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A web-based application for assessing jurisdictional geospatial readiness

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A WEB-BASED APPLICATION FOR ASSESSING JURISDICTIONAL GEOSPATIAL READINESS

By

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GEOSPATIAL READINESS

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Jurisdictions along the Gulf Coast are threatened by hurricanes. The effects of hurricanes are devastating, and the response and recovery efforts are crucial for saving lives and property. Geospatial technologies have been implemented in the response and recovery phases. However, the potential of geospatial technologies were not utilized due to data and capability issues. This study was implemented to design and develop a tool that would help a jurisdiction determine if it can apply geospatial technologies effectively in the response and recovery phases. This tool enables a jurisdiction to complete an assessment regarding GIS data, hardware, software, and personnel capabilities. Assessment results are scored using a weighted linear model, and scores are shown to the user. A rules-based system was built to show the jurisdiction methods for improving its score to the optimum level. This tool enables jurisdictions to diagnose geospatial readiness and make modifications that enhance response and recovery.

DEDICATION

This research and thesis is dedicated to the Lord. He has blessed me in so many ways and given me so much. He has been my strength and my guide through all of the good times and trials.

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ACRONYM LIST

1. CSS .... Cascading Style Sheets
2. DHS.. Department of Homeland Security
3. EGT..Enterprise GIS Task Force
4. ESRI..Environmental Systems Research Institute
5. FEMA ....Federal Emergency Management Agency
6. GIS .... Geographic Information Systems
7. GIT ....Geographic Information Technology
8. GRSAT .... Geospatial Readiness Self Assessment Tool
9. GRI.. Geosystems Research Institute
10. GUI ....Graphical User Interface
11. HAZUS-MH ....Hazus Multi Hazard
12. HTML .... Hypertext Markup Language
13. KML..Keyhole Markup Language
14. NOAA ....National Oceanic and Atmospheric Administration
15. PHP ....PHP Hypertext Preprocessor
16. RSAT .... Risk Self-Assessment Tool
17. RVAT...Risk and Vulnerability Assessment Tool
18. SAW... Simple Additive Weighting
19. WLC..Weighted Linear Combination

CHAPTER I

INTRODUCTION

Geospatial Technologies are an invaluable tool for a variety of fields. Particularly, Geographic Information Systems (GIS) is used in many projects and is growing in popularity. A GIS is defined as a computer system that allows for capturing data, storing data, querying data, analyzing data, and displaying geospatial data (Chang, 2008). Furthermore, GIS has become important in Emergency Management (Johnson, 2008). A successful implementation of GIS in emergency management is critical for saving lives and property. Unfortunately, not all jurisdictions are geospatially prepared. Jurisdictions may lack the required geospatial data and capabilities to fully assist in disaster response and recovery efforts. This unpreparedness may result in more property damage and more risk to human life. Therefore, a need exists to assess a jurisdiction's geospatial readiness, and if the jurisdiction is not ready, recommend methods to get that jurisdiction geospatially ready.

The goal of this study is to design and develop a tool that jurisdictions can use to determine if it can implement a GIS successfully for hurricane disaster management. The tool is accessible via the internet making it available to jurisdictions along the Gulf Coast. The Geospatial Readiness Self Assessment Tool (GRSAT) accomplishes both previous tasks. Previous research applicable to tools developed for the GIS emergency management field was used to designate the components of the assessment. Two main components used for the assessment tool are data quality and system capabilities. Data are comprised of 12 GIS data layers as defined in a post-Katrina workshop. Capabilities consist of 4 subcomponents which are software, hardware, data storage, and GIS analysts. Larger weights are assigned to the data and capabilities components considered higher in importance. Responses are scored and a final "readiness" score is determined using a linear weighted model. The equations, assessment, and interface are developed for usage on the internet.

The web-based tool was developed using PHP Hypertext Preprocessor (PHP), which is an open-source scripting language. PHP is used for automatic grading of assessment responses and recommending fixes to the user through rules-based artificial intelligence. A database stores the scores for each jurisdiction. A mapping server is used so each jurisdiction can view its jurisdictional boundary with a color that represents its assessment score on a map. Individual jurisdiction users can only view their assessment results, but administrator privileges can be granted to those in emergency management positions that desire a view of regional results.

The objectives for this study are as follows:

1. Quantify geospatial readiness using linear weighted formulas. The following components that are examined and quantified are GIS data, GIS capabilities, and overall geospatial readiness scores.
2. Recommend fixes to the user using the results achieved in Objective 1.
3. Develop a web-application that accomplished Objectives 1 and 2 and offer it to the user in a rich Graphical User Interface (GUI).
4. Perform a trial run of the finished product and check answers that the system provides.

CHAPTER II

BACKGROUND INFORMATION AND LITERATURE REVIEW

Chapter two is a review of the literature and background information for the logic and methods that are important for the development of the GRSAT. The first section provides a review of relevant literature for GIS implementation in the emergency management field. The second section provides a review of similar products to the GRSAT. The third section provides an examination of the input requirements for existing spatial products. The fourth section briefly details artificial intelligence concepts relevant to the GRSAT. The fifth section provides a review of the literature that guided development of the web application. The sixth section focuses on human cognition of colors used in maps that clearly convey the map-makers intentions, particularly those associated with risk.

GIS in Emergency Management

Haddow et al. (2008) defines Emergency Management as the discipline dealing with risk and risk avoidance. Cova (1999) states that emergency management consists of four phases which are mitigation, preparedness, response, and recovery. Furthermore, Cova states that the mitigation phase involves actions that eliminate or reduce the degree of long term risk to humans and property. Based on Cova's definition of mitigation, the GRSAT will be useful in the mitigation process. Cova defines the preparedness phase as actions taken to develop operational capabilities and create a response to a disaster. The transition to the last two phases occurs when the disaster strikes. Disasters are either natural or man-made. The GRSAT focuses on hurricanes, which are natural disasters, which, Abbott (2006) defines as “an event or process that destroys life and/or property.” Cova defines the response phase as actions performed directly before, during, or directly after the disaster to save lives and reduce damage. Cova defines the recovery phase as activities to bring life back to improved levels. GIS has aided in all four phases of emergency management. The following paragraphs provide a more detailed discussion of the four phases of emergency management, beginning with the mitigation phase.

GIS literature for the mitigation phase concentrates primarily on mapping community vulnerabilities and community improvements. For example, Tran et. Al (2009) uses GIS to create a flood risk model and maps for the Vietnam area. Creating risk maps are beneficial because the maps show threatened areas and enable jurisdictions to make necessary mitigation improvements. Kar and Hodgson (2008) use GIS to create a model that determines the best locations to place evacuation shelters for hurricanes. The results from Kar and Hodgson’s model can be used to determine locations for new shelters and in location-allocation models. Both examples show that the researchers have similar goals, which are to use GIS for determining risks and improvements before disasters occur. Zerger (2002) states that the application of GIS to natural hazard risk management is important for risk reduction. Zerger’s statement points to the importance of using GIS in the mitigation phase. Of equal importance, GIS is also used in the preparedness phase.

Cova (1999) states that the preparedness phase involves planning, training, warning, and informing the public. GIS is often implemented in this stage. For example, before a hurricane makes landfall the National Weather Service issues maps that warn the public by showing possible landfall locations using the three and five day cones. The

National Weather Service also uses county based warnings and watches for other hazardous environments and public announcements. Maniruzzaman et. Al (2001) uses GIS to show areas that are likely to be affected by a cyclone. They state that the tool is useful for planning disaster response. In the preparedness phase, GIS is used to warn the public or inform emergency management officials where damage is likely to occur. Once a disaster occurs, the response phase ensues (Cova, 1999).

In the response phase, GIS is used to help coordinate operations and help with the rescue efforts. Cova (1999) states the response phase can consist of search and rescue, shelter/evacuation, resource deployment, and emergency plan activation. GIS is often sought as a tool for rapid implementation after a disaster, but impediments exist to the effective use of GIS in this manner. Kevany (2003) studied the usage of GIS after the World Trade Center attacks in New York, New York. Kevany states that GIS preparation is key to an effective emergency response, but effective response is diminished when a lack of preparation exists. Kevany's statement points to the need of a tool that would help cities prepare for a successful GIS implementation in disaster response. The overall goal of this research is to help find these impediments and offer a method to fix them, so jurisdictions are prepared in the response phase. Zerger et. Al (2003) studied the use of GIS as a real-time support tool. They used a trial to test the effective use of GIS. The trial showed that GIS is an important tool, but using GIS for real-time support can be problematic since many technical and personnel impediments arose in the study. Research performed at Mississippi State University titled "Capturing Hurricane Katrina Data for Analysis and Lessons-learned Research", showed that data problems arose when GIS was used for response efforts. One problem that surfaced from the research performed at Mississippi State University was the lack or inaccessibility of geospatial data. The lack of preparation in identifying sources for rapid data acquisition and missing data is a common problem that impacts effective use of GIS for disaster response. Problems with dispersed and inaccessible data point to a need for a tool that could help communities identify their GIS strengths and weaknesses. After the immediate disaster when relief efforts are complete, the recovery phase follows.

