due to the diverse nature of these problems. Even so, the literature on GIS emergency medical service location problems provides some useful examples that can serve as a guideline for future studies. To gain an additional applied benefit of location problems literature, researchers are modeling these problems in a GIS decision support environment, in which the decision-makers can have easier control over the data manipulation and modeling preferences (Bender et al. 2001; ReVelle and Eiselt 2004).

### **2.3 Spatial Decision Support Systems (SDSS)**

Throughout most of its history, GIS have mainly been used by experts in the field. Spatial concepts and techniques are often complex and require considerable practice to be well understood. However, with the emergence of geo-enabled services such GPS, “Google” mapping products, and various social network location services, the general public is getting exposed to some powerful GIS capabilities. Likewise, local governments are realizing GIS potential and are

increasingly investing in using geospatial techniques to solve various problems. In order to bridge the gap between complex GIS analytical techniques and their applicability to a larger user base, the emergence of Spatial Decision Support Systems (SDSS) is aiming to reduce the complexity of GIS analysis.

Spatial decision support systems are part of a field broader than GIS as a similar framework is often used to reduce complexity of other quantitatively complex problems, largely from a business information technology aspect. Spatial Decision Support Systems differ from conventional GIS modeling by providing a system that coherently organizes data and models, and enables the user to easily modify a few key elements of the analysis. The clear benefit these systems bring to the applied dimension of facility siting research is that they enable decision-makers to perform analysis without requiring them to understand all the intricacies of the tools and models that make up the system. This notion is important as decision-makers are often not proficient with GIS modeling. Therefore, coherently displaying the variables and objectives in the modeling process might help them get a better grasp of the problem. Recently, the SDSS approach began to be utilized by GIS researchers, as a systematic process makes the use of GIS more straightforward and practical.

Spatial Decision Support Systems help decision-makers evaluate different scenarios involving human decisions rather than just providing one unique solution which a decision-maker should accept. Thus, the use of SDSS distinguishes between unstructured, semi-structured, and structured problems (Scheibe et al. 2006). Semi-structured problems are of most interest to researchers as they can be analyzed by algorithms but also require human intuition and decision-making abilities to solve the problem. Since multiple-criteria problems often include a tradeoff among different options, the decision-maker often needs to consider a compromise in

order to reach a nearly optimal solution. In terms of current EMS location research, most GIS decision support studies consider the real-time management of ambulance facilities, as this process requires a quick evaluation of uncertain data (e.g. Henderson and Mason 2005).

Spatial decision support is heavily used in planning and forecasting of complex systems such as location problems, urban land use patterns, and environmental sustainability projects. The kinds of problems that typically interest geographers and spatial planners involve a large set of feasible solutions and multiple conflicting evaluation criteria (Malaczewski 1999). Researchers explain that the geographic nature of urban planning stimulates the development of SDSS, especially while employing a GIS as the model base (Rubenstein-Montano 2000). Much like the GIS literature in general, the literature on SDSS rarely considers problems in the smaller urban settings. It seems that in order to reach the application in the public and private sector, researchers often consider bigger urban areas. These bigger metropolitan areas often require a more complex analysis, and consequently require more resources. Additionally, static location problems are rarely studied in the SDSS environment. This is partly due to the common practice in which optimal locations for static phenomena are analyzed by regular GIS modeling and there is no consideration for enabling flexibility and iteration in the modeling process.

Since most of the methods and algorithms used in SDSS are site specific, these techniques do not strive for law-giving generalizations, but rather lean towards idiographic goals as explained by Philips (2004). There appears to be a lack of standardization of methods used in SDSS, as many researchers adopt methods which are convenient for their particular case study. In addition, Li and collaborators (Li et al. 2004) suggest that there are two apparent needs for improving GIS as a decision support tool. First, there need to be improvements in methods that

help the comparison of alternatives. Second, the GIS community needs to recognize that there are multiple participants in most spatial decision-making processes.

Location problems are complex and can be analyzed by numerous techniques. For many location problems, different algorithms and techniques often yield multiple, nearly optimal solutions. In the end, it is up to a decision-maker to evaluate the different options and make the final decision. Human decision-making is often unpredictable and unreasonable; however, presenting the right alternatives might nudge people towards a better solution without restricting their right of choice (Thaler and Sustein 2009). Humans often reason with intuition, which combined with loosely organized concepts and models can lead to undesirable decisions (Leung 1997). Although there is a lot of uncertainty associated with techniques in GIS, the ability of decision support systems to synthesize, organize, and model large amounts of information makes this approach appealing for many researchers.

## Chapter 3: Methodology and Description of the SDSS

### 3.1 Data

Availability and quality of the relevant data are important for success in any GIS analysis. The Spatial Decision Support System developed in this research requires a number of data inputs, and quality of those data inputs determines the validity of the outputs of the system.

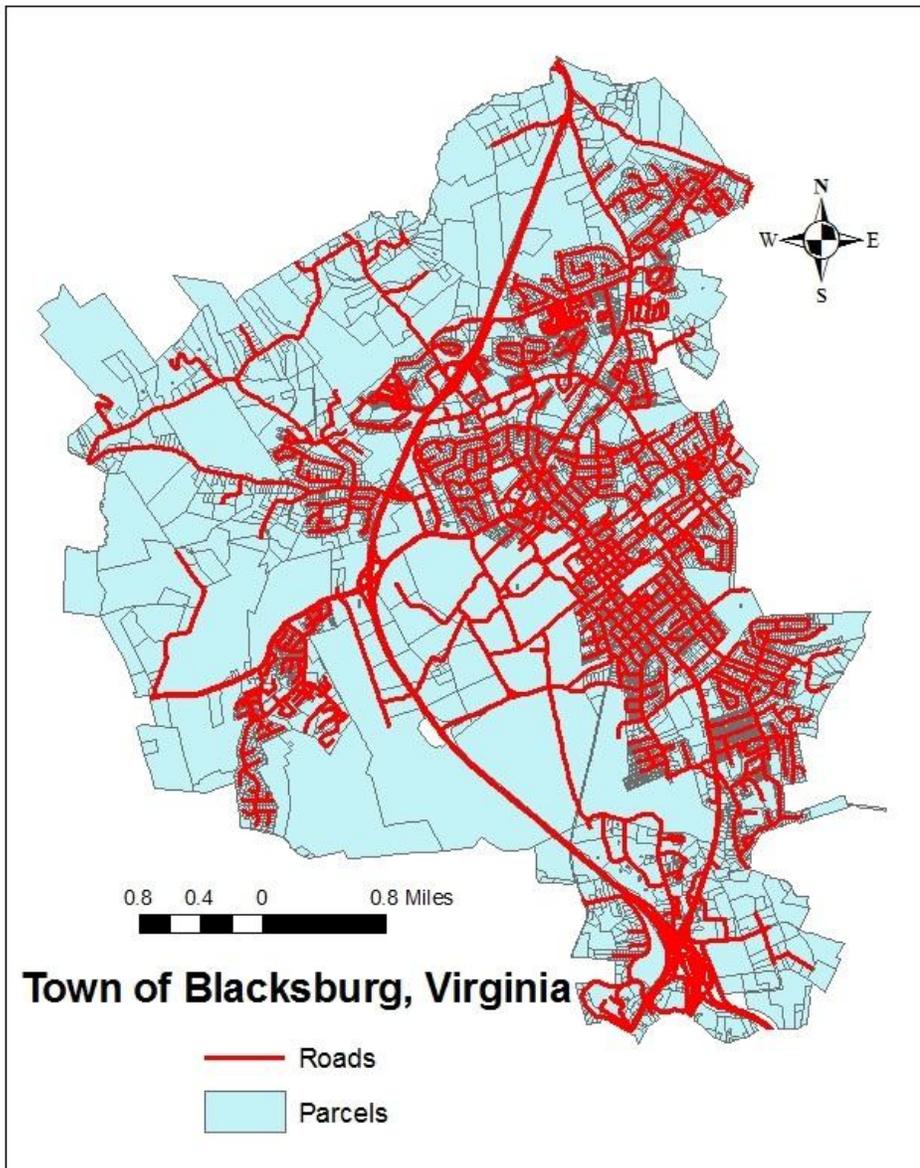
The data and formats the system requires are:

1. Parcel data in the form of an ESRI polygon feature class with attributes for value, size, address, and unique ID.
2. Address data in the form of an ESRI point feature class.
3. Census blocks data in the form of an ESRI polygon feature class containing a population attribute.
4. Valid ESRI road network dataset with time (minutes) impedance.
5. Output ESRI point feature class to store the data of current set of facility alternatives.

For the purpose of testing the developed system, the Town of Blacksburg GIS staff provided most of the necessary data.

One of the essential input datasets is the parcel database, which enables the selection of a subset of parcels to serve as potential EMS facility alternatives. As with any other facility location problem, selection of the best possible location largely depends on the available resources. Considering the current state of the economy, it is important to analyze the land value of the potential parcels for development, even in community oriented projects such as EMS facility location. With limited resources, town officials might be forced to disregard the potentially most suitable locations if they are unaffordable. In the actual project, the town administrators considered vacant parcels, or parcels with buildings less than \$50,000 in value. Additionally, parcels needed to be larger than five acres in order to be suitable for a proposed EMS facility. An ESRI polygon feature class containing the information on parcel values and

sizes for the Town of Blacksburg (Figure 3.1) was used to evaluate the parcel analysis of the SDSS.



**Figure 3.1** Map of Blacksburg Roads and Parcel datasets

Another very important dataset for the EMS facility location analysis is the road network. The analysis of the road network was used to determine which potential EMS facility locations would supply (cover) the Town's existing population better. In order to test the validity of the road analysis part of this application, the Town of Blacksburg roads centerline ESRI polyline feature class (Figure 3.1) was used. Before this dataset could be used in analysis of the software

system developed in this research, it needed to be configured using ESRI ArcCatalog so it could perform as a network dataset within ESRI ArcMap software. This configuration was necessary so that the network analyst tools in ArcGIS could recognize parameters of the road data such as speed limits, traffic lights, and one-way streets. Important consideration of network dataset configuration is the network impedance attribute. With respect to the SDSS developed in this research, the network dataset needs to have time (minutes) impedance configured. Time impedance was calculated using two existing road attributes, length in miles and speed limit in miles per hour, based on the following equation:

$$\text{Road Segment Travel Time (min)} = (\text{Length (miles)} / \text{Speed limit (mph)}) * 60$$

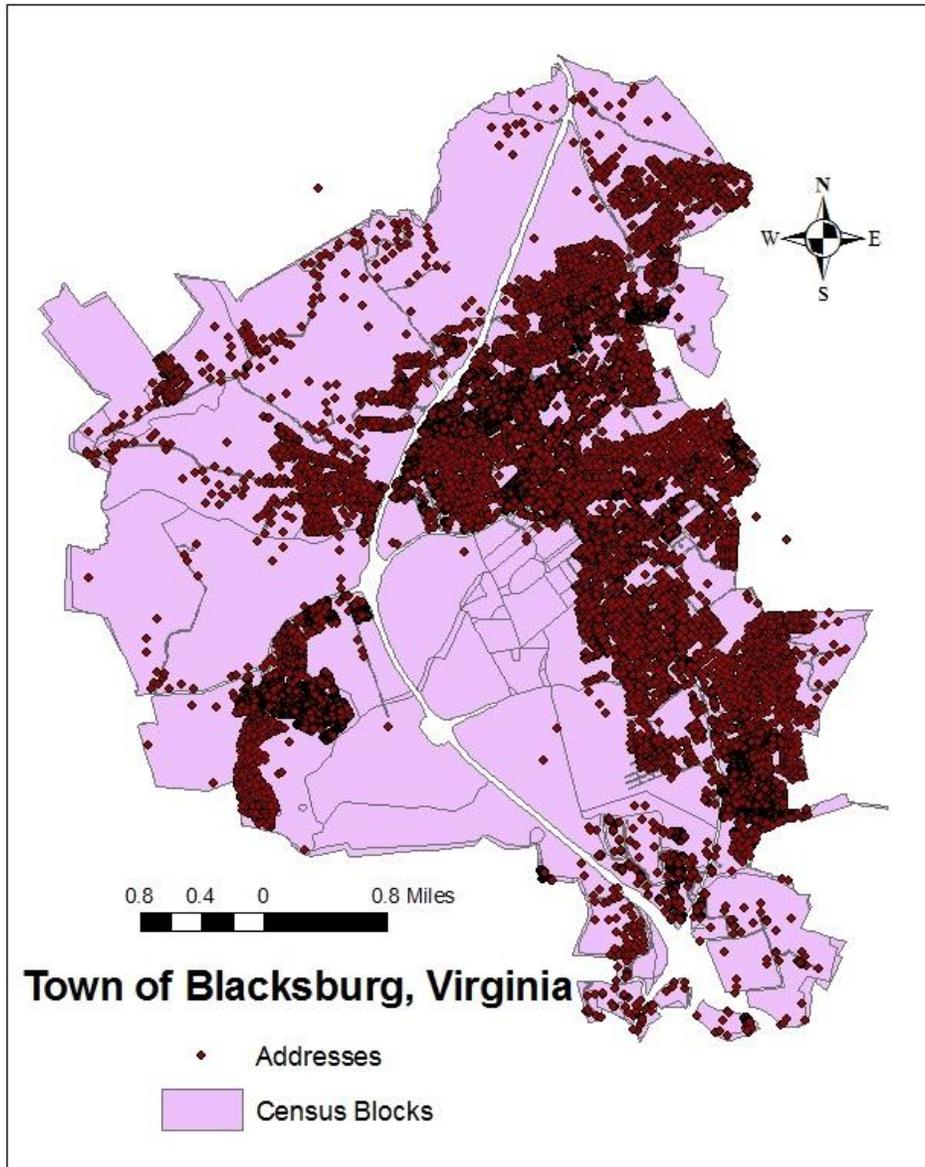
**Equation 3.1 The equation used to calculate time impedance of road segments**

The Resulting time attribute represented the travel time in minutes for each of the segments of the road network.

Other input data (Figure 3.2) required by the SDSS include the ESRI point feature class containing all of Blacksburg's addresses, and a census blocks (Summary File 1) ESRI polygon feature class. Both of these datasets were used to measure the accessibility or coverage of potential facilities. Even though service area (acres) coverage is a valid measure of accessibility, analysis involving EMS siting can certainly benefit from additional measurements such as population coverage. Thus, the resulting Spatial Decision Support System enables the user to observe various coverage measurements drawn from different data sources, namely service area in square miles, and addresses and population measurements within the resulting service area.

Along with required inputs, the user needs to provide an empty ESRI point feature class to store the relevant data for the potential facility alternatives. This feature class can be created using ESRI ArcCatalog software. This dataset stores information such as parcel geometry (centroids), original parcel attributes, and population and coverage statistics for the current

subset of parcel alternatives. Once created, the output point feature class can be reused as previous data is deleted by the SDSS.



**Figure 3.2 Map of Blacksburg Address and Census Block datasets**

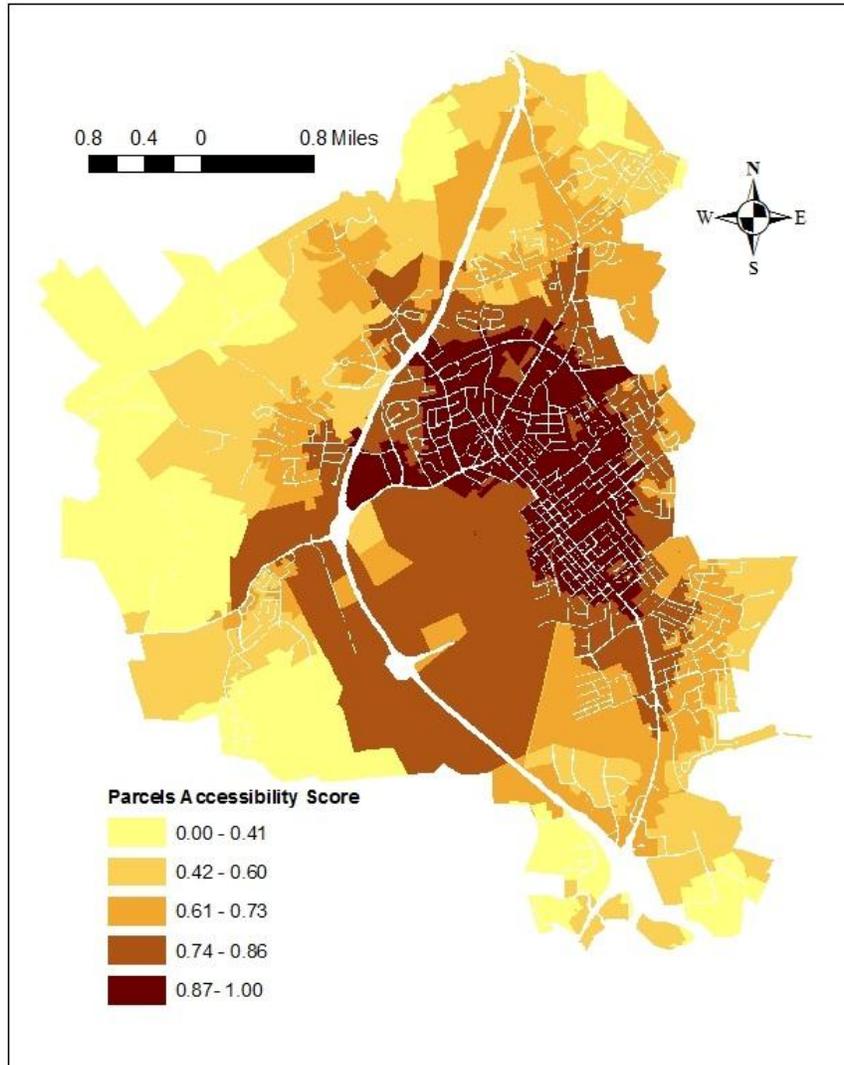
For testing and evaluation of the SDSS, Town of Blacksburg data were used. Blacksburg's GIS staff was in the process of siting an EMS facility and shared their data for the purpose of this research. They provided Blacksburg parcel, road, and address datasets. The road dataset had the necessary attributes (length, speed) required for time impedance, but it also had certain limitations. The roads were represented as centerlines of the respective segments without

the number of lanes attribute. Additionally, there were no data accounting for impedance at different intersections. The parcel dataset had all the necessary attributes but it seems that the database has some errors and missing information which might lead to incorrect outputs of the system. Additionally, census block ‘Summary File 1’ dataset for Town of Blacksburg was downloaded from ESRI website. In the Town of Blacksburg project, the critical information used in decision-making was population covered by four and eight minute polygons created using ESRI ArcGIS “Network Analyst” tools. According to the EMS Act of 1973, all emergency calls must be answered within ten minutes for urban areas such as Blacksburg. Since all of the locations in Blacksburg can be reached in less than ten minutes, the Town’s administrators placed more emphasis on other medically critical thresholds. In case of an emergency such as a heart condition, reaching patients within 4 minutes significantly improves their chances of full recovery.

### **3.1.1 Accessibility score**

To help the user with parcel selection process, an accessibility score (Figure 3.3) was calculated for each of the parcels. This parcel attribute is optional and does not need be calculated in order to complete the analysis by the developed system. This score is different from coverage score used in final ranking of alternatives as it based solely on relative parcel positions along a road network. The goal is to provide the user with some measure of accessibility in order to help with selection of a smaller subset of parcels which undergo a more elaborate accessibility and coverage analysis. The accessibility score is determined by each parcel’s connectivity in terms of travel time to all other parcels along the road network. This measurement was acquired by calculating an “Origin-Destination Cost Matrix” in ArcMap, using all parcel centroids as both

‘origins’ and ‘destinations’. The resulting matrix provides a travel time for all possible connections. This information was then summarized for each parcel by calculating an average time it takes to travel to the rest of the parcels.



**Figure 3.3 Map of Blacksburg Parcels' Accessibility Score**

Resulting averages were further standardized with lower averages (more accessible) yielding higher scores on a 0 to 1 scale. The standardization was deemed appropriate as it might make more sense to the user than actual average travel time, which ranged from three to ten minutes among town of Blacksburg parcels. As ArcMap's "Origin-Destination cost Matrix" tool has memory limitations with regards to how many origins and destinations can be loaded for a

single analysis, a Python geoprocessing script (Appendix A) was developed to iterate incrementally over the entire parcels dataset in order to generate accessibility score. The script incrementally loads different origins (100 at a time), while always loading entire dataset for ‘destinations’. This logic yields the same accessibility scores as loading entire dataset to both ‘origins’ and ‘destinations’ would if the memory limitation had not been reached. This script can be reused for other localities as long as the number of parcels is similar to the Town of Blacksburg (10803 parcels). For bigger datasets this script might not be appropriate or might need to be modified as ArcMap memory limit might be reached by loading all of the destinations alone.

## **3.2 Description of the SDSS**

### **3.2.1 Introduction**

The primary focus of this study was to develop the Spatial Decision Support System (SDSS) within the ESRI ArcGIS software that could help decision-makers with varying levels of GIS expertise to analyze the EMS facility location problem. The use of the SDSS would enable the testing of a variety of scenarios and options, and also provide visualization and analysis of the results. The current tools for this type of analysis are available within ESRI’s software but require familiarity with cumbersome GIS tools. On the other hand, people making decisions regarding the placement of the town’s facilities such as EMS are often not familiar with GIS and come from different areas of expertise. Therefore, a user interface that synthesizes different tools scattered across the ESRI ArcGIS software, with incorporation of various visualization and analysis techniques could prove to be more valuable for targeted decision-makers.

The SDSS developed in this research was designed as a custom Visual Basic for Applications (VBA) ‘User-Form’ - which serves as a user-interface through synthesis of many existing GIS tools. The SDSS processes are written and executed in the VBA programming environment within ESRI’s ArcMap software. The system’s ‘User-Form’ is organized as a multi-page “wizard” (Figure 3.4), which guides a decision-maker through various steps in the analysis process. Although existing ArcGIS tools are not modified, the synthesis and simplification existing tools potentially creates a more user-friendly environment for less proficient GIS users.

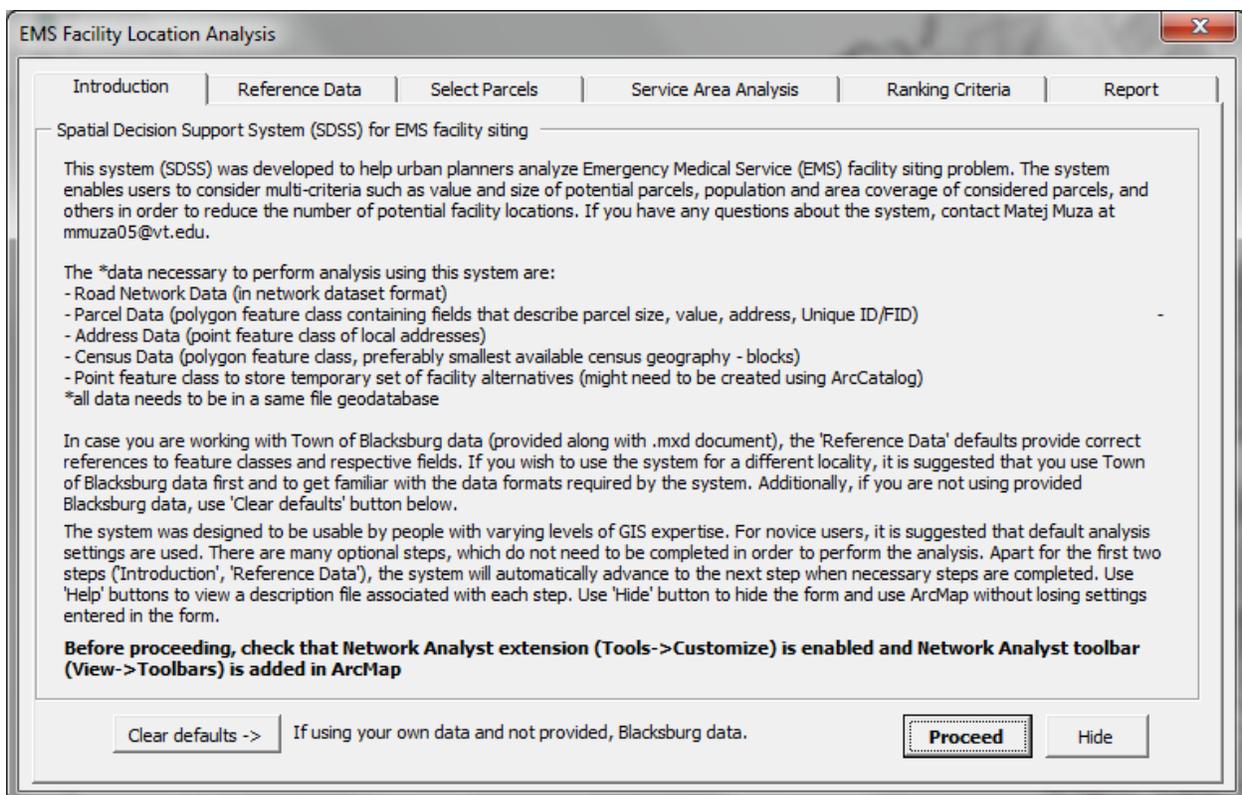
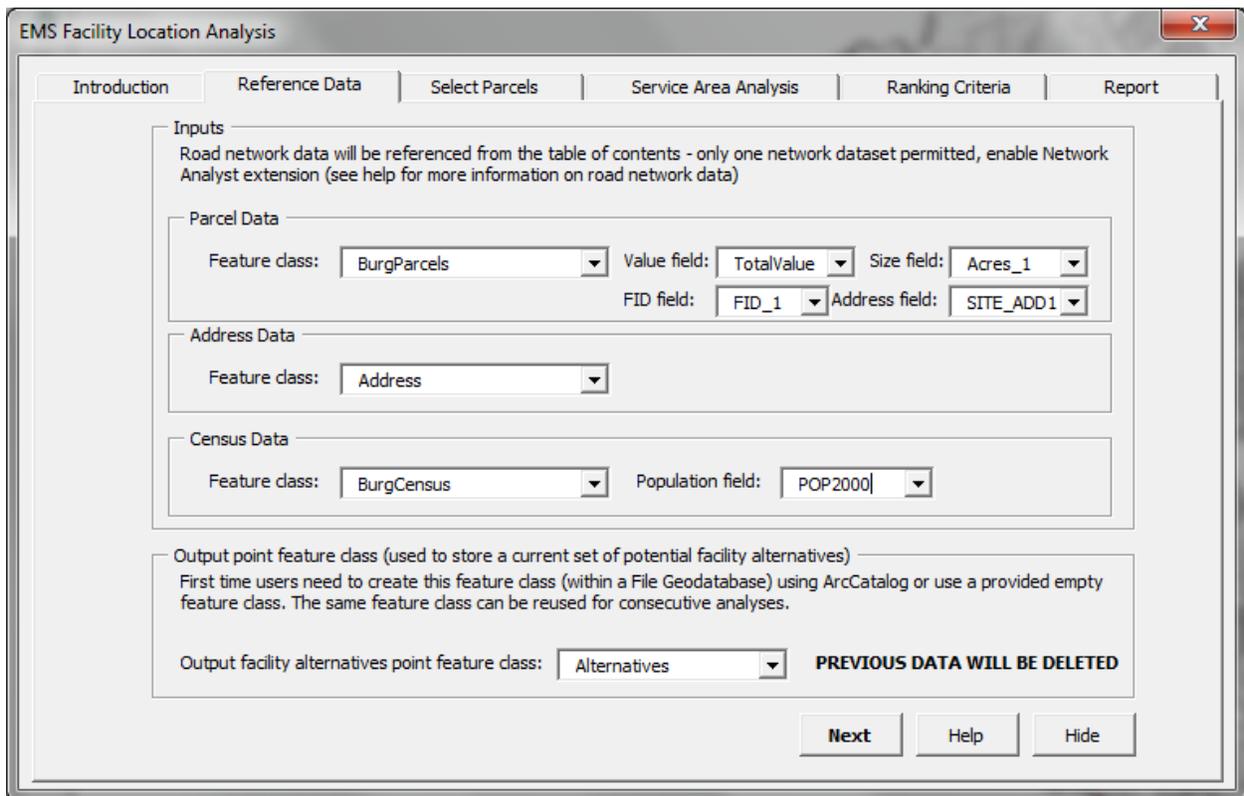


Figure 3.4 The ‘Introduction’ page of the main ‘User-Form’ of the SDSS

The first page of the SDSS serves as an introduction to its basic purpose, functionality, and requirements. The system is somewhat complex so it is important to provide some introductory information before the user begins to use it. Information provided includes the introduction of the problem, author contact information, data requirements, certain disclaimers about usage, and a warning to turn on required extensions. Additionally, the first page enables

the user to clear the default values of layer and field names provided for commonly used Blacksburg data. After reading the instructions, the user can click ‘Proceed’ button to continue to the next step. Each step has a ‘Hide’ button to enable the user to close the ‘User-Form’ without removing the entered information. Additionally, most of the pages (if there is not enough help within the ‘User-Form’ page) have ‘Help’ buttons which open separate help forms (Appendix B). In most cases the pages are automatically switched when the user has completed necessary steps. Otherwise, ‘Next’ and ‘Proceed’ buttons can be used to advance to next steps, along with page tabs which can be used to switch pages in any direction at any time.