Cova (1999) states that common activities in the recovery phase are disaster assistance, reconstruction, debris clearing, and damage assessments. GIS is a useful aid for recovery efforts. Herath (2003) used GIS to perform flood damage estimates for the Ichinomiya Basin. Kumar et al. (2007) used GIS to perform a tsunami damage assessment in India. GIS is used in every phase to assist emergency management officials. However, GIS usage in the emergency management field raises some issues. Preparation is key to being able to fully and successfully implement a GIS for disaster management. The following paragraphs discuss in detail limitations found in GIS usage in emergency management.

One important component of a GIS is data. Geospatial data were found to be very important after Hurricane Katrina and Hurricane Rita (Mills et al, 2008). However, a limitation to geospatial data usage is data accessibility. Geospatial data are often housed within different agencies (NewKirk, 1993). However, one solution is data acquisition and storage prior to a disaster. For example, after the attack on the World Trade Center of September 11, 2001, GIS was used to provide aid for response and recovery efforts. Via, the Emergency Mapping and Data Center developed and maintained a database prior to the attacks, enabling greater accessibility (Kevany, 2003). A similar problem was found during Hurricane Katrina. DeCapua (2007) noted geospatial data were dispersed and inaccessible. Additionally, Zerger et Al. (2003) states that one of the impediments of GIS usage within disaster management is the availability of spatial data. The inaccessibility and dispersion of geospatial data lead to the creation of data repositories for various sectors in GIS (Keavany, 2003; Laefer et al., 2006; Mills et al., 2008). This need for accessible and accurate geospatial data is the reason for including a geospatial data component within the GRSAT. However, many GIS data layers exist, and accounting for every data layer would not be feasible. A project at Mississippi State University, titled "Katrina Lessons Learned Research Phase 1", surveyed GIS workers along the Mississippi Gulf Coast. The survey determined layers that were most important in the aftermath of Hurricane Katrina. The survey responses are valuable to the GRSAT because it enables a design of a smaller assessment while maintaining the integrity of a data assessment. Additionally, a lesson learned from the World Trade Center attacks was data should have been backed up at another location in the event of the GIS facility having an emergency (Kevany, 2003). To sum up these findings data can be ruled down to 10-15 data layers using previous research and data storage issues should be addressed. Data is only one component for an operable GIS. The other components are hardware, software, humans, and organizational protocols (Bolstad 2008). The hardware and software component is just as important as the geospatial data component.

The hardware and software are an important requirement to have an operating GIS, which is the reason for examining a jurisdiction's hardware and software in the GRSAT. Tran et Al. (2009) stated that preparation for implementing a GIS involves computers, hardware, software, and human resources. Additionally, Zerger (2003) used a disaster scenario held north of Queensland, Australia to find that using a GIS for real-time support was hindered due to the slow computer processing power. The findings of Tran et Al. and Zerger lead to a need for examining hardware that sustains a GIS. The computer hardware needs be capable of effectively running the GIS software. According to ESRI's website, the minimum system requirements needed to run the ArcGIS software was an Intel processor, Windows XP or newer, 1.6 GHz processor, and 1 GB RAM of memory. Most computers on the market today meet these specifications. A need also exists for examining a jurisdiction's GIS software. Many GIS software packages are available, and one of the common software packages used by many is ArcGIS, which is provided by ESRI. However, effective use of hardware and software is determined by how capable the human operating the system is.

Knowledge to manage hardware, software, and data is critical during an emergency situation. After the attacks on September 11, 2001, Kevany et Al. (2003) found that one lesson learned was the lack of knowledge in GIS. Kevany et Al. continues by stating that emergency managers should be trained to operate basic GIS programs. Furthermore, Zerger et Al. (2003) held a disaster scenario that showed that the lack of experience in GIS hindered emergency management officials full usage of the decision making aid. Zerger et Al. also found that much of emergency management was not familiar with the advanced spatial analytical capabilities offered by a GIS. Zerger et Al. states the results from the disaster scenario gave new insight that training should be required for risk managers. The findings from Kevany et Al. and Zerger et Al. point to a need to examine human knowledge and GIS capabilities.

Similar Spatial Products

This section provides a discussion of similar geospatial products that have the same goals or logic as the GRSAT. A review of the following products will give understanding to the logic of quantifying risk and how to effectively use results generated from these tools. The products discussed are the Risk and Vulnerability Assessment Tool (RVAT), HAZUS-MH, Risk Self-Assessment Tool (RSAT), and the GIS Program Self-Assessment, beginning with the RVAT.

The RVAT, which is provided by the National Oceanic and Atmospheric Administration (NOAA), assesses which people, resources, and property are at risk of being damaged or destroyed from a natural disaster (NOAA, RVAT Home Page). The goal of RVAT is to make jurisdictions more prepared for disasters by determining potential hazards before a disaster strikes. In the following paragraphs describing RVAT, all data and information were found on the RVAT website, which is also cited in the works cited section at the end.

The RVAT consists of six analyses which are: Hazards Analysis, Critical Facilities Analysis, Societal Analysis, Economic Analysis, Environmental Analysis, and Mitigation Opportunities Analysis. The Hazards analysis shows areas that are at risk of a natural disaster. The Critical Facilities Analysis shows important buildings, such as fire and police stations, that are located in high hazard risk areas. The Societal Analysis determines where to focus resources by locating locations of populations that have special needs such as low income residents or non-English speaking residents. The Economic Analysis determines high economic areas, such as business districts and industrial parks, that are vulnerable to hazards. The Environmental Analysis determines environmental resources at risk from secondary hazards from a natural disaster. The Mitigation Opportunities Analysis examines methods that could reduce resulting vulnerabilities from the five previous analyses. These six analyses enable the RVAT to show vulnerabilities that exist within a jurisdiction. The similarities between the GRSAT and RVAT can be found in the purpose and logic of each.

Both the GRSAT and RVAT try to expose weaknesses within a jurisdiction so changes can be made to make that jurisdiction more prepared. However, the GRSAT looks to expose geospatial vulnerabilities while the RVAT looks to expose vulnerabilities within community populations, structures, and property. The GRSAT is an introduction to the RVAT, meaning that the GRSAT will help a jurisdiction become geospatially prepared allowing the jurisdiction to fully implement RVAT to expose population, structure, and property vulnerabilities. The methods for deriving results for both tools are similar in logic.

The GRSAT and RVAT require user-supplied input for the tool to function. The GRSAT uses human answers, and the RVAT uses GIS data. One drawback to RVAT's required input is the amount of data required. To perform each RVAT analysis requires many GIS data layers. States without a developed geospatial data clearinghouse will have to create the data manually or that state may not be able to run the RVAT. A study was performed that compared GIS data availability between Mississippi and Florida using RVAT as the standard. Mississippi had 62% of the base layers needed to implement RVAT which was less than Florida's 94.4% (Lipscomb, 2009). If all data layers are present, the RVAT does an excellent job at exposing the vulnerabilities for each community. More information on the data requirements for the RVAT is located in the section called "Spatial Product Input Requirements." Once the input requirements are met, both tools process the data using similar methodology.

The GRSAT and RVAT used linear-style functions to generate scores. The GRSAT converted human input to numeric values, and the RVAT used values within a GIS data layers attribute table or GIS calculated values. These numeric values would be entered as variables into equations that generate a score. For example, the Hazards

Analysis, which is an RVAT analysis, assesses the priorities for each hazard through a scientific, quantifiable probability assessment. The model used to score hazards is:

$$(Frequency + Area\ Impact) \times Potential\ Damage\ Magnitude = Total\ Score \quad (2.1)$$

where Frequency, Area Impact, and Potential Damage Magnitude used a scale from 1 to 5, where 5 was the highest risk. The scores calculated by RVAT are shown to the user in a map format highlighting the areas of risk. A similar tool to the RVAT is HAZUS-MH. Both tools are similar in that they examine risks from natural disasters.

HAZUS-MH was developed by the Federal Emergency Management Agency (FEMA). All information on HAZUS-MH was found on FEMA's website unless stated otherwise. HAZUS-MH differs from RVAT in that it examines the potential losses that could occur from earthquake, floods, and hurricane winds, while RVAT examines and maps populations and areas that are at risk of damage or loss. HAZUS-MH differs from the GRSAT in similar ways the RVAT does. The GRSAT serves as an introductory assessment to HAZUS-MH. The GRSAT helps a jurisdiction establish or update its GIS, afterward the GIS can be used to run HAZUS-MH. The methods for implementing HAZUS-MH are similar to the GRSAT.

HAZUS-MH must be acquired from FEMA. However, HAZUS –MH is not a stand-alone program, therefore one must have Environmental Systems Research Institute (ESRI) ArcGIS software to run the software. This limitation can be pricey since one will have to purchase this software if he does not have ESRI's ArcGIS. One benefit to HAZUS-MH is that data to run HAZUS-MH is included with the software. Therefore HAZUS-MH requires less data collection and preparation compared to the RVAT. The data provide by HAZUS-MH is used within the models to generate invaluable results for the user.

Three models are available in HAZUS-MH which can calculate damages from earthquake, floods, and hurricane winds. The following estimates are available from the earthquake model: ground shaking and ground failure, estimates of casualties, displaced households and shelter requirements, damage and loss of use of essential facilities, estimated cost of repairing damaged buildings, quantity of debris, damage to buildings, and direct costs associated with loss of function. The results from the earthquake model are generated on the county to regional scale. The hurricane wind model estimates the damage and losses from hurricane winds. Five variables that the model considers are: debris in the wind, wind pressure, the length of time that the wind blows at a given speed, and rain. Two modules are used within the flood model. The first module, flood hazard analysis, creates a hazard analysis based on the characteristics of the flood, such as discharge, frequency, elevation, flow velocity, and ground elevation to estimated flood depth. The second module uses the results from the first module to calculate damage and losses. The output from HAZUS-MH shows maps and tables of losses and damages from three types of natural disasters. Results from these three models help decision makers determine areas that should take necessary actions to be prepared. HAZUS-MH is beneficial to decision makers, but it also has limitations.

The results from HAZUS-MH are invaluable for jurisdictions that are mitigating for the three previous disaster types. However, HAZUS-MH does not encompass all disasters. For example, HAZUS-MH does not assess man-made disasters or some natural disasters such as wildfires. HAZUS-MH is also limited by the quality of input data. If data are not updated or are in a poor scale, the results will not be as reliable. Another limitation of HAZUS-MH is the output scale. HAZUS-MH is useful for county to regional scale problems. If the user desired a larger scale in the output, he would have to provide larger scale data. HAZUS-MH is also limited in that it does not give the user recommendations on how to improve problem areas. Nonetheless, these limitations do not render HAZUS-MH useless. HAZUS-MH is incredibly invaluable to emergency management. The next tool discussed is similar to the GRSAT in logic and application environment.

The Office of Infrastructure Protection's Sector Specific Agency Executive Management Office and the Infrastructure Information Collection Division developed a product called the Risk Self-Assessment Tool (RSAT). Information on the RSAT was found on the Office of Infrastructure Protection's Sector Specific Agency Executive Management Office and the Infrastructure Information Collection Division home page. Although the RSAT is assessing different criteria, the logic and application is relevant to objective three. The RSAT is a secure web-based application that diagnoses security threats at stadiums and arenas. The RSAT generates two reports to the user. The Self-Assessment Report provides the user information regarding his facility's strengths, problem areas, and methods for improving vulnerabilities. A Benchmark Report is also generated for the user enabling the user to see how his facility compares to other facilities that are similar in size to his. The GRSAT does not offer the capability of a benchmark analysis because the design of the system was such that users from differing jurisdictions could never know each other's score. The RSAT is similar to the GRSAT in several aspects. The RSAT did not require geospatial data. The assessment was accomplished through a survey. The RSAT also reported to the user his strength and weaknesses. This is similar to objective 1, but the GRSAT gives raw scores. The RSAT also provides recommendations to the user for improvements which is similar to objective 2. The

RSAT's functionality and application environment offer great guidance for all objectives. The final tool that is discussed is similar to the GRSAT because it assesses GIS readiness.

A GIS Program Self-Assessment is offered by the Vermont Center for Geographic Information. Information about the GIS Program Self-Assessment was found on the Vermont Center web page. The GIS Program Self-Assessment was created by the Enterprise GIS Task Force (EGT). The program is designed to assess the usage of Geographic Information Technology (GIT) within the state departments. The program assesses very similar criteria to that of the GRSAT. The assessment also determined GIT needs. The format of the assessment was a paper test, and the test-takers would write the answers themselves. The Self-Assessment was broken into 11 sections which were:

1. General- Input regarding the user's organization and the role of GIT within the organization
2. Coordination- Input regarding the coordination of GIT within the agency and outside the agency
3. Management- Input regarding storage plans and management of geospatial information
4. Data Acquisition, Documentation, and Maintenance- Input regarding the documentation and maintenance of geospatial data
5. Standards and Best Practices- Input regarding the research and utilization of geospatial technology standards
6. Data Access and Distribution- Input regarding geospatial data documentation, sharing, exchanging, and accessibility
7. Enterprise Integration- Input regarding coordination of geospatial activities across the organization

8. Training and Skills Development- Input regarding the organizations GIT training and budgeting
9. Geospatial Resources- Input regarding GIT hardware, software, and personnel
10. Planning for the Future- Input regarding the organization's plan in utilizing GIT
11. Other- Input regarding the organization's strengths and weaknesses within the agency's geospatial department

To see the assessment with all input variables visit the following url: http://www.vcgi.org/about_vcgi/projects/egis/GIS_Program_Self_Assessment_v3_webappindex.pdf. The GRSAT is similar to the GIS Program Self-Assessment in what it assesses, but several differences exist.

Both tools use an assessment to gather data from the user about his GIS technology. However, the GRSAT focused more on individual data layers while the GIS Program Self-Assessment assessed GIS data as a whole. Both assessments examined hardware, software, data storage, and human components. The GRSAT performs the assessment electronically while the GIS Program Self-Assessment is a paper test. The GRSAT provides feedback to the user for improving his score. It is possible that this can be accomplished with the GIS Program Self-Assessment through human interpretation. Nonetheless, both assessments satisfy a need which is to quantify geospatial readiness.

Spatial Products Input Requirements

The input requirements for the RVAT and HAZUS-MH will be examined within this section. Successful implementation of RVAT or HAZUS-MH requires geospatial data. A review of these data requirements is beneficial because it offers insight into important data layers, and it helps reinforce the need for having an assessment that quantifies geospatial readiness. The benefit of other tools discussed, such as the GIS Program Self-Assessment and RSAT, is no GIS data are required. The same is true for the GRSAT. This is impartial approach gives jurisdictions from the least to most prepared the ability to take these assessments. On the contrary, tools like the RVAT cater to more prepared jurisdictions.

Eighty two layers are necessary to implement RVAT. However, 11 of the 82 layers were derived from other base layers. Each analysis required different GIS data. The findings from Lipscomb (2009) point to the need of having a well established GIS data clearinghouse or database. The Coastal Storms Initiative—Florida Pilot Risk and Vulnerability Assessment Tool, Lessons Learned Report stated where each data layer was acquired or the method for deriving that layer. An examination of data sources show that even for a well-established GIS state, such as Florida, RVAT can be very partial to potential users. Users must have a well established GIS data system to run the RVAT. Tables 2.1-2.6 show the GIS data layers required for each analysis.

Table 2.1 Data required for the Hazards Analysis within RVAT.

Hazards Analysis
Natural Hazard Summary Risk Area
Storm Surge Risk Area
Flood Risk Area
Special Flood Hazard Area
CBRA Zones
Wind Risk Area
Erosion Risk Area
Range Monument
Woodland Windthrow Hazard
Coastal Vulnerability Index
Evacuation Zones

Table 2.2 Data required for the Critical Facilities Analysis within RVAT.

Critical Facilities Analysis
Composite Critical Facility Risk
Fire and Rescue
Police
Communication
Transportation
Utilities
Government
Shelter
School
Hospital/Nursing Home
Animal Care
Disaster Operations
Disaster Services
Hazardous Materials
Solid Waste/Landfill
Water Treatment Plant
Waste Water Treatment Plant

Table 2.3 Data required for the Societal Analysis within RVAT.

Societal Analysis
High-Need Block Group
Land Use Residential
Composite Societal Vulnerability
High-Need Residential
Percent Minority Population
Percent Households Below Poverty
Percent Persons over Age 65
Percent Single Parent with Child Families
Percent No High School Diploma
Percent Public Assistance Income
Percent Housing Rental
Percent No Vehicle Available

Table 2.4 Data required for the Economic Analysis within RVAT.

Economic Analysis
Transportation Land Use in Moderate to High Hazard Zones
Retail/Wholesale Trade Land Use in Moderate to High Hazard Zones
Services Land Use in Moderate to High Hazard Zones
Manufacturing Land Use in Moderate to High Hazard Zones
Agriculture Land Use in Moderate to High Hazard Zones
Land Use — Transportation
Land Use — Retail/Wholesale Trade
Land Use — Services
Land Use — Agriculture
Land Use — Manufacturing
Largest Employers — Brevard and Volusia
Land Use or Land Cover

Table 2.5 Data required for the Environmental Analysis within RVAT.

Environmental Analysis
Solid Waste Facility
Toxic Release Inventory Site
Oil Facility
NPDES Permit Site
Significant Habitat Area
Wetland
Superfund Site
Federal Land
Flood Prone Soil
Florida Natural Areas Inventory
Historical Significant Site
National Wildlife Refuge
State Preserve
Golf Course
Soils
Toxic Release Risk Area
Marina
Biodiversity Hotspot

Table 2.6 Data required for the Mitigation Opportunities Analysis within RVAT.

Mitigation Opportunities
Undeveloped Land in Moderate to High Hazard Zones
Land Use — Undeveloped Land
Zoning
County Park
CBRA Zones
Federal Land
NFIP Policies
NFIP Policies
NFIP Repetitive Loss Claims
NFIP Repetitive Loss Claims
NFIP Claims
Percent Homes Built Before 1970
Percent Mobile Homes
Coastal Construction Control Line

Tables 2.1-2.6 show the full extent of RVAT's data requirements. The large amount of data is a setback to implementing RVAT. The RVAT is not an appropriate assessment for all jurisdictions. Only jurisdictions that have a well established GIS department are potential candidates for the RVAT. The GRSAT or the GIS Program Self-Assessment are more suitable assessments for jurisdictions that do not have well developed GIS departments. Another tool that requires jurisdictions to have a well developed GIS department is HAZUS MH.