**Figure 3.5** The ‘Reference Data’ page of the main ‘User-Form’ of the SDSS

The second page (Figure 3.5) of the SDSS requires the user to select the data to be used in the analysis process. This step is necessary to reference required input ESRI feature classes from ArcMap’s ‘Data Frame’ so the system can correctly manipulate the data in the latter steps. Text on the top of the page explains how the system references the network dataset from

ArcMap's 'Data Frame'. As the network dataset is unique in comparison to other datasets and it can be located in the 'Data Frame' by the SDSS, the user is only required to import the network into ArcMap as a map layer. In addition, the 'Network Analyst' extension needs to be enabled, and 'Network Analyst' toolbar needs to be added to ArcMap. This is one of the potential limitations of the SDSS as some ArcMap users do not have a 'Network Analyst' extension license. More detailed network dataset instructions are provided in the 'Help' window for the 'Reference Data' page.

The SDSS uses drop down menus which display current datasets loaded into ArcMap's 'Data Frame' to enable the user to point to required datasets and also to reference an output point feature class which is used to store a current subset of potential facilities. The drop down menus filter the feature classes by type, so polygon feature classes are visible in 'Parcel' and 'Census' data menus while point feature classes appear in 'Address' and 'Output' data menus. In addition to referencing the required datasets, there are additional menus which enable the user to reference the required attribute fields of respective datasets. In essence, enabling the user to reference the data allows the user to perform the analysis for any locality as long as the datasets and respective attributes are in the same format. This notion satisfies one of the goals of this research, which was to provide a framework for EMS facility siting regardless of the locality, even though the Town of Blacksburg was used to test the system.

### **3.2.2 Parcel analysis**

The initial goal of the SDSS is to identify eligible locations for further, coverage analysis. It is likely that many of the locations favorable in terms of coverage are not vacant or are too expensive for a town's designated budget for this project. Thus, the SDSS first considers factors

such as parcel value and size in order to identify eligible locations for further analysis. There are several ways the user can filter the parcels to reach an optimal sample for further analysis. The analysis of parcel value and size can be used to eliminate certain locations. The most suitable facility locations are often located in the town's central business district, where the land value is higher and the land is often already developed. In contrast, parcel size tends to increase as distance from the town center increases. The EMS facility siting project conducted by the Town of Blacksburg generally considered vacated parcels or developed parcels with buildings less than \$50,000 in value, and parcels larger than 5 acres in size.

The third page (Figure 3.6) of the SDSS enables the user to filter the parcel polygon feature class to create a subset of potential alternatives. The user has an option of using three different selection (filtering) methods. The suggested method uses the original parcel value and size attributes. Two optional selection methods include standardized, zero to one scores for parcel value and size, and using built-in ArcMap selection tools. Under the first and recommended selection method, the user is able to specify acceptable ranges for parcel value and size criteria. After entering the criteria values, the user can view the resulting selection subset of parcels by clicking the 'Execute Selection' button. If the subset of parcels is between one and twenty, the 'Place Facilities' button becomes enabled. Otherwise, the user can change the criteria and re-click the 'Execute Selection' button until a desired subset of parcels is reached. The threshold of 20 was introduced to avoid the potentially long 'Service Area' network analysis which takes about 20-40 seconds for each of the potential parcels depending on computer performance (if needed, the 'Help' section for this page indicates that the 20 parcel threshold can be removed per user's request to the author). In case the initial user-defined criteria produce a

subset that is too large, the optional ‘Accessibility score’ criteria can be introduced to eliminate less accessible parcels which would likely produce poor coverage.

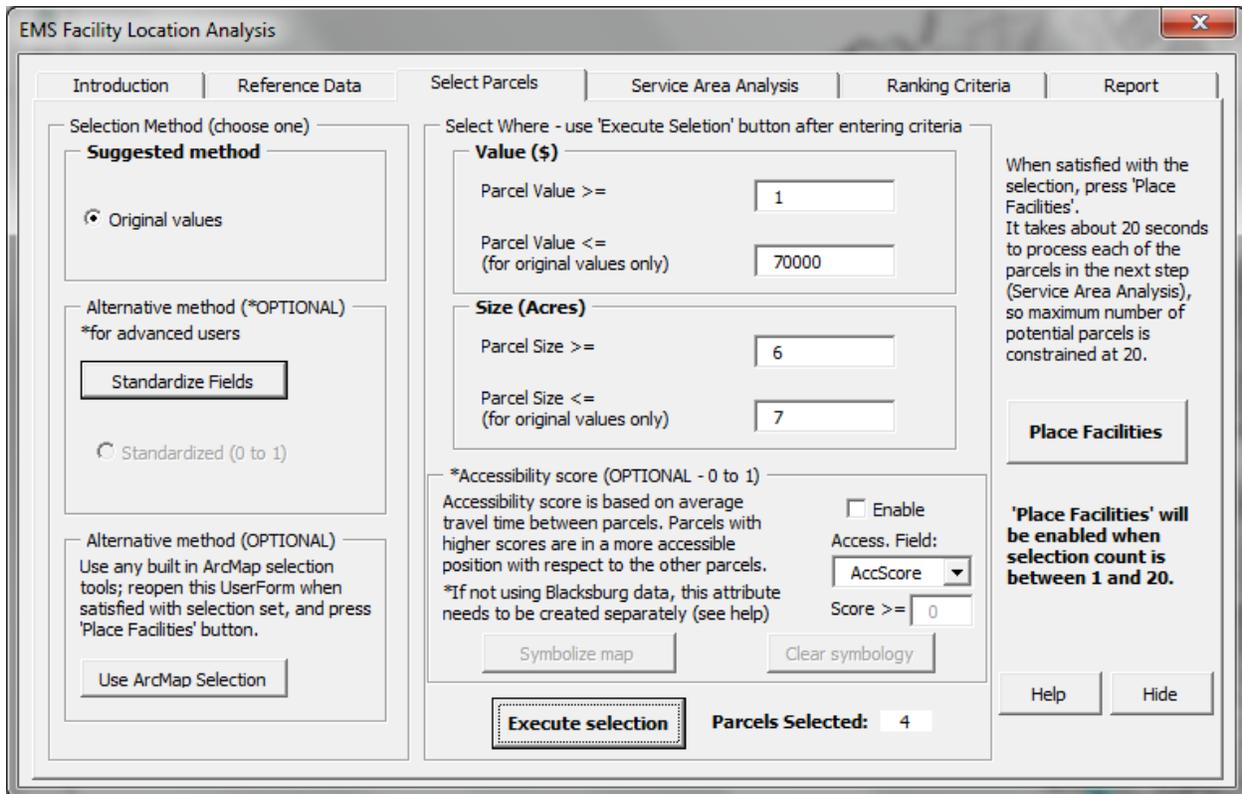


Figure 3.6 The ‘Select Parcels’ page of the main ‘User-Form’ of the SDSS

The second, optional, selection method uses similar criteria logic but instead of original parcel attributes it considers standardized (0 to 1) parcel scores. These standardized scores can be useful if the user wishes to use the parcel value and size attributes in the weighting scheme which determines overall parcel suitability score later in the analysis process. This standardization process needs to be performed by the user as the ranges of values for parcel value (price) and size are too large to provide a valuable standardization method from overall ranges alone. By requiring the user to specify the cutoffs for the standardized membership, the standardized score becomes more meaningful.

In order to create the standardized parcel scores the user needs to use a separate ‘User-Form’ (Figure 3.7) initiated by clicking on the ‘Standardize Fields’ button. This separate ‘User-

Form' guides the user through the standardization process. First, the user needs to specify which parcel characteristic to standardize, value or size. The second step is to specify the method of standardization (membership function). Based on selected membership function, the user can enter between two and four values to assign the membership scores to parcels. The images help the user interpret how the functions standardize the data. In essence, the user can define where the characteristic's membership starts to increase, where it is at full membership (standardized value = 1), where it begins to decline, and finally where it returns to zero.

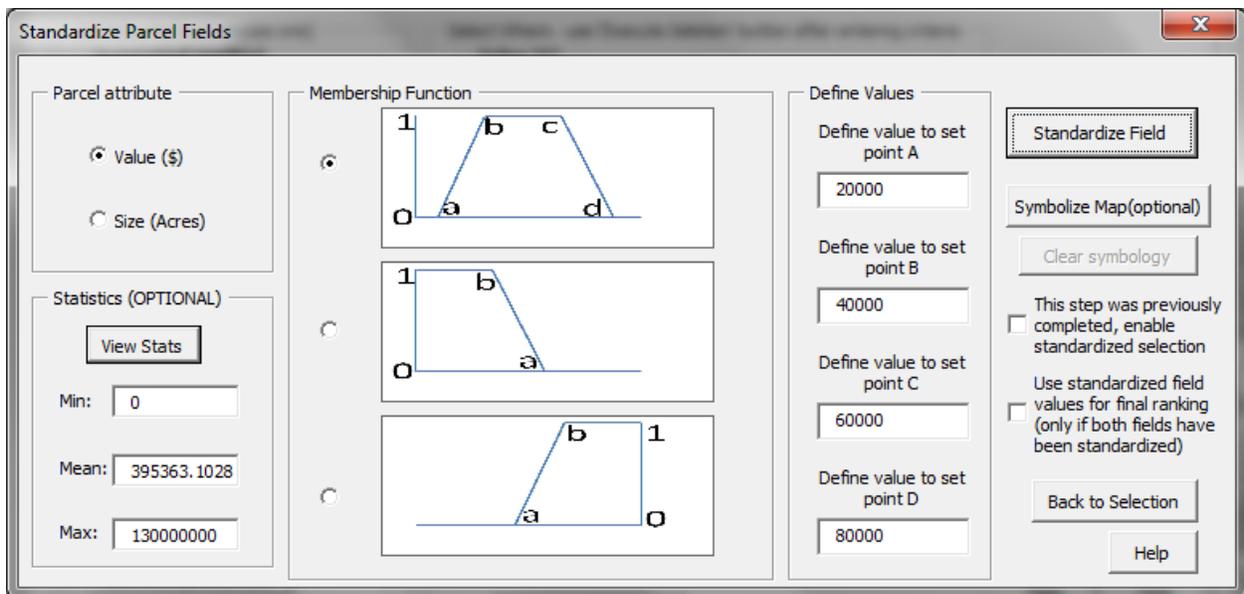


Figure 3.7 The 'Standardize Parcel Fields' 'User-Form' of the SDSS

By completing the standardization process for both parcel value and size attributes, the 'Standardized' selection option becomes enabled in the 'Select Parcels' page of the SDSS. Additionally, there is a check-box in the 'Standardize Parcel Fields' 'User-Form' that allows the user to enable the 'Standardized' selection in case this process was already completed on a previous run of the system. This is an example of the effort to enable users to easily iterate the analysis and observe the results in a timely, efficient manner. There is an additional check-box in the 'Standardize Parcel Fields' 'User-Form' which allows the user to apply the standardized attributes in the final ranking. This is the only way of incorporating the value and size attributes

in the final suitability score as all of the measurements need to be standardized between zero and one. Once the user enables the 'Standardized' selection, logic similar to the suggested method can be applied to select parcels. The main difference with this method is that the user only needs to specify the lower bound of the range as the upper bound is automatically set to 1 (most suitable, full membership). As with the suggested method, the user can use 'Accessibility score' to filter out parcels in case other criteria yield a large sample set of parcels.

The final, optional, selection method enables the use of built-in ArcMap selection tools. A click on the 'Use ArcMap Selection' button hides the active 'User-Form' and enables the user to use any of the built-in ArcMap tools, such as 'Select by Attributes' using any attributes (not only value and size), 'Selection by Location', and selection by user defined rectangle (or click). This selection method can be particularly useful for users who have extensive local knowledge and can produce a better subset of potential alternatives using attributes and methods different from the methods provided by the SDSS. Once the user is satisfied with the selection set, re-opening of the SDSS displays the 'Select Parcels' page with the updated number of selected parcels from the ArcMap selection. After the user has selected 1 to 20 parcels for further analysis, the 'Place Facilities' button is enabled. Regardless of the selection method, the 'Place Facilities' button manipulates the selected subset of parcels as it derives a centroid of each of the parcels and places that point as a record in the output point feature class. The reduction of parcels to points is necessary to perform the network 'Service Area' analysis. The output point feature class will thus be used to store the parcel centroids and all the relevant parcel measurements produced in the following analysis steps.

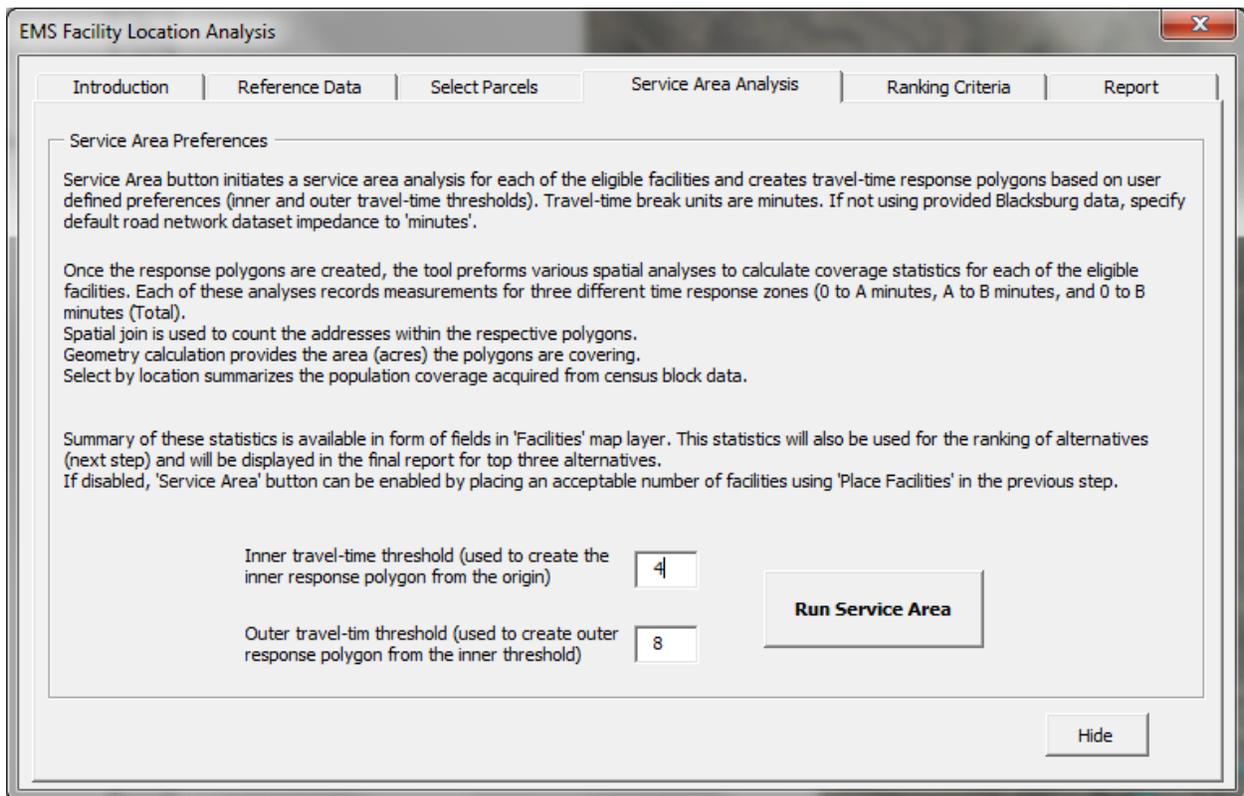
### 3.2.3 Network analysis

After potential facility locations are identified by the parcel selection process, the next step in the analysis process measures the coverage of town's area and population for each of the eligible parcels. A widely accepted method for the analysis of the coverage using the road network is the use of ArcGIS "Network Analyst". Network Analyst is a set of tools provided by ESRI ArcGIS software that can perform various analyses on a road network such as routing, service area, and shortest path analysis. The most suitable tool for this project is the "Service Area" tool, which can create polygons from a point of interest (e.g. EMS facility) based on user-defined equal travel-time distances. In essence, the tool creates 'Service Area' polygons by calculating travel times in each of the possible directions and the boundary of the polygons is delineated as travel time reaches user defined time threshold.