HAZUS MH does not have a data requirement like RVAT. According to the three user manuals provided by the Department of Homeland Security, the provided data inventory enables the user to run the three models within HAZUS MH. However, HAZUS-MH requires additional software to run, more specifically ESRI's ArcGIS. This requirement of software points to a need for examining a jurisdiction's software within the GRSAT. To run the previously mentioned GIS software requires certain hardware specifications. Hardware requirements point to a need for examining a jurisdictions available hardware. Nevertheless, the data used in running HAZUS MH was examined.

The provided data in HAZUS MH will only give a rudimentary estimate of potential damage. The developers of HAZUS MH suggest that the user incorporate local data to achieve more accurate results. The following data was used in the running of the Hurricane, Flood, and Earthquake models:

- Demographic Data
- Population Distribution
- Age, Ethnic, and Income Distribution
- General Building Stock
- Square Footage of Occupancy Classes for Each Census Tract
- Essential Facilities
- Medical Care Facilities
- Emergency Response Facilities (fire stations, police stations, EOCs)
- Schools
- High Potential Loss Facilities
- Dams
- Nuclear Power Plants
- Military Installations
- Facilities Containing Hazardous Materials
- Transportation Lifelines
- Highway Segments, Bridges and Tunnels
- Railroad Tracks, Bridges, Tunnels and Facilities
- Light Rail Tracks, Bridges, Tunnels and Facilities
- Bus Facilities
- Port Facilities
- Ferry Facilities
- Airports Facilities and Runways
- Utility Lifelines
- Potable Water Facilities, Pipelines and Distribution Lines
- Waste Water Facilities, Pipelines and Distribution Lines
- Oil Facilities and Pipelines
- Natural Gas Facilities, Pipelines and Distribution Lines
- Electric Power Facilities and Distribution Lines
- Communication Facilities and Distribution Lines
- Vehicles
- User defined facilities

Both RVAT and HAZUS-MH require GIS data to run. However, HAZUS-MH supplied default data, which helps minimize time spent acquiring required data. Unfortunately, the implementation of HAZUS-MH was hindered by software requirements. RVAT required many data layers to run thus making implementation more difficult. Both tools have further supported the examination of a jurisdiction's GIS data, hardware, and software.

Scoring Techniques

Accomplishing objective one requires the use of Simple Additive Weighting (SAW) or also known as Weighted Linear Combination (WLC). Malczewski (1999) states that the WLC is one of the most common decision making methods in GIS. Malczewski (1999) defines the WLC as, "a decision rule for deriving composite maps using GIS" (Transactions in GIS, 2000, p.5). The WLC has two critical components. One is the weight assigned to the attributes, and the other is the attributes (Malczewski, 2000). The WLC is described as: "Formally, the decision rule evaluates each alternative, Ai, by the following formula:

$$Ai = \sum_j w_j x_{ij} \quad (2.2)$$

where x is the score of ith alternative with respect to the jth attribute, and the weight w_j is a normalized weight, so that $\sum w_j=1$" (GIS and MULTICRITERIA DECISION ANALYSIS, 1999, p.198). Malczewski (1999) recommends following six steps when using a WLC. The first step is determining which data layers are going to be used for the analysis. The second step is standardizing the selected data layers. The third step is determining the weights for each data layer. The third step is often a challenge when using the WLC. Chang (2008) states that the weights help determine the importance of each variable. Therefore, determination of weights is an important consideration when using WLC.

Determination of weights is a subjective task. The goal of assigning the weight is to make an attribute more important than another. One method of assigning weights is accomplished by polling experts and asking them to rank the importance of each variable. For example, a study was performed to determine site suitability for emergency shelters. Eight data layers were used for the analysis, and a list of the layers was given to a team of educated experts in that particular field. Each expert assigned weights to each layer based on what he or she felt was most important. After the survey, the average of the weights for each layer was taken and used in the model (Kar et al., 2008). Chen et al. (2008) applied the assessment method to determine weights for an analysis performed on hill-slope communities at high risk of hazards. Chen et al. sent the assessment to experts, who assigned weights to the variables. Chen et al. took the results and derived a mean weight for each variable. Consulting with experts is a common method for weight derivation. However, the subjectivity of this method is a limitation for the accuracy of the model built using this methodology. After weights are determined, the user can move to step four.

Malczewski (1999) states that the fourth step is multiplying each data layer by its corresponding weight. The fifth step is taking the sum of the products from the fourth step to generate a final score. The sixth step was assigning ranks to the final scores and generally, the higher the score the better the alternative. The six steps Malczewski recommends are helpful for establishing a method for quantifying geospatial readiness, thus providing a means to accomplish objective one.

Artificial Intelligence

Accomplishing objective two requires the development of an algorithm. Artificial intelligence offers a solution to this problem. Winston defines artificial intelligence as "the study of ideas that enable computers to be intelligent" (Artificial Intelligence, 1984, p.1). Additionally, Winston states that the goals of the artificial intelligence field are to "make computers more useful" and to "understand the principles that make intelligence possible" (Artificial Intelligence, 1984, p.2). Several methods exist to create an artificial intelligent system.

One of the most efficient methods to represent a dynamic application is through a rule-based approach (Scown, 1985). Winston (1984) states that "rule-based problem-solving systems are built around rules" (Artificial Intelligence, 1984, p.166). The rules are constructed with an "If" and a "then" (Scown, 1985). Scown continues by stating the "If" checks if certain conditions are true, and if the conditions are true, the "then" statement will execute a piece of code. Combining all rules together forms the expert system or rules-based system. This rules-based system is the tool to solve objective two.

Web Application Development Tools

Web application development tools were examined to determine a method for accomplishing objective three. Several programming languages and web services are discussed in this section providing an overview of what each is useful for.

Accomplishing objective three is important so that jurisdictions will not have any difficulty or confusion when running the GRSAT. A common first step for building a web application is to design a basic page layout. The basic language for designing any webpage is Hypertext Markup Language (HTML). HTML is a language that encodes World Wide Web documents (Spainhour et. Al, 2003). HTML consists of tags and attributes which enabled the developer to create the layout of the webpage. Spainhour et Al. continue by stating that HTML is very easy to learn and use. The benefits of HTML mentioned by Spainhour et Al. make it a desirable choice for use in accomplishing objective three. Combining HTML with Cascading Style Sheets (CSS) and Javascript enables the creation of a rich user interface. However, HTML is not a programming language but a markup language. A programming language must be used to create the functionality for the web application.

PHP Hypertext Preprocessor (PHP) is a commonly used web scripting language (Spainhour et. Al, 2003). PHP can be downloaded from http://www.php.net for free of charge. Lerdorf (2003) states that PHP runs on the server side meaning all PHP tags and functions will be processed and replaced before the output is shown to the user. Lerdorf continues by stating that PHP can be embedded within HTML files. Embedding PHP into HTML generates custom and dynamic web pages. Using PHP will programmatically enable the accomplishment of objective one and two. PHP is useful for executing functions and processing data, but PHP does not store data. The GRSAT requires data storage; therefore, a data storage application is needed.

Several data storage options exist. One basic method is the use of text files. Unfortunately, using text files does not enable the user to access pre-built queries; therefore, queries must be developed by “brute-force” programming. Another and more acceptable solution is a database. There are many database packages in existence, but one of the most commonly used packages in web development is MySQL. MySQL is an open source database package that is provided by Sun Microsystems. According to Sun Microsystems, MySQL is the most popular open source database software. MySQL has greater speed than other databases, and it is easy to use (Sun Microsystems). Combining

PHP and MySQL enables the development of dynamic web applications and the ability to store data. However, one goal within objective three is to deliver results from objective one in a map format. Unfortunately, PHP and MySQL cannot accomplish this task, so a map server is needed.

Several map server solutions available are Google Maps API, GeoServer, and ESRI's ArcIMS. The benefit of Google Maps API and GeoServer is both programs are open source. On the contrary, according to ESRI's vendor Civil Solutions, ArcIMS costs $5,000.00 for up to two core licenses. Given the price of ArcIMS, Google Maps API and GeoServer are a cheaper solution. Geoserver is written in Java and focuses on data sharing and data creation. Google Maps API can be placed on a website using Javascripts and can display geographic data using Keyhole Markup Language (KML). The needs of the GRSAT indicate Google Maps is a more suitable solution. Not to mention, many users are familiar with the Google Maps interface.

Human Cognitive Component

One problem addressed in objective three was the design of a color scheme. The results from objective one must be displayed to the user in a method that helps the user interpret scores without confusion. Longley et al. (2005) state that one important function of a map is to communicate geographic information. Longley et al. continue by stating that depending on the project and data type, maps can make data interpretation easier and reveal patterns. Most humans interpret visual data better than numerical data. The importance of visual representation places a need for an understandable color scale. Harrower et al. (2003) state that the use of colors on a map is important for showing the message of a map. Likewise, Slocum (1999) states that maps are an effective method for taking advantage of people's color associations. Emphasis must be placed on the presentation of the results, more specifically the color scale, to effectively communicate geospatial readiness to the end user.

Longley et al. (2005) state that one common method to display ordinal data for polygons is using graduated colors. One example of a graduated color ramp is the one used by the Department of Homeland Security (Homeland Security, 2008). DHS uses the Homeland Security Advisory System to warn about the risk of terrorist acts (Homeland Security, 2008). The Homeland Security Advisory System consists of five threat levels. The five levels of terrorist risk are low (green), guarded (blue), elevated (yellow), high (orange), and severe (red) (Homeland Security Presidential Directive). The Homeland Security Advisory System uses a modified-diverging scheme. Brewer (1994) defines a diverging scheme as two hues diverging away from a common light. Harrower et al. (2003) state that a diverging color scheme is used when there is a break point that needs emphasis. A diverging color scheme is a viable option for the GRSAT because it will effectively communicate the contrast between geospatially ready and not geospatially ready.