Perhaps the most important consideration in creation of a network dataset is definition of impedance attribute. For the purpose of this project, the network dataset impedance needs to be set to time (minutes) as time is an essential coverage criteria for EMS. The time impedance was calculated using the speed limit and length attributes of provided road dataset. Additional network attributes such as intersection impedance, number of lanes, and others could be used to make the network analysis more accurate. Due to the lack of certain network data attributes, this project assumes that the ambulance vehicles drive the maximum speed limit along each of the road segments. In reality, the ambulance travel performance depends on the traffic conditions which are dynamic and difficult to incorporate in road network analysis.

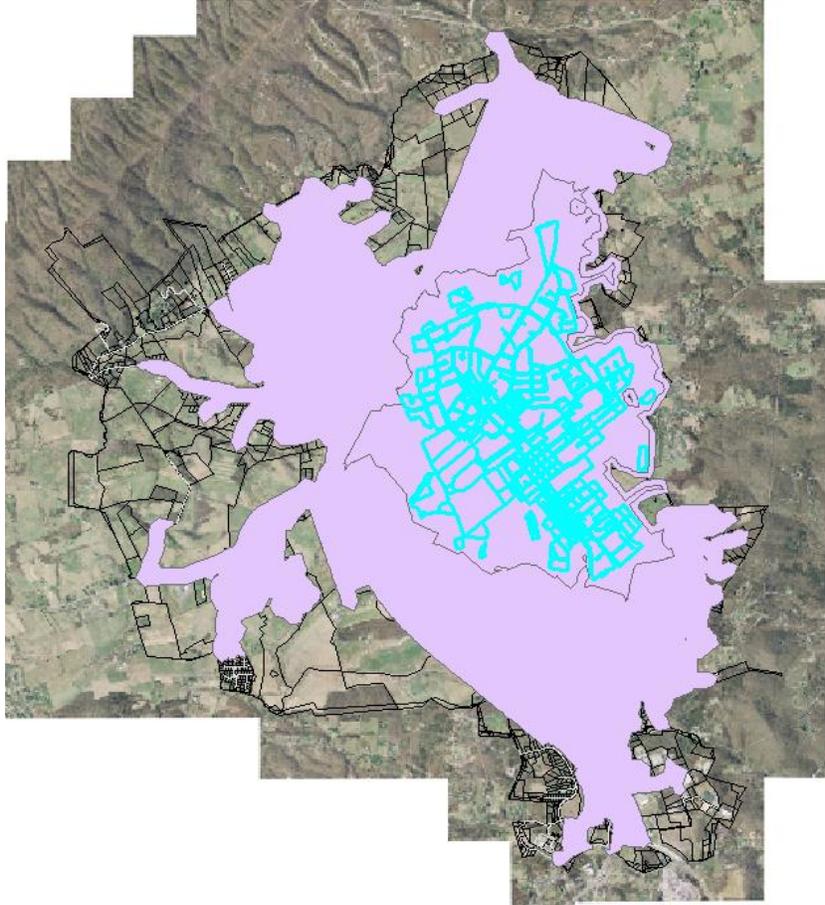
Page four (Figure 3.8) of the SDSS is used for the 'Service Area Analysis' of the potential facility alternatives as it enables the user to input two desired travel-time thresholds for coverage analysis. Even though the user only specifies two travel-time threshold parameters, this

step executes the majority of the analysis of the SDSS. A brief summary of those analysis processes is described within the ‘Service Area Analysis’ page. In essence, by clicking on the ‘Run Service Area’ button the user initiates ArcMap’s ‘Service Area’ network analysis for each of the facility alternatives points derived in the previous step. Service area analysis outputs two response polygons (Figure 3.9) which are used to calculate various coverage measurements which are further used for the final ranking of the potential facilities. This portion of the SDSS executed the majority of the EMS siting analysis and saves considerable time through automation of analysis processes.



**Figure 3.8** The ‘Service Area Analysis’ page of the main ‘User-Form’ of the SDSS

Once the ‘Service Area’ response polygons are calculated by network analyst, the SDSS executes three geoprocessing tasks for each of the alternatives in order to attain measurements of coverage.



**Figure 3.9** Screen capture of the analysis initiated by ‘Run Service Area’ button

First, a spatial join is used to account for the number of addresses contained by each of the respective response polygons. Spatial join uses the response polygons boundary to query which of the addresses fall within the polygon and it reports the total count of addresses which are stored as an attribute in the output feature class. Next, through access of geometry of each of the response polygons, the area (acres) coverage is recorded as an attribute of the output feature class. Lastly, a version of ArcMap’s ‘Select by Location’ tool is used to select all the census blocks contained by each of the response polygons. The SDSS selects the census blocks which are completely within the respective response polygons and uses those blocks to calculate population counts for respective alternatives. This selection method underestimates the population counts when compared to other selection methods which may overestimate the

population counts by selecting census blocks which extend outside of the response polygon boundary. As with the previous two outputs of the geoprocessing steps, census population counts are recorded in the attribute fields of the output feature class. Once the 'Service Area Analysis' is completed; the user is directed to the next analysis step, 'Ranking Criteria'.

The fifth page of the SDSS, 'Ranking Criteria' (Figure 3.10), is designed to enable the user to introduce weights to available factors (measurements) in order to observe only the most suitable alternatives in the final step. The ranking method provided by the tool is fairly simple, and it can be omitted if the user decides to accept the defaults weights. The default weights are somewhat conservative as they place equal importance on census population and area coverage measurement for the overall (origin to outer travel-time threshold) response polygon. Otherwise, by enabling weights the user can increase the importance of a certain measurement while the other measurements' importance decreases at the same time. The main requirement behind the ranking tool is that the numerical values or weights which determine importance of measurements always add up to one. There are eleven possible factors to consider in the weighting process. Nine of these factors are derived from the combinations of three calculated measurements (address count, area coverage, and census population) and three different travel-time response polygons (origin to inner time threshold, inner to outer time threshold, Total – origin to outer time threshold). The two remaining factors are parcel value and size which are only available if specified earlier in the analysis process, during the standardization of parcel attribute fields. Using that method, the parcel value and size are used both for filtering (as a criteria) and for weighting (as a factor) during the analysis process.

In order to reach the final, weighted score for each of the alternatives, the tool standardizes each of the acquired measurements to a value between zero and one. Measurements

are standardized using a simple linear function which assigns standardized values by based on measurements' values along the range (maximum-minimum) of the measurements for the current subset of alternatives. As a result, these relatively standardized values are only useful for a one subset of parcel alternatives at a time. Once the measurements are standardized, they are multiplied by weights and added. The resulting values represent the overall suitability score which is used in ranking of the alternatives. Since both the standardized measurement values and weights are based on values between zero and one, the resulting suitability scores are between zero and one as well. However, the suitability scores are only relative to the current subset of alternatives and would be misleading if compared to the scores of a different subset of parcels. The objective of the score was to compare the suitability of the current alternatives, rather than assessing alternatives' suitability as an absolute measurement.

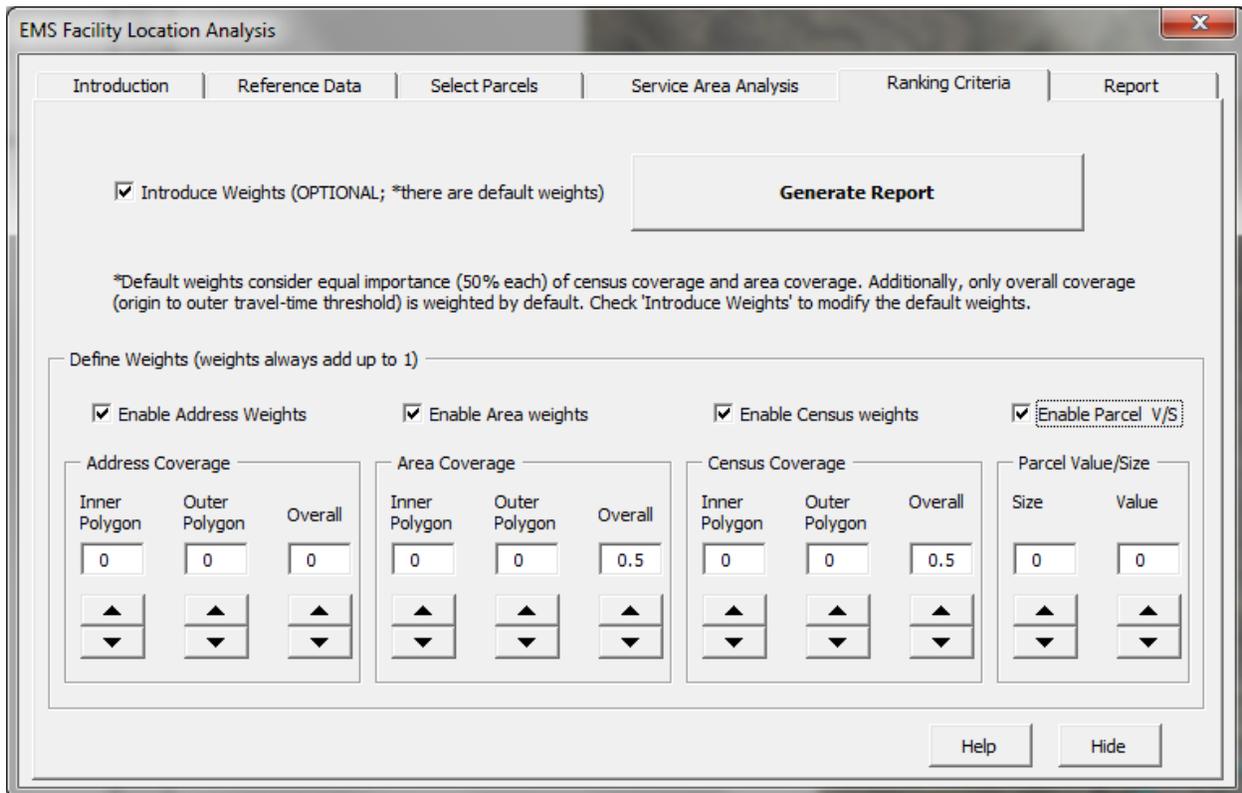


Figure 3.10 The 'Ranking Criteria' page of the main 'User-Form' of the SDSS

### **3.2.3 Outputs of the SDSS**

The final page (Figure 3.11) of the SDSS is designed to present the results of the current SDSS analysis. Since this application is designed to serve as a decision support system, the output of the analysis is organized in a way that should stimulate better decision-making. It is important to present a few different alternatives for the user (the report presents three highest-scoring alternatives), but not too many as that might overwhelm the user and make the comparison of alternatives difficult. The visualization of different alternatives is available both in form of maps (displaying parcels and respective travel-time response polygons) and in form of a table for comparison of numerical measurements of alternatives. The presented numerical information for alternatives includes the parcel value and size attributes, as well as the population and area measurements derived from travel-time response polygons. If the user requires further analysis with the set of potential alternatives, all of the data used and collected through the analysis process is stored in the output alternatives feature class and can be accessed through standard ArcGIS tools from that source. Additionally, the user can easily iterate the process for a different set of parcels and observe different results in the 'Report' page.

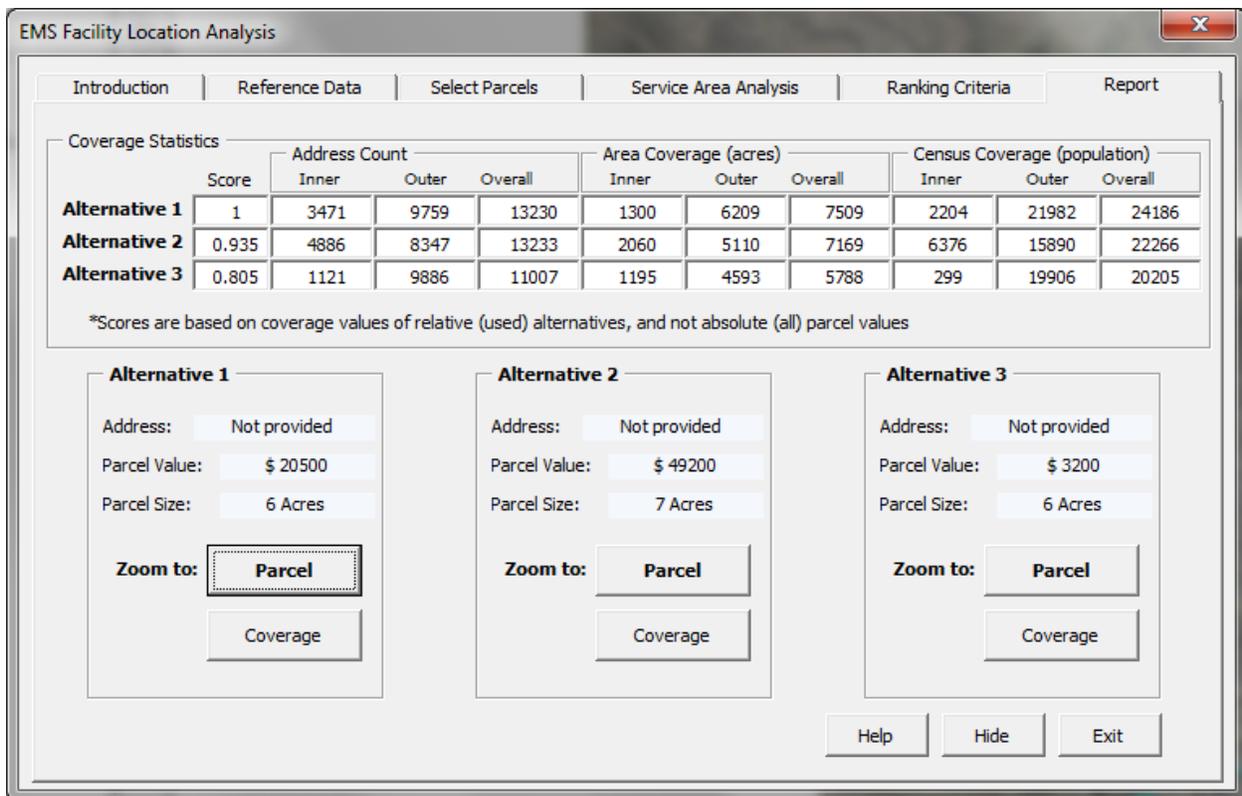


Figure 3.11 The 'Report' page of the main 'User-Form' of the SDSS

The report page of SDSS 'User-Form' is used to present the outputs and enable the user to interactively observe the three most suitable parcels and their respective service areas. The table on the top of the page contains the values for all the coverage measurements derived from the tool for top three alternatives, as well as the score determined by the user weighted ranking from the previous step. Additionally, the user can observe the information on parcel address, value, and size below the table. Along with the additional information, the user is able to zoom to both the parcel and the respective time response polygons of the top three alternatives.