One method for creating a diverging color scheme is by using the color associations within American culture. Monmonier (1991) states that the color red is often associated with danger or warning. Monmonier continues by stating that green is often associated with lower risk. Monmonier also states that hazard maps often use a three color sequence of red, yellow, and green. However, the final output desired for the GRSAT is five colors which are similar to the number of colors used by the Department of Homeland Security. Using Monmonier's logic of color associations, an output color ramp with shades of red for the lower scores and shades of green for the higher scores is beneficial to jurisdictions because there is less confusion. To obtain a median color that transitions the red to green, Brewer (1994) recommends that a common light hue or a neutral gray is used as the median or break class color. In summary, this research has provided invaluable logic for designing a five color ramp scale that effectively communicates geospatial readiness.

CHAPTER III

METHODS

Chapter three provides a discussion of the methods used to complete objectives one, two, and three. The first portion of this chapter provides a discussion of the components that were used to quantify geospatial readiness and build the linear weighted models. The second portion provides a discussion of the algorithm developed to determine fixes. The third portion of this chapter provides a discussion of methods used to develop the web application. This chapter concludes with a discussion of modifications that were made to the GRSAT after its initial release.

Components Used to Quantify Geospatial Readiness

The first step to accomplish objective one was to determine what should be quantified that would indicate whether a jurisdiction was geospatially ready or not. Two major components were decided upon using previous research as guidance, which were data and capabilities. Both of these components were divided into sub-components. This section provides a discussion of the sub-components within the data and the capabilities components of the GRSAT.

The data section was comprised of input variables that examined the availability and quality of a jurisdiction's data. Determining the data layers that should be examined was done by using the results of Katrina Lessons Learned Research Phase 1 from Mississippi State University as guidance. Twelve GIS data layers were selected for the data component, which were a roads, hospitals, railroads, fire departments, shelters, police stations, utilities, parcels, tax rolls, waste services, waste water treatments, and a communications layer. These twelve layers were examined and used to determine a data score. The other half of the assessment was the capabilities component.

The capabilities portion was derived by using previous research as guidance. Four components were selected within the capabilities section, which were hardware, software, GIS data storage, and GIS analysts. Each of these components were examined and used to generate an overall score for capabilities. The following section will discuss in detail how these components were examined and quantified.

Examining and Quantifying the GIS Data Component

This section provides an explanation of the methods used to examine and quantify the GIS data component for the GRSAT. The twelve data layers were examined by asking the user about each layer's availability, format, scale (if applicable), and frequency of update. Availability examined whether or not a jurisdiction could access that data layer. Data layer availability was a "Yes" or "No" question. If the answer was "No", the user moved onto the next data layer. If the answer was "Yes", the user continued with the input variables for that data layer. The next question the user answered is the format of that data layer.

The data format question had three possible choices, which were GIS, Other Electronic, and Paper Map. An example of a GIS formatted data layer is an ESRI shapefile. An example of "Other Electronic" is a scanned paper map. A paper map format is a hardcopy map with no electronic version in existence. The ideal format is to have the data layer in a GIS. The second best format is an electronic version, followed by the paper map format. The next question examined update frequency.

The update frequency question examined how often that data layer was updated. Three possible choices existed for this question which were semi-annually, annually, or every 2 years or greater. The ideal choice for update frequency was semi-annually, followed by annually, then every 2 years or greater. The idea for this question is that the more often a data layer is updated the more it will account for changes in the real world. The final question examined that data layer's scale.

The scale question was asked only for line and polygon GIS data layers. Point data did not have a scale question. The possible choices for the scale question were large, medium, and small. Large scale was defined as larger than 1:24,000. Large scale yields higher map detail making it the most desirable. Medium scale was defined as 1:24,000 to 1:100,000. Medium scale results in moderate detail making it the second best choice. Small scale was defined as smaller than 1:100,000. Small scale results in low map detail making it the least desirable. The answers to the four previous input variables were used to generate an overall score for that data layer.

The responses from these previous input variables were given numeric values through the use of if-then statements. The if-then statements evaluated the answer a user chose and then assigned the programmed numerical value to that answer. This process was done for every answer for every data layer. Beginning with the availability response, the answer was assigned a 1.0 if the value was "Yes" and a 0.0 if the value was "No." Table 3.1 shows the numerical values assigned to the responses to the last three data input variables. All numerical values were heuristically determined using the advice of Dr. William H. Cooke (Professor, Mississippi State University) as guidance. Assigning numerical values to responses was the initial step. These values were used for calculating scores for each data layer.

Table 3.1 Numerical values assigned to responses from the data component.

Format	Frequency/Update	Scale(if applicable)	Value Assigned
GIS	Semi-Annually	Large	1.0
Other Electronic	Annually	Medium	0.7
Paper Map	Every 2 years or greater	Small	0.1

Each data layer score was calculated through the use of a linear weighted model. The numerical variables used within the model were dependent upon the user's answers. The other numerical values in the model were the weights. The weights used within the weighted linear model are shown in Table 3.2. The weights summed to 100 so the score for any data layer ranged from 0 to 100. The larger weight was used in calculation with the format component of the data. This was done because the format was the most important component to a data layer. Both weights and numerical values from the four data input variables were combined in an equation to derive a score for that data layer.

Table 3.2 The weights used in scoring each data layer.

Weight	Value
Weight 1 (Format)	33.34
Weight 2 (Update Frequency)	33.33
Weight 3 (Scale)	33.33

Two possible equations existed for data layers. Equation 3.1 was used for data layers that did not have scale component, such as point data. Equation 3.2 was used for data layers that had a scale component such as lines and polygons. The difference between Equation 3.1 and Equation 3.2 was the number used for the scale component.

Equation 3.1 used a value of 1.0 for scale while Equation 3.2 used the value depending on the user's input. The use of the pseudo-scale variable in equation 3.1 ensured that each component for each data layer was weighted equally for all data layers. The availability variable at the beginning of the equation was used to give a score of zero if the layer did not exist. If the layer did exist a value of 1 was assigned and the rest of the equation would be evaluated based on the user's input. The scores for all data layers were used to determine an overall data score.

Model with pseudo-scale component:

$$Score=(Availability)*((weight1*Format)+(weight2*Update)+(weight3*Pseudo\text{-}Scale)) \tag{3.1}$$

Model with actual scale component:

$$Score=(Availability)*((weight1*Format)+(weight2*Update)+(weight3*Scale)) \tag{3.2}$$

Equation 3.3 was used in deriving an overall data score. The sum of all weights in equation 3.3 summed to 1.0. The weights were heuristically determined using results from surveys that were completed in the Katrina Lessons Learned Research Phase 1 at Mississippi State University as guidance. Figure 3.1 shows the survey results from the Lessons Learned Research Phase 1. Although not all data layers in Figure 3.1 were used in the GRSAT, the bar chart in Figure 3.1 served as an invaluable guide for determining weights for the data equation. Table 3.3 shows the weights that were used for each data layer. Layers found to be more critical were weighted the highest. The weights and 12 GIS data layers scores from Equations 3.1 and 3.2 were used to derive the final data score. This final data score was used in the final geospatial readiness score calculation.

Model used for deriving an overall data score:
Data=(Weight1*Roads)+(Weight2*Hospitals)+(Weight3*Railroads)+(Weight4*$Fire_Departments)+(Weight5*Shelters)+(Weight6*Police_Stations)+(Weight7*Utilities)+(Weight8*Tax_Rolls)+(Weight9*Waste_Services)+(Weight10*Waste_Water_Treatments)+(Weight11*Communications)+(Weight12*Parcels) (3.3)

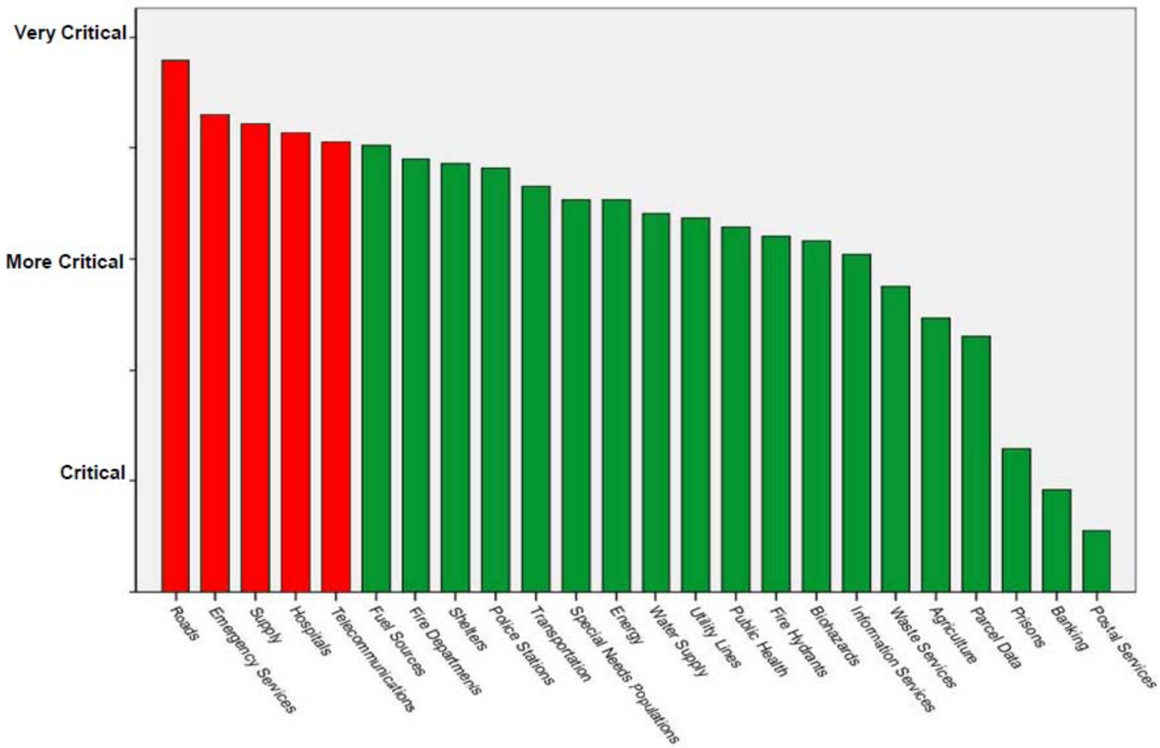

Figure 3.1 Survey results showing criticality of GIS data layers.

(Geosystems Research Institute, 2003)

Table 3.3 The weights that were used for each data layer.

Data Layer	Weight
Roads	0.144
Hospitals	0.115
Railroads	0.129
Fire Departments	0.108
Shelters	0.094
Police Stations	0.072
Utilities	0.058
Tax Rolls	0.036
Waste Services	0.044
Waste Water Treatment	0.042
Communications	0.122
Parcels	0.036

Examining and Quantifying the Capabilities Component

The capabilities portion of the GRSAT was broken into four components. The first component was hardware, which examined a jurisdiction's computing and printing abilities. Each jurisdiction was asked how many computers were available, the currency of the computers, and the number of printers they had. The three possible choices for the number of computers were more than five, one to five, or zero. The ideal choice was more than five. The four possible choices for computer currency were new (less than two years old), new to old (two to five years old), old (greater than five years old), or does not apply. The ideal choice was "new". Three possible choices existed for the number of printers which were more than three, one to three, or zero. The ideal choice was more than three. The answers to the previous three input variables were used to generate a score for the hardware component of the capabilities section. The next component examined was software.

The software component contained two input variables, which were the type of software that the jurisdiction uses and the currency of that software. Possible answer choices for the type of software were ESRI related software, purchased software other than ESRI, open source software, and I do not have GIS software. The ideal choice was ESRI related software. Possible answer choices for software currency were latest version, lacking updates, beta version, or does not apply. The ideal choice was the latest version. The third component examined was data storage.

Examination of data storage was achieved by asking the user about data archival frequency, location of archived data, and data storage capacity. The four possible choices for archival frequency were semi-annually, annually, or every two years or greater. The ideal choice was semi-annually. Possible choices for data archival locations were archived at multiple locations, archived on location, archived off location, or does not apply. The ideal choice was data archived at multiple locations. Possible choices for data storage capacity were greater than 5 Terabytes (Tb), between 500 Gigabytes (Gb) and 5 Tb, less than 500 Gb, or does not apply. The ideal choice was greater than 5 Tb. The next component examined in the capabilities section was a jurisdiction's GIS analysts.

Examination of GIS analysts was achieved by asking a jurisdiction how many GIS analysts were employed and the average years of experience for these analysts. Possible choices for the number of GIS analysts were three or more, two, one, or none. The ideal choice was three or more. Possible choices for the average years of experience were 10 years or higher, 5-9 years, 0-4 years, or does not apply. The ideal choice was 10 years or higher. The GIS analyst component within capabilities concludes the capabilities portion of the GRSAT. Appendix A shows the complete assessment used by the GRSAT. It includes both the data and capabilities portion with all input variables and possible answers. Nonetheless, the capabilities portion was processed and scored using similar methodology found in the data portion.

The answers from the capabilities portion were assigned values using if-then statements. Tables 3.4, 3.5, 3.6, and 3.7 show the numerical values that were assigned to the answers from the capabilities portion sorted by each component. This conversion step was done to change string values into numerical values. Afterward, these numerical values were used within models.

Table 3.4 Numerical values assigned to hardware responses.

Hardware					
Number of Computers		Currency of Computers		Number of Printers	
More than five	1.0	New(Less than two years old)	1.0	More than three	1.0
One to five	0.7	New to Old(two to five years old)	0.7	One to three	0.7
Zero	0.0	Old(Greater than five years old)	0.1	Zero	0.0
		Does not apply	0.0		

Table 3.5 Numerical values assigned to software responses.

Software			
Type of GIS software		Currency of software	
ESRI related software	1.0	Latest version	1.0
Purchased software other than ESRI	0.8	Lacking updates	0.8
Open Source Software	0.8	Beta version	0.5
No GIS software	0.0	Does not apply	0.0

Table 3.6 Numerical values assigned to data storage responses.

Data Storage					
Archival Frequency		Archival Location		Storage Capacity	
Weekly or more often	1.0	Multiple Locations	1.0	Greater than 5 Tb	1.0
Monthly	0.7	On location	0.7	Between 500 Gb and 5 Tb	0.7
Annually or Greater	0.1	Off location	0.1	Less than 500 Gb	0.1
Never	0.0	Does not apply	0.0	Does not apply	0.0

Table 3.7 Numerical values assigned to GIS analyst responses.

GIS Analyst			
Number of GIS analyst		Average Years of Experience	
Three or more	1.0	10 Years or Greater	1.0
Two	0.8	5-9 Years	0.8
One	0.5	0-4 Years	0.5
None	0.0	Does not apply	0.0

Each capabilities component was evaluated using its own weighted linear model. Equation 3.4, 3.5, 3.6, and 3.7 are the models used to calculate a score for hardware, software, data storage, and GIS analyst, respectively. Table 3.8 shows the numerical values of the weights used in Equations 3.4-3.7. These weights were heuristically determined through the advice of Dr. William H. Cooke (Professor, Mississippi State University). All weights within each equation summed to 100. Therefore, the final score for each capabilities component ranged between 0 and 100. Scores from each capability component were used to generate an overall capabilities score.

Model used for deriving a hardware score:
*Hardware=((weight1*Computer Count)+(weight2*Computer Currency)+(weight3*Printer Count))* (3.4)

Model used for deriving a software score:
*Software=((weight1*Software Type)+(weight2*Software Currency))* (3.5)

Model used for deriving a data storage score:
*Data Storage=((weight1*Archival Frequnecy1)+(weight2*Archival Location)+(weight3*Storage Capacity))* (3.6)

Model used for deriving a GIS analyst score:
*GIS Analyst=((weight1*Number of Analysts)+(weight2*Average Analyst Years))* (3.7)

Table 3.8 Weights used in the capability models.

Weights used in the Capabilities Section							
Equation 3		Equation 4		Equation 5		Equation 6	
Weight1	33.34	Weight1	50	Weight1	33.34	Weight1	50
Weight2	33.33	Weight2	50	Weight2	33.33	Weight2	50
Weight3	33.33			Weight3	33.33		

Equation 3.8 was used to calculate an overall capabilities score. All components were made equally important so weights 1, 2, 3, and 4 in Equation 3.8 were all assigned a value of 0.25. The score generated from Equation 3.8 was used in the final geospatial readiness score calculation.

Model used for deriving an overall Capabilities score:
*Capabilities=((weight1*Hardware)+(weight2*Software)+(weight3*Data Storage)+(weight4*GIS Analyst))* (3.8)

Quantifying the Overall Geospatial Readiness Score

The final geospatial readiness score was calculated using a linear weighted model. The calculation used the scores generated from Equation 3.3 and 3.8. Equation 3.9 generated the final geospatial readiness score. Weights 1 and 2 were both 0.5. This score and all other scores from Equations 3.1-3.8 were reported to the user. This final step completes objective 1. The next step was to recommend improvements to sub-optimal scores.

Model used for deriving an overall Geospatial Readiness score:
*Geospatial Readiness Score = ((Weight1*Data)+(Weight2* Capabilities))* (3.9)

$$Geospatial\ Readiness\ Score = ((Weight1*Data)+(Weight2*Capabilities)) \quad (3.9)$$

Determination of Fixes to Improve the Geospatial Readiness Score

This section provides a discussion of the methods used to accomplish objective 2. If a jurisdiction had a geospatial readiness score lower than 70, fixes were recommended to the user. An algorithm was developed that accomplished this task. The algorithm determined recommendations for fixing each data layer and which data layers should be fixed, recommendations for fixing each capabilities component and which capabilities components should be fixed, and recommendations for fixing overall geospatial readiness. The data component was the first component examined by the algorithm.