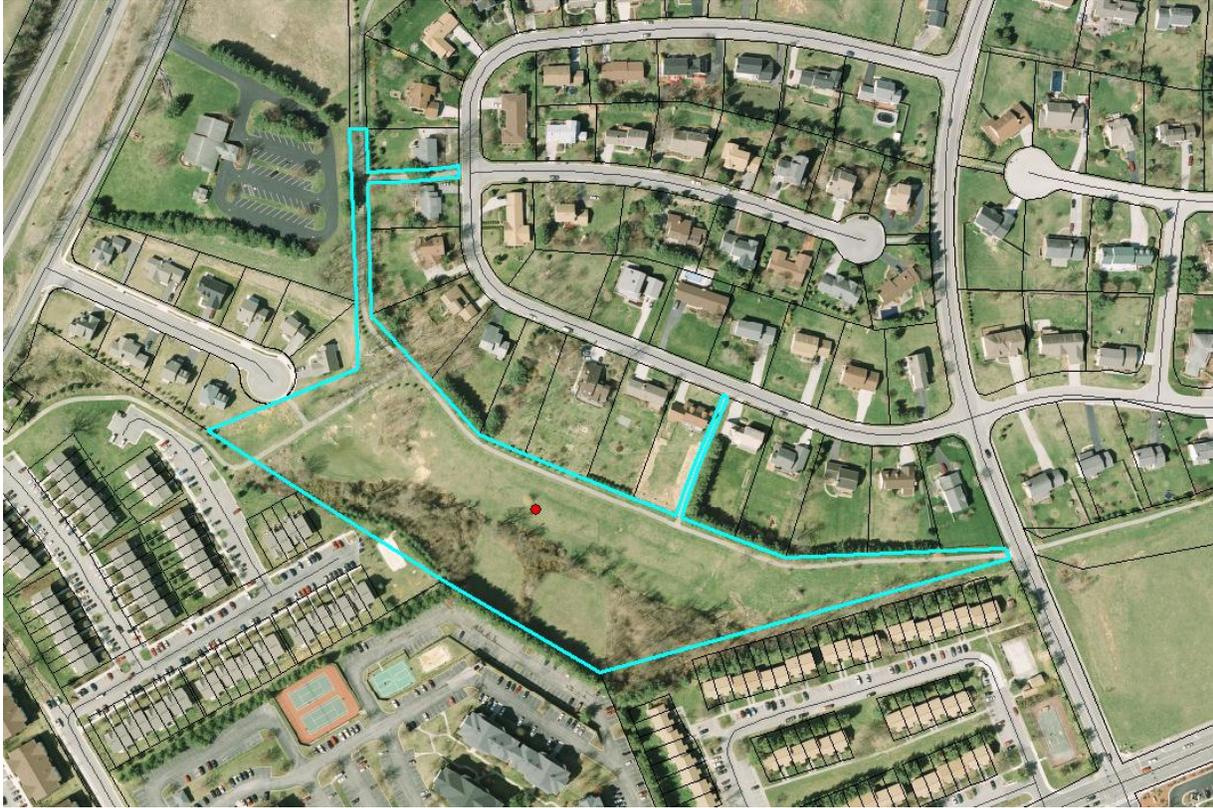


Figure 3.12 Screen capture of a zoom to parcel using SDSS

As the user zooms to a feature of interest, the original ‘User-Form’ is hidden so that the zoomed view can be seen without obstruction. Figure 3.12 shows an example view of a zoom to a parcel of interest. The parcel is also selected (highlighted) in order to help the user distinguish the parcel from the neighboring parcels. The smaller ‘User-Form’ (Figure 3.13) is used for navigation back to the ‘Report’ page of the original ‘User-Form’ and to the previous zoom extent.

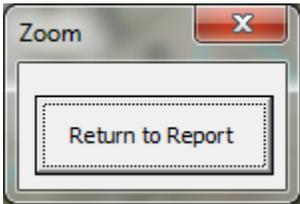
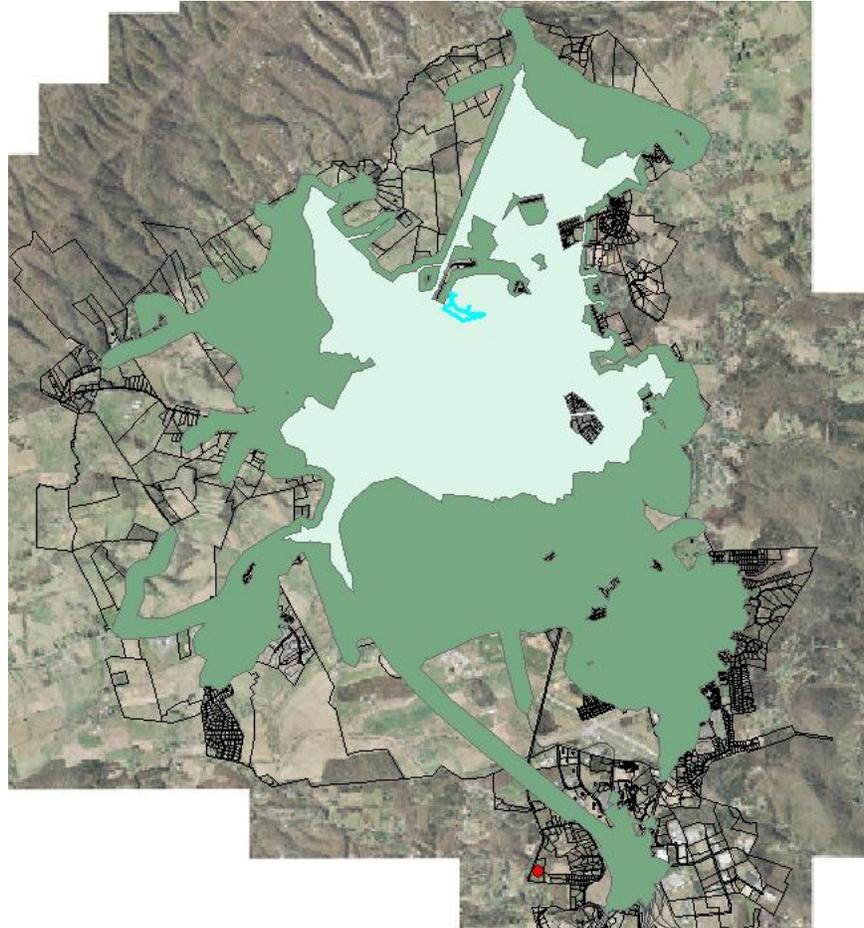


Figure 3.13 The ‘Zoom’ ‘User-Form’ of the SDSS

For display purposes (optional), high resolution aerial imagery may be loaded in ArcMap software and used to provide the context of parcel surroundings. Having additional layers loaded

in ArcMap will not affect the analysis of the SDSS in any way. A zoom to the coverage of the respective parcel, portrayed by the travel-time response polygons is shown in Figure 3.14. Allowing the user to observe the results both visually as a map and in form of numerical attributes in a table is designed to stimulate decision-making by enabling nearly simultaneous comparison of facility alternatives.



**Figure 3.14** Screen capture of a zoom to response polygons

### **3.3 Evaluation of the SDSS**

The main goal of this research was to develop a Spatial Decision Support System which makes the facility siting analysis understandable to multitude of GIS users and stimulates decision-making through synthesis and simplification of available GIS tools. In order to portray the significant effects different criteria can have on the outputs of the system, two case studies were performed and described. The first case study considered criteria proposed by Town of Blacksburg planners, while the second case study assumed more relaxed criteria (unlimited budget). In addition, for purpose of assessing the success of the SDSS, evaluation copies of the system were sent to local planners. The planners were instructed to use the SDSS and to provide feedback in form of a survey (Appendix C). The resulting survey responses were used to describe the success of the particular needs the SDSS was designed to resolve. In essence, the users were asked to state the previous experience with GIS and siting analyses, provide feedback on various elements of SDSS such as user-interface design, analysis steps and techniques, and visualization and presentation of results.

For the purpose of acquiring feedback from human subjects, a Virginia Tech's Institutional Review Board (IRB) protocol was completed and approved (Appendix D) in order to insure proper conduct with regards to human subjects' activity in this research. This protocol explains the guidelines by which subjects were recruited to participate, and how subjects were expected to participate and provide feedback. An email invitation for participation of SDSS was sent to local GIS managers from following public entities: Montgomery County, Town of Blacksburg, Town of Christiansburg, and Town of Radford. Town of Blacksburg and Montgomery County planners responded to recruitment email and agreed to participate. The GIS managers were encouraged to invite any planners within their organizations to participate in

evaluation and complete the survey. One planner from Montgomery County and five planners from Town of Blacksburg used the SDSS and filled out an evaluation survey. The evaluation copy of the SDSS that was sent to local planners used data for the Town of Blacksburg, Virginia by default. Additionally, a user manual was provided, which contains all of the help information which is available within the SDSS and in the 'Help' 'User-Form's' (Appendix B) of the SDSS. Even though default data enabled testing of the SDSS for analysis of Town of Blacksburg, the users were informed that they can use different data as long as all the data format requirements were satisfied.

## Chapter 4: Results and Discussion

### 4.1 Case Studies

To provide an example of sensitivity of results in an EMS facility siting analysis, two case studies observing different scenarios were performed using the SDSS. The first case study considered the criteria proposed by the Town of Blacksburg planners, while the second case study considered an unlimited budget and relaxed parcel size requirements. Although the compared scenarios are very different, the variation of coverage measurements between the two cases demonstrates the significance different criteria can have in predicting the potential performance of an EMS.

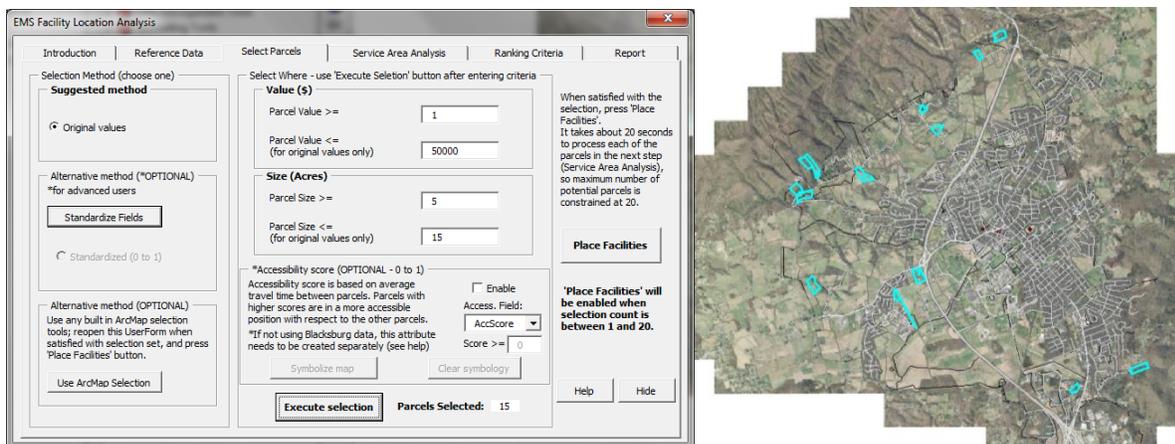


Figure 4.1 Screen captures of the criteria and resulting parcels used in first case study

The first case study considered the criteria (Figure 4.1) suggested by the Town of Blacksburg planners. These criteria required a parcel value less than \$50 000 and parcel size between five and fifteen acres. Those requirements yielded a subset of 15 parcels (Figure 4.1) which underwent the service area analysis to acquire coverage measurements. Once coverage measurements were attained, a weighting scheme displayed in Figure 4.2 was used to calculate unique suitability scores for the subset of parcels. The same weighting scheme was used in both scenarios, and it divides the importance between area coverage (50 % weight) and population

coverage (25 % census and 25 % address count measurements). The weights were then equally divided among the travel-time zones.

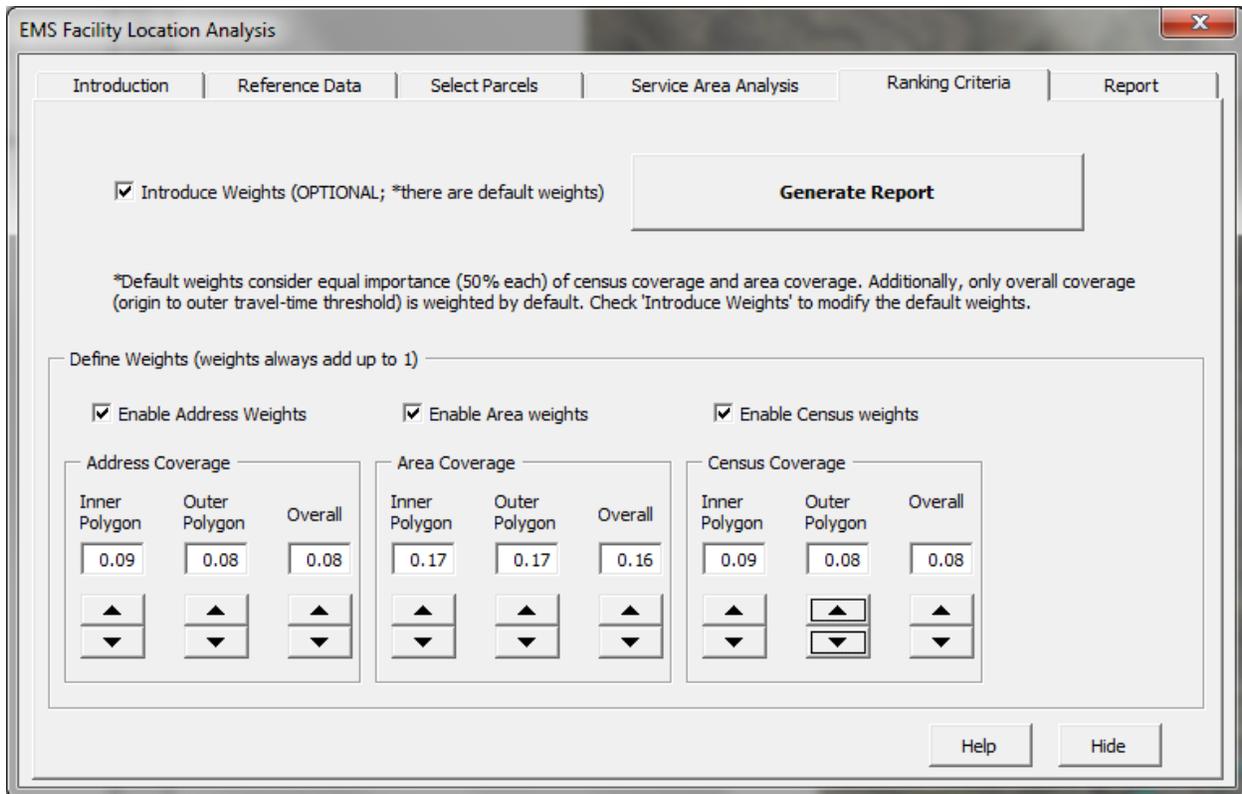


Figure 4.2 Weighting scheme used to calculate suitability scores in case studies

The second case study considered less rigorous criteria. This case study assumed an unlimited budget for the new facility and thus considered all the parcels in terms of value attribute. Additionally, parcel size criteria were relaxed to consider all the parcels between 3 and 20 acres. These requirements produced a very large subset of potential parcels, and parcel accessibility score criteria was used (parcels with scores greater than 0.95 were considered) to eliminate most of the parcels as they would produce relatively less favorable town coverage. The resulting query produced a subset of 11 parcels (Figure 4.3) which were used for the service area analysis to obtain detailed coverage measurements. The same weighting scheme (Figure 4.2) used for the first case study was applied to the second case to produce overall suitability scores.