Fixes for each data layer were calculated using a rule based approach. The fix calculation was performed by substituting a value of 1.0 for each component of a data layer. For example, equation 3.10 shows a fix calculation with the fix value being substituted in for the format component. In equation 3.10, the variable “Fix” was 1.0, and the other values were set to the user’s original responses. Equation 3.10 was run two more times, if the layer had a scale component. On the contrary, equation 3.10 was run 1 more time, if a scale component did not exist. The maximum score was taken from these fix calculations. The maximum score was used to determine which fix substitution made the greatest change. The fixed component with the highest score was designated as the first fix. This first fix was kept as 1.0 in the second fix calculation. For example, if format generated the highest score from the first fix run, format would be 1.0 in the second fix run, and the other components would be tested. The maximum score from the second run determined the second fix. If a layer had a scale component, the first and second fixes were used in the third equation run to determine the last fix. The maximum score was taken from the third run to determine the final fix needed. Furthermore, if the availability for a data layer was 0, the user was told to acquire that data layer rather than any fixes being reported. This fix process was performed for each data layer. If any maximum scores from the fix equations were equal, the following priority was used to determine the fixes: format (1), scale (2), and update frequency (3). Afterward, improvements were calculated for the overall date component.

Model used in the algorithm to determine a fix for a data layer:
Fix1 Score=(Availability)((weight1*Fix)+(weight2*Update)+ (weight3*Scale))* (3.10)

The methods for fixing the overall data component was similar to the methods used to fix each individual data layer. Equation 3.11 provides an example of a fix equation. In this example, the roads layers score was substituted with the fix value. A fix value of 70 was substituted in for each data layer, if that data layer's final score was below 70. The maximum score was taken from each run of the fix equations. The fix yielding the highest score was kept. This process was repeated 12 times, and the fixes required to reach the optimal score (70) were reported. Afterwards, fixes were generated for each capabilities component.

Model used in the algorithm to determine a fix for the overall data component:
*Overall_data_score=(Weight1*Fix)+(Weight2*Hospitals)+(Weight3* Railroads)+(Weight4*$Fire_Departments)+(Weight5*Shelters)+ (Weight6*Police_Stations)+(Weight7*Utilities)+(Weight8*Tax_Rolls)+ (Weight9*Waste_Services)+(Weight10*Waste_Water_Treatments)+ (Weight11*Communications)+(Weight12*Parcels)* (3.11)

The methodology used to determine fixes for each data layer and the overall data section was applied to the capabilities component. All capabilities components, which were hardware, software, data storage, and GIS analyst, were examined individually and fixes were recommend for each component. A fix value of 1.0 was used within the fix equation for each of the four capabilities components. Furthermore, fixes were generated for the overall capabilities component, and a fix value of 70 was used. The following fix was performed to improve the overall geospatial readiness score.

If the overall data or capabilities scores were below the optimal level, a fix equation was run to determine a method for improving the overall geospatial readiness score. The fix told the user to fix data, capabilities or both depending on the user's responses. A fix value of 70 was used in the determination of fixes for overall geospatial readiness. After the generation of all fixes, the results were shown to the user. The determination of fixes accomplishes objective two.

Development of the Web Application

The first phase for completing objective three was choosing a hosting service. The hosting service chosen was Yahoo because it was reliable and user friendly. The languages and tools used to build the GRSAT were HTML, CSS, PHP, MySQL, Keyhole Markup Language (KML), Google Maps API, and JavaScript. HTML and CSS were used to build the design and layout of the application. HTML was also used for the creation of input forms, which gather the required input from the user. Additionally, HTML was used for applying the diverging color ramp, which is explained in table 3.9 PHP was used to build the functionality of the application which was:

- Allow users to login and logout
- Grade the test
- Recommend fixes
- Access the database
- Insert information into the database
- Query the database
- Generate KML files
- Write to and Read text files

MySQL was used to save the geospatial readiness scores and KML data for each jurisdiction. KML was used to create polygon files that were visible to a user or the administrator within a mapping application. Google Maps API was used to display these KML files. Lastly, JavaScript was used to display the Google Map Interface on the page and was also used to create the dynamic capabilities on the client side. These languages and tools were combined to generate a rich, dynamic, and interactive application thus completing objective three.

Table 3.9 Diverging color ramp used within the GRSAT.

Color Ramp for the GRSAT			
Color	**Score Range**	**Hexadecimal Code**	**Meaning**
Red	0-19	#E41B17	Very Vulnerable
Orange	20-39	#FF9900	Vulnerable
Beige	40-59	#FFF8C6	Slightly Vulnerable
Light Green	60-79	#00FF00	Little Vulnerability
Dark Green	80-100	#348017	Not Vulnerable

Modifications

Upon completion of objectives one, two, and three, the GRSAT was tested by the developer and several other users. These users made recommendations for improving the GRSAT. Using these recommendations two modifications were made to the GRSAT. Both modifications involved a change in the assessment, grading system, and recommendation of fixes. The change was made to the Communications and Utilities layer.

The Communications layer was divided into three sub layers which were a cell tower layer, telephone layer, and an internet layer. The score for the cell tower layer was calculated using equation 3.1, since it did not have a scale component. The scores for the telephone and internet layer were calculated using equation 3.2. The score from these three layers were used to derive a Communications Score. Equation 3.12 shows the equation used to calculate an overall communications score. The weights for each layer were heuristically determined by experts in academia. This new communications score from equation 3.12 was used in equation 3.3 as the communications layer score. A similar modification was made to the utilities component within the data section.

Model used for deriving an overall Communications score:

$$Communications\_Final=(0.31*Telephone)+(0.35*Cell\_Tower)+(0.34*Internet) \quad (3.12)$$

The utilities component was divided into a water layer, gas layer, and electric layer. The scores for the water, gas, and electric layer were calculated using equation 3.2. The scores from these three layers were used to calculate a final utilities score. Equation 3.13 shows the model for the final utilities score. The score generated from equation 3.13 was used in equation 3.3 as the utilities component. These modifications meant a change in the assessment because more input variables were added to address these layers, and it also meant a change in the grading system which is seen in equation 3.12 and 3.13. Changes were also required for the fix algorithm.

Model used for deriving an overall Utilities score:

$$Utilities\_Final=(0.35*Electric)+(0.34*Water)+(0.31*\$Gas) \quad (3.13)$$

Each data layer within the communication and utilities components were tested for fixes using a similar equation to equation 3.10. A fix value of 1 was used. This process generated steps for fixing each data layer within the communication and utilities components. Furthermore, the communication and utilities components were tested as a whole to determine which data layers to fix within each of these components. The fix equations were similar to equations 3.12 and 3.13, respectively. The difference was that a fix value was used to test each data layer. The fix value was 70. After the generation of fixes, the necessary fixes were reported to the user.

CHAPTER IV

RESULTS

Chapter four provides a discussion of the results achieved from the completion of objectives one, two, and three. The first portion of the results section provides a discussion of a test run that was performed to demonstrate how the models performed and quantified the user's responses. The second portion provides a discussion of that same test run, but the focus is on the capability of the fix algorithm. The third portion provides a discussion of the whole web application, more specifically the functionality and user experience.

Quantification of Geospatial Readiness

Objective one required the development of linear weighted models. These models can be found in the methods portion of this document. However, to show the ability of these models a trial run is necessary. The trial run helps demonstrate the full potential of the application. The city used in the trial run is Starkville, Mississippi. The responses to the assessment do not represent the actual GIS data and capabilities of Starkville. Nonetheless, the focus of this trial run will be on input used and the output that is generated.

Quantification of the GIS Data Component

The input variables regarding GIS data were answered in no particular method. Table 4.1 shows the answers used in the GIS Data section. If a GIS data layer did not have a scale question, “NA” was inserted into the “Scale” cell of that layer. Following the submission of these responses, the models are deployed to generate the scores.

Table 4.1 Trial run responses for the GRSAT’s GIS data component.

Layer	Avail.	Format	Update Frequency	Scale
Roads Layer	Yes	GIS	Annually	Large
Hospitals Layer	Yes	GIS	Every 2 Years or Greater	NA
Railroads Layer	Yes	GIS	Every 2 Years or Greater	Small
Fire Departments Layer	Yes	Paper Map	Every 2 Years or Greater	NA
Shelters Layer	Yes	GIS	Semi-Annually	NA
Police Stations Layer	Yes	Other Electronic	Every 2 Years or Greater	NA
Water Layer	Yes	GIS	Annually	Small
Gas Layer	Yes	Paper Map	Every 2 Years or Greater	Medium
Electric Layer	Yes	GIS	Annually	Large
Parcels Layer	Yes	Paper Map	Every 2 Years Or Greater	Medium
Tax Rolls Data	Yes	NA	Semi-annually	NA
Waste Services Layer	No	--	--	NA
Waste Water Treatment Layer	Yes	GIS	Semi-annually	NA
Telephone Layer	Yes	GIS	Semi-annually	Large
Cell Tower Layer	No	--	--	NA
Internet Layer	Yes	GIS	Semi-annually	Medium

Table 4.2 shows the scores that were generated from the responses that are in Table 4.1. The overall data score was 64, which is below the optimal level. The models accomplished the goal of quantifying the user’s responses. These scores enable the user to pinpoint strengths and weaknesses within his data. However, determining which layers to fix may not be as obvious as it appears. The fix algorithm will determine which data layers should be fixed to get the most improvement with the least amount of changes.

Table 4.2 Scores generated from responses in Table 4.1.