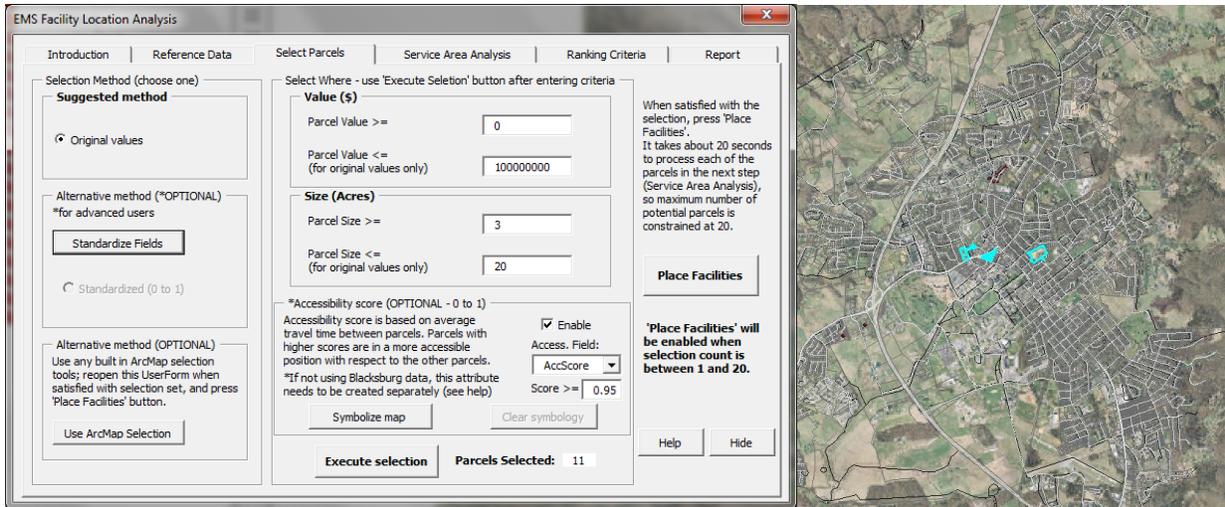


Figure 4.3 Screen captures of the criteria and resulting parcels used in second case study

Three highest-scoring parcels for each scenario are presented in greater detail in Figure 4.4, where many parcel attributes (including coverage measurements) are displayed.

Additionally, the map representations of the highest-scoring parcel's coverage zones are portrayed in Figure 4.5. The comparison of attained coverage measurements from the two case studies exemplifies the importance of an EMS facility siting analysis employing an interactive decision support system. Planners can quickly observe the significance of the difference of two scenarios by comparing the coverage measurements of three highest scoring parcel alternatives as displayed in Figure 4.4.

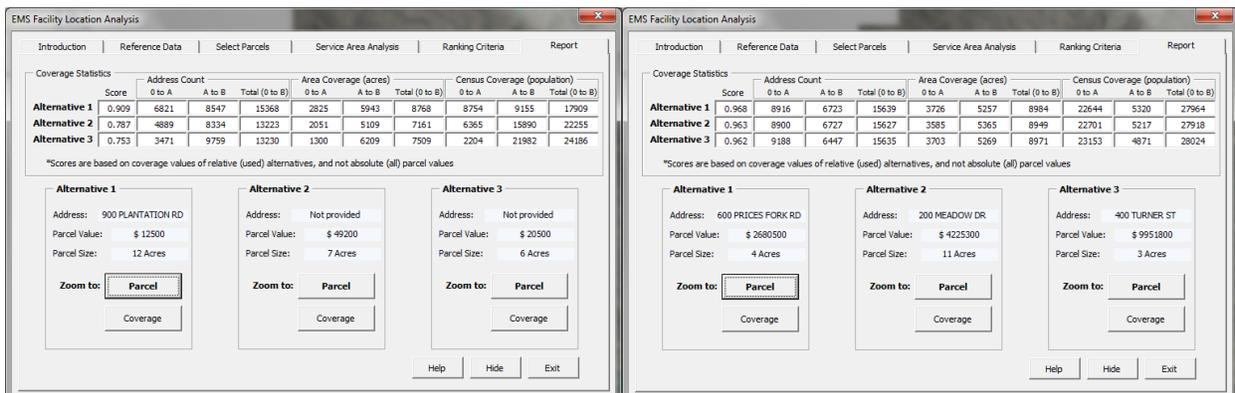
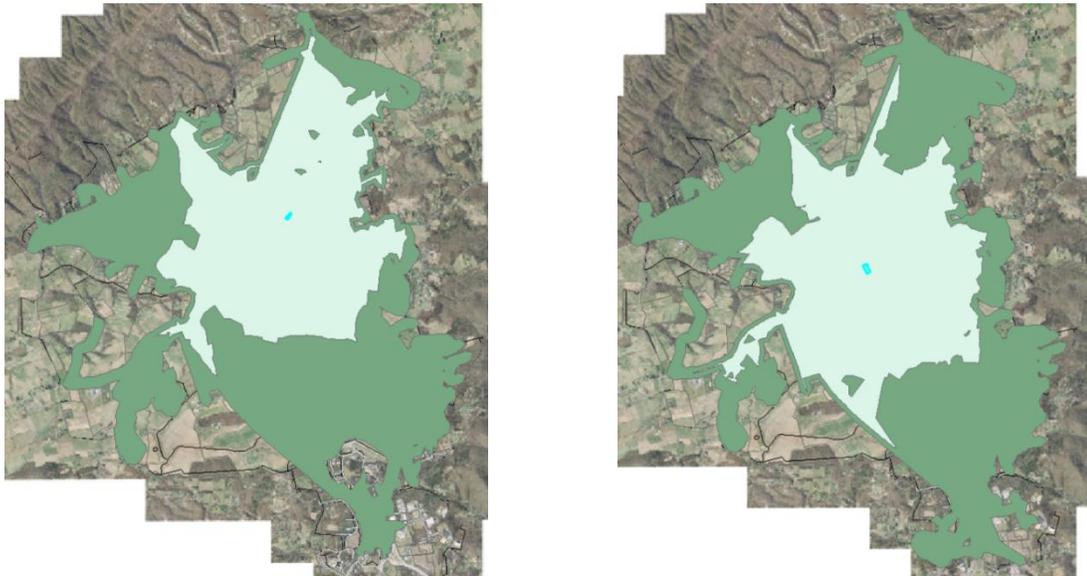


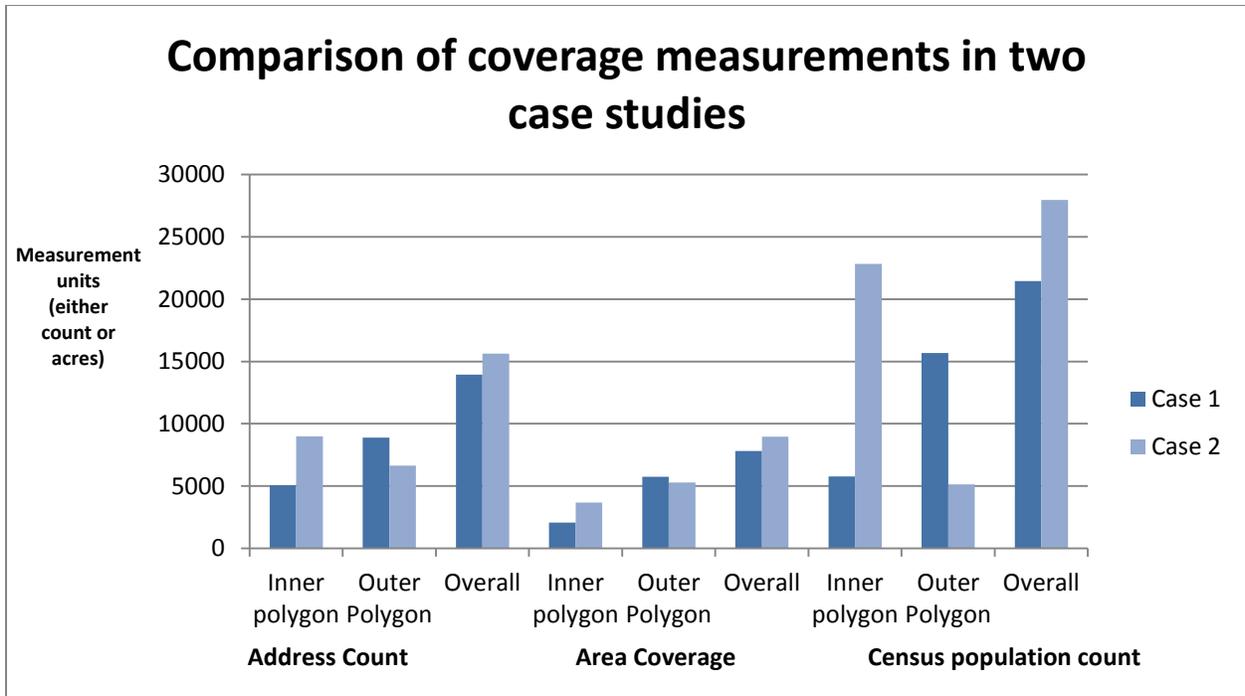
Figure 4.4 Comparison of the detailed description of the three highest-scoring parcels for each of the case studies (first case on the left, second case study on the right)

It is clear that a scenario with relaxed criteria (second case study) produces much better coverage measurement for critical inner travel-time response zone (origin to four minutes in this case). This difference can also be easily interpreted by observing the graphical representations (Figure 4.5) of the travel zones which is interactively available through the SDSS.



**Figure 4.5 Map comparison of the travel time response zones for the highest-scoring parcels in each of the case studies (first case on the left, second case study on the right)**

To explain the significance of the difference between the two scenarios, the coverage measurements for the three highest-scoring parcel alternatives were averaged for each case study and used for comparison (Figure 4.6). It is clear that second scenario resulted in parcel alternatives with more favorable coverage measurements for the inner travel-time response zone (origin to four minutes). This zone is very important (as explained by the Town of Blacksburg planners) since persons requiring an emergency service for health issues such as a cardiac failure have significantly greater chance of recovering if they receive help within four minutes. Consequently, municipalities striving to improve their EMS efficiency need to consider this travel time threshold as an important factor in future EMS management.



**Figure 4.6** Chart comparing three highest-scoring alternatives of the two case studies

The numerical comparison of differences in coverage measurements for two scenarios portrays the difference in potential quality of EMS service these sites would provide. In terms of address count, the second scenario's top three alternatives covered 43.78% (3941) more addresses within four minutes on average. The additional area coverage within four minutes was 43.93% (1613 acres) larger for the second scenario alternatives on average. Even greater difference was evident with the census population count, as number of people potentially served within four minutes was 74.71% (17058 people) greater for the second scenario alternatives on average. However, the first scenario alternatives covered the population and area better for the outer travel-time response zone (four to eight minutes). The differences for this time response zone were 25.31%, 7.94%, and 67.24% for address count, area coverage, and census population count, respectively. As the Town has a finite population, a large proportion is usually located within eight minutes of many locations. The advantage of sites in the second case study is that they serve a majority of the covered population within four minutes as opposed to the first case

study sites, in which a majority is served from four to eight minutes of travel-time (lower quality of EMS service). Even with the outer zone coverage favoring the first scenario, the total coverage (origin to eight minutes) was greater for the second scenario for all three coverage categories. The actual percentages of the difference for the overall travel-time zone considered were 10.83%, 12.88%, and 23.31% for address count, area coverage, and census population count, respectively.

	Parcel Value (\$)	People served within four minutes	Cost per person
Case 1	12,500	8754	\$1.43
Case 2	2,680,500	22644	\$118.38

**Table 4.1 Comparison of most suitable alternatives in each case study**

The significance of these differences can be described in a perhaps more compelling manner for urban planners by comparing the differences in cost of parcels and potential quality of service. For example, the comparison of most suitable parcels in each case scenario (Table 4.1) portrays the cost associated with potential improvement in EMS efficiency. As evident by comparison of cost per person served within four minutes, the proportion of the difference is substantial, but a nominal difference of \$116.95 per person is certainly not unfeasible for decision-makers in charge of budget allotment. Considering the likelihood that the proposed site will be utilized for couple of decades, this cost becomes even lower on a person per year basis. Even though this comparison is not statistically rigorous and is subject to data uncertainty, the descriptive comparison of scenarios shows the importance of considering different criteria.

## 4.2 Results of the Evaluation Survey

The Spatial Decision Support System (SDSS) developed in this research was evaluated by a group of local urban planners and GIS staff with interest in Emergency Medical Service (EMS) facility siting. The SDSS, along with all the Town of Blacksburg GIS data required for the analysis were sent to urban planners and GIS staff in municipal organizations within Montgomery County, Virginia. The subjects were encouraged to use the system and provide a feedback in the form of a survey. The survey involved questions regarding the user's previous experience, and SDSS usability, analysis techniques, and output visualization. Six subjects from local organizations responded to the survey and enabled the descriptive evaluation of this research.

The responses on questions regarding previous GIS and siting experience show that the system was evaluated by a variety of users in terms of GIS expertise. When asked to self-identify their skill level, three subjects responded they were beginners, while others identified as intermediate (one) and advanced (two) GIS users. Four subjects indicated they were involved in a siting analysis utilizing GIS tools in the past, while others were relatively new to most concepts considered in this study. Similar responses were given to the inquiry about use of GIS for a siting analysis, where four out of six had previous experience. Although the number of participants is low, a variety of experience with GIS and siting analysis provides an interesting set of subjects and enables the assessment on how the SDSS was considered by users at different levels of relevant expertise. One of the interesting comments in the free response section of this part of the survey stated that the previous experience with siting analysis involved too many criteria and lacked dynamic what-if scenarios which are enabled by the SDSS. After using the SDSS, most of the subjects (66%) specified they would use SDSS over other available siting tools. Eighty three

percent of the subjects strongly agreed that the SDSS was a valid approach to reducing a large set of potential alternatives (10803 parcels in Blacksburg) to a smaller subset of most suitable alternatives.

The second survey section included questions about the user interface of the SDSS. All of the subjects agreed that the SDSS would likely be easier to learn and is more intuitive than conventional GIS tools (ArcMap). This was one of the main goals of this research, as it was important to create an intuitive user interface so users of various GIS expertise levels could get involved in this type of analysis. In general, it seems that subjects were satisfied with the user interface. Most of the subjects (83%) indicated that the system had an optimal complexity in terms of options and with respect to complexity of analysis it supported. One participant specified that user interface of the SDSS was overly complex. Another subject commented that the SDSS organizes the process in a series of cohesive steps where each build on the previous, and that type of approach enables semi-skilled GIS users to obtain good results without needing to utilize the advanced options of the tool. An additional comment explained that the potential limitation of the SDSS was that it does not have the capability to add additional, 'localized', criteria and use them in an intelligent fashion as it does with the already available criteria.

The third survey section included questions about the analysis steps of the SDSS. In terms of the analysis steps of the SDSS, the subjects agreed with the statement that the flow of analysis steps was logical and intuitive. The subjects were somewhat divided about inquiry on whether they would be able to replicate a similar analysis using built-in ArcMap tools as two participants strongly disagreed, one remained neutral, while the rest agreed with the statement. In addition, all participants strongly agreed that this type of SDSS considerably saves time by

automating analysis steps. When prompted to give a free response on the analysis techniques employed by the SDSS, one of the subjects commented that:

*The tool provides an excellent means to perform site selection. I was very surprised by the robustness yet ease of use of the methods employed and the advanced options offered. One really only needs to enter or select the right choices to get good results.*

Another subject commented that a similar process can be replicated using ArcMap tools but the SDSS greatly reduces the time needed to complete the analysis.

The last portion of the survey provided questions regarding the presentation of the outputs of the system through various visualization techniques. Most (83%) participants strongly agreed that the ability to visualize results in both numerical form as a table and in graphical form as a map was critical in the decision-making process for this type of analysis. In addition, the same proportion of subjects strongly agreed that nearly simultaneous visualization of the numerical and graphical views provided by the SDSS enabled easy comparison of alternatives. One of the comments on the visualization and presentation of the results explained the advantage that this type of system has in potentially incorporating multiple groups and decision-makers in the analysis process:

*Ultimately, the real benefactors of the site selection tool will be the decision makers. I envision the tool used in a highly interactive environment with the decision maker(s) working directly with the site selection staff to obtain answers in almost real time and in a clear and concise fashion.*

### 4.3 Discussion

Based on the case studies and survey responses, it is evident that the SDSS satisfied many of the goals envisioned at the onset of this research. The comparison of the case studies exemplifies the importance of considering various criteria, and the SDSS provides an efficient environment to iterate the analysis and observe the tradeoffs associated with different scenarios. The results of the evaluation of the survey, although limited in terms of number of participants, provide a good general assessment of the success of this research. The subjects were asked to provide feedback on the effectiveness of the general goals envisioned for the SDSS. While the responses provided favorable feedback in general, certain responses also point to potential limitations of the system and difficulties in designing a system for a wide variety of users. The results of this research certainly justify the intent of the research to create a more comprehensive GIS tool for a specific project. It appears that the synthesis and deduction of the options of the existing GIS tools can go a long way in bringing the GIS closer to an average decision-maker.

There were many positive tendencies in terms of subjects' responses to the evaluation survey. The users generally agreed that this type of system is valid for the nature of the analysis and that they would use this tool over the other available tools. Additionally, the users agree that the developed system would be easier to master than similar existing GIS tools. Moreover, the users agree that the SDSS saves analysis time through automation of analysis tasks. This is certainly an important notion as novice users often lose interest in overly repetitive and time consuming analysis processes. In general, it appears that the visualization techniques of the system were successful, as the SDSS goals were to provide a few alternatives with detailed information and enable intuitive comparison of those alternatives. In conclusion, this research

can serve as a good framework for similar research projects, which strive to bring complex computational GIS analyses involving large datasets closer to an average decision-maker.

#### **4.4 Limitations and Future Research**

By having a wide range (in terms of previous GIS experience) of subjects, the survey results helped recognize certain limitations of the SDSS. One of the subjects that self-identified as a GIS beginner responded that the user-interface is overly complex. This would likely be true for most novice planners without GIS experience. Although the goal of this research was to bring siting analysis closer to an average decision-maker, the complexity of the system that is required to preserve the integrity of a GIS siting analysis resulted in a fairly extensive user-interface. In order to create a simpler user-interface, a developer would have to make additional assumptions about user's preferences and disable some of the potentially useful functionality. Consequently, this would make for a less compelling system for the advanced decision-makers which require additional flexibility when performing the analysis.

There are numerous potential directions for future EMS facility siting research. Some of the development challenges faced in this research emphasize some of the important considerations for the development of Spatial Decision Support Systems. There is an obvious tradeoff associated with providing users with greater control over the analysis and having a simple and intuitive user interface. For the system developed in this research, a slight edge has been given to the enabling greater control over the analysis as targeted decision-makers were planners which are in most cases familiar with general siting techniques and would prefer a larger set of analysis options. A future research effort on siting analysis might consider a simpler

user interface that further reduces the complexity of the analysis and enables the use of the system by an even broader audience of decision-makers.

In addition, many improvements to the SDSS developed in this research can be enabled by improving the quality and substance of data. A more spatially precise population dataset would provide for more accurate population coverage measurements and thus remove uncertainty and improve slight inefficiencies associated with population data used in this research. The SDSS described here underestimates the population coverage as it considers census blocks completely within the coverage zones. This could be improved by either more precise data or by enabling the system to consider the blocks intersecting the boundaries of coverage zones and estimate the population of parts of those blocks within the zones under the assumption of even population distribution within the blocks. Additionally, a more accurate and a more detailed (in terms of attributes such as traffic information, number of lanes) road dataset would enable the incorporation of multiple travel conditions and respective scenarios. Additional data such as spatial data of previous EMS demand and movements of population throughout different times of day (for work, school) could be used to add complexity to the analysis. Moreover, the availability of more accurate data would enable a more rigorous statistical comparison of different case studies, and could potentially lead to philosophical debates over a value of human life in terms of decision-makers' willingness to spend more money to serve more people within the medically critical service response times.

Although one of the objectives of this research was to enable a broader use of GIS for EMS facility siting, the true potential in engaging the broad audience lies in emerging web GIS applications and services. The development of a Spatial Decision Support System of EMS facility siting in the form of a GIS-enabled webpage would introduce many potential benefits for

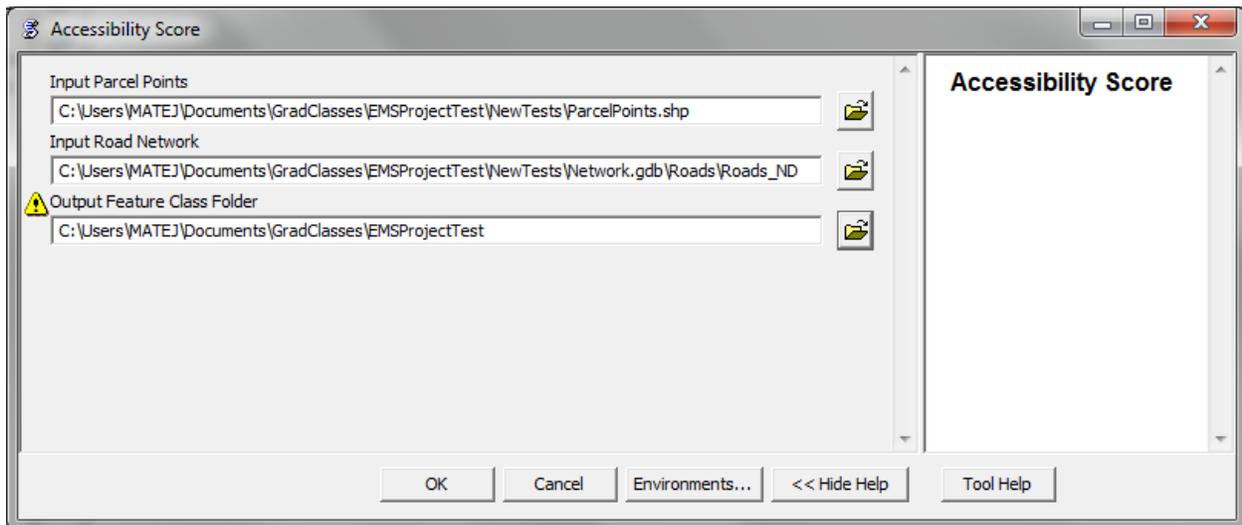
this type of research. For one, the availability of this type of tool on the web would enable any user having internet access to perform the analysis and would not require proprietary software licenses as is the case with SDSS developed in this research. Additionally, by virtue of having a potentially large audience analyzing the problem, there is a potential to involve multiple decision-makers as stakeholders in the decision-making process. However, the development of such a web GIS application is not possible at this point in time as not all of the data required for analysis is readily and freely available at state or national scales in the US. Parcel datasets are maintained locally and will likely not be aggregated for public use in the near future. Nationwide road network dataset and census population data exist and could potentially be implemented in the envisioned web version of the SDSS.

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## Appendix A: Accessibility Score Python Script



```
# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create()
gp.overwriteoutput = 1

# Local variables...
OD_Cost_Matrix = "OD Cost Matrix"
ParcelPoints = gp.GetParameterAsText(0)
Roads_ND = gp.GetParameterAsText(1)
Lines = "OD Cost Matrix\\Lines"
ODLines_Folder = gp.GetParameterAsText(2)

i = 0
i2 = i + 100
currowID = 0
CurrentMinutes = 0
AvgMinutes = 0
LineCount = 0

for i in range(0, 10900, 100):

    # Process: Make OD Cost Matrix Layer...
    gp.MakeODCostMatrixLayer_na(Roads_ND, OD_Cost_Matrix, "Minutes", "", "", "",
"ALLOW_UTURNS", "", "NO_HIERARCHY", "", "STRAIGHT_LINES")
    gp.AddMessage("OD created")
    i2 = i + 100
```

```

gp.SelectLayerByAttribute_management(ParcelPoints, "NEW_SELECTION", "\"FID\" >= 0 AND
\"FID\" <= 10802")
gp.AddMessage("\"FID\" >= 0 AND \"FID\" <= 10802")
gp.AddMessage("Destinations selected")

# Process: Add Locations (2)...
gp.AddLocations_na(OD_Cost_Matrix, "Destinations", ParcelPoints, "CurbApproach # 0", "5000
Meters", "", "roads SHAPE;Roads_ND_Junctions NONE", "MATCH_TO_CLOSEST", "APPEND",
"NO_SNAP", "5 Meters")
gp.AddMessage("Destinations loaded")

# Process: Select Layer By Attribute...
gp.SelectLayerByAttribute_management(ParcelPoints, "NEW_SELECTION", "\"FID\" >= " + str(i) +
" AND \"FID\" < " + str(i2) + """)
gp.AddMessage("Origins selected")
gp.AddMessage(str(i) + " = i")
gp.AddMessage(str(i2) + " = i2")
gp.AddMessage("\"FID\" >= " + str(i) + " AND \"FID\" < " + str(i2) + """)
# Process: Add Locations...
gp.AddLocations_na(OD_Cost_Matrix, "Origins", ParcelPoints, "CurbApproach # 0", "5000 Meters",
"", "roads SHAPE;Roads_ND_Junctions NONE", "MATCH_TO_CLOSEST", "APPEND",
"NO_SNAP", "5 Meters")
gp.AddMessage("Origins loaded")

# Process: Solve...
gp.Solve_na(OD_Cost_Matrix, "SKIP")
gp.AddMessage("OD solved")

# Process: Select Data...
##gp.SelectData_management(OD_Cost_Matrix__4_, "Lines")

# Process: Copy Features...
gp.CopyFeatures_management(Lines, ODLines_Folder + "\\Lines" + str(i) + ".shp", "", "0", "0", "0")
gp.AddMessage(ODLines_Folder + "\\Lines" + str(i) + ".shp")
gp.AddMessage("OD lines copied")

currowID = 0
CurrentMinutes = 0
AvgMinutes = 0
LineCount = 0

PointsRows = gp.UpdateCursor(ParcelPoints)
PointsRow = PointsRows.next()

LinesRows = gp.searchcursor(ODLines_Folder + "\\Lines" + str(i) + ".shp")
LinesRow = LinesRows.next()
currowID = LinesRow.GetValue("OriginID")
gp.AddMessage(str(currowID))

while LinesRow:
    if currowID != LinesRow.GetValue("OriginID"):

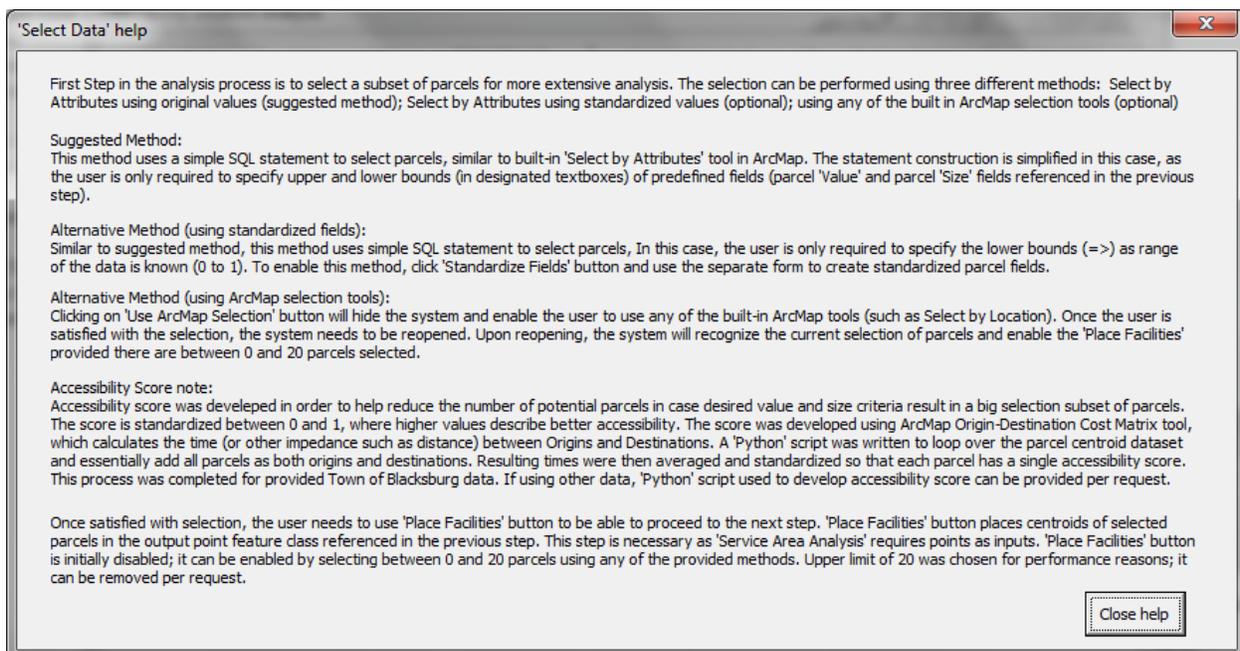
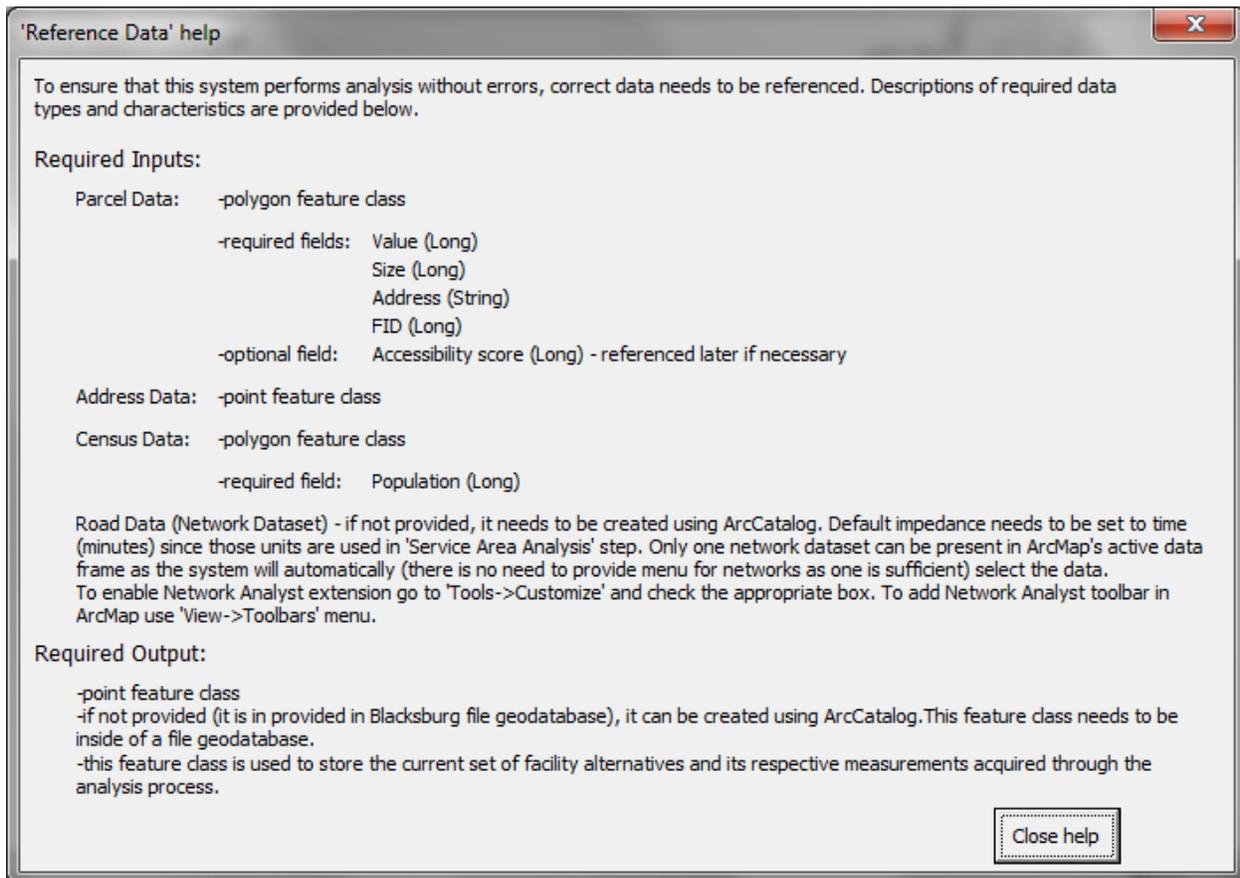
```

```
currowID = LinesRow.GetValue("OriginID")
AvgMinutes = CurrentMinutes / LineCount
PointsRow.SetValue("AccessScor", AvgMinutes)
PointsRow.SetValue("LineCount", LineCount)
PointsRows.UpdateRow(PointsRow)
gp.AddMessage(str(AvgMinutes))
PointsRow = PointsRows.next()
CurrentMinutes = 0
LineCount = 0
```

```
CurrentMinutes = CurrentMinutes + LinesRow.GetValue("Total_Minu")
LineCount = LineCount + 1
LinesRow = LinesRows.next()
```

```
AvgMinutes = CurrentMinutes / LineCount
PointsRow.SetValue("AccessScor", AvgMinutes)
PointsRow.SetValue("LineCount", LineCount)
PointsRows.UpdateRow(PointsRow)
```

## Appendix B: SDSS Help User-Forms



'Standardize Parcel Fields' help

This step was designed to enable advanced users to standardize parcel fields to membership values between 0 and 1. These standardized fields can then be used in two other steps; 'Select Data', and 'Ranking Criteria'.

To enable selection based on standardized fields, complete the standardization process for both parcel 'value' and 'size' fields. If standardization was completed on the previous run of the system, check the check box under the 'Symbolize Map' button on the right.

To enable the use of standardized fields in ranking process, use the other (lower) checkbox on the right. Make sure you have standardized both fields before checking this box (error will occur later otherwise).

To omit this step, use 'Back to Selection' button.

To begin standardization, check either 'Value (\$)' or 'Size (Acres)' radio button, depending on the field you want to standardize. As an option, user can view (to gain basic information) descriptive statistics of the selected field by clicking on 'View Stats' button.

More importantly, user needs to specify the membership function which will be used to standardize the data. The graphs representing the membership functions portray the membership values on the 'Y' axis and original value ranges on the 'X' axis. For example, first membership function will assign a standardized value of 0 (least suitable) to any parcels with original values between 0 and A (as defined by user). Original values between A and B will be assigned a standardized value between 0 and 1 depending on the position of the respective parcel value along the A to B range (i.e. original value of 3 would be assigned a standardized value of 0.33 on A (2) to B (5) range). Original values closer to B will have larger standardized values than original values closer to A. Original values in B to C range will be assigned a standardized value of 1 (most suitable). Values between C and D will be assigned a standardized value between 0 and 1, similar to A to B range, except values closer to C will have larger standardized values than values closer to D. Lastly, original values from D on will be assigned a standardized value of 0. Similar logic was used for other membership function methods, with obvious differences in ranges that user input values define.

Once the user inputs the required range values, 'Standardize Field' button calculates standardized values and stores them as fields within the Parcel feature class. As an option, the user can symbolize map based on the last standardized field. This step might be useful in order to see if the standardization inputs match what user expected in terms of suitable values. If imagery is used as a background (as is in Blacksburg example), it is suggested that this step is omitted.

Close help

'Ranking Criteria' help

In order to create an even smaller subset of potential facility alternatives (parcels) and present the user with only few most suitable alternatives, potential alternatives need to be ranked based on certain criteria.

For multiple criteria participation in the weighting/ranking process, measurements collected in 'Service Area Analysis' process were standardized between 0 and 1, using the relative position of each of the alternatives along the relative (for current subset of alternatives) 'Min' to 'Max' range of respective measurements.

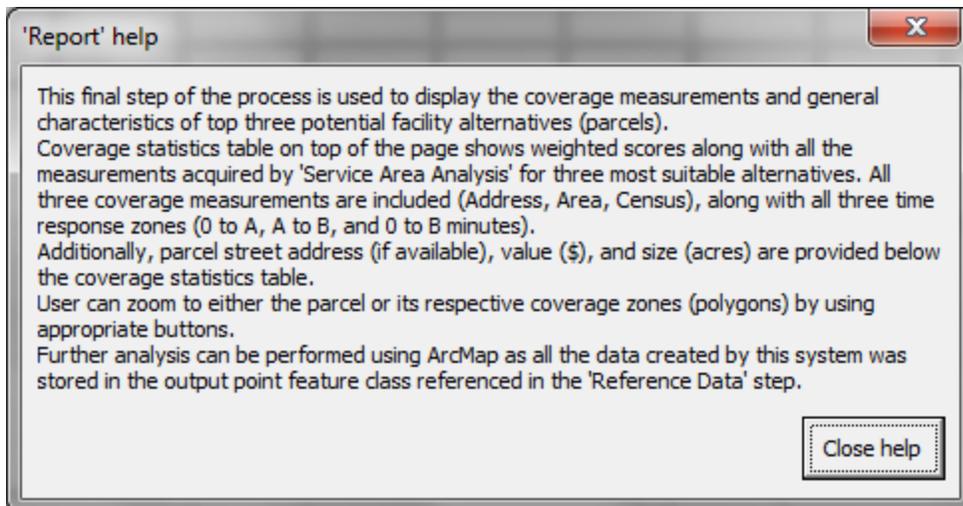
There are default weights which will produce a ranking of alternatives. These default weights can be considered conservative as they look at the total (0 to B minute polygons) coverage measurements of census population (50% weight) and area (50% weight). Address coverage was omitted from default weights so that population measurements are not counted twice (census is already considered).

The user can control these weights by checking 'Introduce Weights' checkbox. With weighting enabled, user can control weights for at least three coverage characteristics (Address, Area, Census) and all three response polygons (0 to A, A to B, 0 to B - Total).

If the user has standardized parcel 'Value' and 'Size' during selection process and specified the intent to use standardized values in the ranking process, two additional controls will appear to introduce parcel 'Value' and 'Size' weights.

Controls are designed so that total weights of all measurements always add up to 1. Once the user clicks 'Generate Report' button, the system calculates scores for each of the current alternatives. Each of the weights is multiplied by the standardized value of respective measurement. All the products of individual multiplications (weight x standardized value) are added to obtain the final score for the respective alternative. Resulting scores were used to present three most suitable alternatives in the 'Report' tab.

Close help



## Appendix C: SDSS Evaluation Survey

---

**Introduction,  
assertion of  
experience**

1. Have you ever been a part of a project involving facility (such as EMS) siting analysis?

- a) Yes
- b) No

2. State your level of GIS proficiency:

- a) No GIS experience
- b) Beginner
- c) Intermediate
- d) Advanced

3. Apart from the developed system you just used, have you ever used GIS for facility siting analysis?

- a) Yes
- b) No

**General  
assessment of  
the developed  
system**

4. Without access to the SDSS you just used, how would you have gone about finding an optimal location for an EMS facility? (Reference any previous experience if applicable)

5. With your recent experience using the SDSS system, what method would you use to perform an EMS siting analysis in the future?

- a) Non-GIS data analysis of criteria (i.e. Excel)
- b) Prior knowledge or experience of feasible alternatives through familiarity of town's zoning and parcel availability
- c) Conventional GIS analysis using built-in ArcGIS tools
- d) Customized SDSS system developed by this research along with other GIS tools

6. This SDSS system is a valuable and valid approach to reducing otherwise large number of potential locations to a smaller subset of alternatives.

- a) Strongly agree
  - b) Somewhat agree
  - c) Neutral
  - d) Somewhat disagree
  - e) Strongly disagree
-

7. Learning to use the SDSS would be easier than learning ArcMap tools required for this type of analysis.

- a) Strongly agree
- b) Somewhat agree
- c) Neutral
- d) Somewhat disagree
- e) Strongly disagree

8. Free response – provide any general feedback on the experience of using the application and its potential for EMS facility siting:

**User Interface**

9. Which of the following statements best describes the user interface of the SDSS in comparison to conventional ESRI's ArcMap interface?

- a) More intuitive than ArcMap
- b) Less intuitive than ArcMap
- c) Similar to ArcMap
- d) Not applicable or do not know

10. User Interface of the SDSS was:

- a) Overly complex (too many options)
- b) Overly simple (should have included more options, descriptions, analysis steps, etc.)
- c) Easy to follow, with a good combination of complexity of analysis and ease of understanding

11. Provide a general feedback on the user interface of the SDSS, including any potential limitations and flaws:

**Modeling and Analysis**

12. Flow of analysis steps was logical and intuitive (Data referencing-> Manipulation-> Selection-> Service Area analysis-> Ranking preferences-> Results and Visualization).

- a) Strongly agree
- b) Somewhat agree
- c) Neutral
- d) Somewhat disagree
- e) Strongly disagree

13. I would be able to replicate a similar analysis process using built in ArcMap tools.

- a) Strongly agree
- b) Somewhat agree
- c) Neutral
- d) Somewhat disagree
- e) Strongly disagree

14. Availability of this kind of tool and its automation and synthesis of analysis steps saves considerable time in the data analysis process.

- a) Strongly agree
- b) Somewhat agree
- c) Neutral
- d) Somewhat disagree
- e) Strongly disagree

15. Provide a general feedback on the modeling and analysis portion of the SDSS, including any potential limitations and flaws:

**Results and  
Visualization**

16. Ability to visualize the results of analysis in various forms (tables, graphs, maps) is critical in decision-making process for a project like EMS facility siting.

- a) Strongly agree
- b) Somewhat agree
- c) Neutral
- d) Somewhat disagree
- e) Strongly disagree

17. Ability to visualize the results in form of both a table and a map interactively as provided by the SDSS makes the comparison of alternatives easier in comparison to using other available tools.

- a) Strongly agree
- b) Somewhat agree
- c) Neutral
- d) Somewhat disagree
- e) Strongly disagree

18. Provide a general feedback on visualization on results presentation of the developed SDSS, including any potential limitations and flaws:

# Appendix D: IRB Approval Form



VirginiaTech

Office of Research Compliance  
Institutional Review Board  
2000 Kraft Drive, Suite 2000 (0497)  
Blacksburg, Virginia 24060  
540/231-4606 Fax 540/231-0959  
e-mail [irb@vt.edu](mailto:irb@vt.edu)  
Website: [www.irb.vt.edu](http://www.irb.vt.edu)

## MEMORANDUM

DATE: February 18, 2011

TO: Bill Carstensen, Matej Muza

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires October 26, 2013)

PROTOCOL TITLE: Development of a Spatial Decision Support System (SDSS) for Emergency Management Service (EMS) Facility Siting

IRB NUMBER: 11-134

Effective February 18, 2011, the Virginia Tech IRB PAM, Andrea Nash, approved the new protocol for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at <http://www.irb.vt.edu/pages/responsibilities.htm> (please review before the commencement of your research).

### PROTOCOL INFORMATION:

Approved as: Exempt, under 45 CFR 46.101(b) category(ies) 2, 4

Protocol Approval Date: 2/18/2011

Protocol Expiration Date: NA

Continuing Review Due Date\*: NA

\*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

### FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals / work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

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