Data Score	64
Roads Layer Score	90
Hospitals Layer Score	70
Railroads Layer Score	40
Fire Departments Layer Score	40
Shelters Layer Score	100
Police Stations Layer Score	60
Utilities Score	61
Parcels Layer Score	30
Tax Rolls Layer Score	100
Waste Services Layer Score	0
Waste Water Treatment Layer Score	100
Communications Score	62

Quantification of the Capabilities Component

The models used for quantifying the capabilities component were also examined during this trial run. Answers were selected in no particular method. Table 4.3 shows the answers chosen within the Capabilities section. These answers were submitted to the results page for grading.

Table 4.3 Answers used for the capabilities section of the trial run.

Hardware		
	Number of Computers	One to Five
	Currency of Computers	New to Old (Two to Five years old)
	Number of Printers	Zero
Software		
	Type of GIS software	ESRI Related Software
	Currency of Software	Latest Version
Data Storage		
	Archival Frequency	Annually or Greater
	Location of Archived Data	Archived on Location
	Data Storage Capacity	Less than 500 Gb
GIS Analyst		
	Number of GIS analysts	One
	Average GIS analyst's years of experience	0-4 Years

The answers from Table 4.3 were assigned value and processed using the capabilities models mentioned within the methods section. Table 4.4 shows the scores that were generated for the capabilities component. The overall capabilities score was 57, which is a score that needs improvement. Similar to the data section, the fix algorithm will guide the user on which fixes will efficiently improve the capabilities components.

Table 4.4 Scores generated for the capabilities component using Table 4.3 as input.

Capabilities Score	57
Hardware Score	47
Software Score	100
Data Storage Score	30
GIS Analyst Score	50

Quantifying Overall Geospatial Readiness Score

Upon the submission and grading of the data and capabilities components, an overall geospatial readiness score was generated. No new input was required to achieve this score. The only numbers required were the overall data and capabilities score which was 64 and 57, respectively. Using these numbers a final score of 60 was generated. This score is below the optimal level so fixes will be recommended to the user. Nonetheless, this trial demonstrates the completion of objective one which was to quantify geospatial readiness. Equally important to the user is improving his geospatial readiness score, which will be examined in the next section.

Recommendation of Fixes

In most cases, the user needs to improve his geospatial readiness score. In the case of the trial run, fixes were generated and shown to the user. Only the fixes needed to get to the optimal level were shown on the results page. These fixes are shown in Table 4.5.

To determine the method for fixing the overall score, the GRSAT recommends addressing the issues within the data and capabilities components. The GRSAT also showed the user methods to fix the data and capabilities.

Table 4.5 All fixes recommended by the GRSAT.

Component	**Fix**
Overall	Data and Capabilities
Data	Railroads Layer and Fire Departments Layer
Roads Layer	None
Hospitals Layer	None
Railroads Layer	Update Frequency
Fire Departments Layer	Format
Shelters Layer	None
Police Stations Layer	Update Frequency
Utilities	Gas Layer(Format and Update Frequency)
Parcels Layer	Format and Update Frequency
Tax Rolls Layer	None
Waste Services Layer	Get a Waste Service Layer
Waste Water Treatment Layer	None
Communications	Get a Cell Tower Layer
Capabilities	Data Storage and Hardware
Hardware	Get a printer or add another printer to inventory
Software	None
Data Storage	Archive data more frequently and get more storage space
GIS Analyst	Get a GIS analyst or more GIS analyst

Improving the overall data score to the optimum level required addressing the needs of the railroads layers and fire department layer. Fixing the railroads layer required updating this layer more frequently. Fixing the fire departments layer required acquiring this layer in a GIS format. These fixes were both made in the second trial run. After fixing the data, the capabilities component was addressed.

Improving the overall capabilities score required fixing the data storage and hardware components. Fixing the data storage component required the user to archive the data more frequently and increase the data storage space. Fixing the hardware component required the user to get a printer or add another printer to the inventory. These fixes were addressed in the second trial. The second trial was done to test these recommended fixes to see if these changes would in fact raise the overall geospatial readiness score to the optimum level.

For every fix that was recommended, that answer was upgraded to the best choice. For example, suppose the user had a paper map of a GIS data layer, rather than having the user upgrade to an electronic format, the GRSAT suggests placing the map into a GIS format. This method of choosing the best fix was performed for both the GIS data and capabilities components. Table 4.6 shows the choices within the data component for the second run of the GRSAT. Table 4.7 shows the choices within the capabilities component used in the second run of the GRSAT. The fixes are in italics within these two tables. These choices were submitted and graded, and new fixes were generated.

Table 4.6 Answers for the GIS data component of the GRSAT with the fixes made. Fixes are in italics.

	Avail.	Format	Update Frequency	Scale
Roads Layer	Yes	GIS	Annually	Large
Hospitals Layer	Yes	GIS	Every 2 Years or Greater	NA
Railroads Layer	Yes	GIS	*Semi-Annually*	Small
Fire Departments Layer	Yes	*GIS*	Every 2 Years or Greater	NA
Shelters Layer	Yes	GIS	Semi-Annually	NA
Police Stations Layer	Yes	Other Electronic	Every 2 Years or Greater	NA
Water Layer	Yes	GIS	Annually	Small
Gas Layer	Yes	Paper Map	Every 2 Years or Greater	Medium
Electric Layer	Yes	GIS	Annually	Large
Parcels Layer	Yes	Paper Map	Every 2 Years Or Greater	Medium
Tax Rolls Data	Yes	NA	Semi-annually	NA
Waste Services Layer	No	--	--	NA
Waste Water Treatment Layer	Yes	GIS	Semi-annually	NA
Telephone Layer	Yes	GIS	Semi-annually	Large
Cell Tower Layer	No	--	--	NA
Internet Layer	Yes	GIS	Semi-annually	Medium

Table 4.7 Answers for the capabilities component of the GRSAT with the fixes made. Fixes are in italics.

Hardware		
	Number of Computers	One to Five
	Currency of Computers	New to Old (Two to Five years old)
	Number of Printers	*More than three*
Software		
	Type of GIS software	ESRI Related Software
	Currency of Software	Latest Version
Data Storage		
	Archival Frequency	*Weekly or More often*
	Location of Archived Data	Archived on Location
	Data Storage Capacity	*Greater than 5 Tb*
GIS Analyst		
	Number of GIS analysts	One
	Average GIS analyst's years of experience	0-4 Years

Scores from the second run of the GRSAT can be seen in Table 4.8. After the recommended fixes were made, the overall score was raised from 60 to 76. The overall data score increased from 64 to 71. The railroad and fire department layers were both raised from 40 to 70. The overall capabilities score increased from 57 to 80. The hardware score increased from 47 to 80. The data storage score increased from 30 to 90.

The overall score, overall data score, and overall capabilities score were all raised to the optimum level after the recommended fixes were made.

Table 4.8 Scores achieved from the input used in Table 4.6 and 4.7.

Component	**Score**
Overall Score	76
Data Score	71
Roads Layer Score	90
Hospitals Layer Score	70
Railroads Layer Score	70
Fire Departments Layer Score	70
Shelters Layer Score	100
Police Stations Layer Score	60
Utilities Score	61
Parcels Layer Score	30
Tax Rolls Layer Score	100
Waste Services Layer Score	0
Waste Water Treatment Layer Score	100
Communications Score	62
Capabilities Score	80
Hardware Score	80
Software Score	100
Data Storage Score	90
GIS Analyst Score	50

Since the overall geospatial readiness score, overall data score, and overall capabilities score were all increased to the optimum level, no fixes were required. However, sub-components with scores below the optimum level still showed recommended fixes to the user. For example, the parcels layer score was zero in the second run, so fixes were still recommended to the user, which were to fix the format and update more frequently. Table 4.9 shows all fixes shown to the user in the second run.

Table 4.9 Fixes recommended by the GRSAT based on input in Table 4.6 and Table 4.7.

Component	Fix
Overall	None
Data	None
Roads Layer	None
Hospitals Layer	None
Railroads Layer	None
Fire Departments Layer	None
Shelters Layer	None
Police Stations Layer	Update Frequency
Utilities	Gas Layer(Format and Update Frequency)
Parcels Layer	Format and Update Frequency
Tax Rolls Layer	None
Waste Services Layer	Get a Waste Service Layer
Waste Water Treatment Layer	None
Communications	Get a Cell Tower Layer
Capabilities	None
Hardware	None
Software	None
Data Storage	None
GIS Analyst	Get a GIS analyst or more GIS analyst

The GRSAT effectively and correctly recommended fixes to the user. All required recommended fixes were used in the second run of the GRSAT. The recommended fixes increased the overall geospatial readiness score, overall data score, and overall capabilities scores to the optimum level. After these fixes and score improvements, there still were fixes that could be made. Nonetheless, the GRSAT accomplished the second objective recommending the least amount of fixes to improve a geospatial readiness score to the optimal score.

The Web-Application

Accomplishing objective three involved bringing objectives one and two together in a web application. This section provides a discussion of the web application. The test run is also integrated into this section to show the look of the results on the user and administrator side. Nonetheless, the first step is to gain access to the GRSAT.

The GRSAT is restricted from the general public. However, potential users apply for the test by filling out a form with his or her contact information. Their information is sent to the GRSAT administrator. The administrator of the GRSAT then contacts the potential user with a username and password. Figure 4.1 shows the registration screen that the user completes to gain potential access to the GRSAT. Once a username and password are given by the administrator, the user can now access the system.

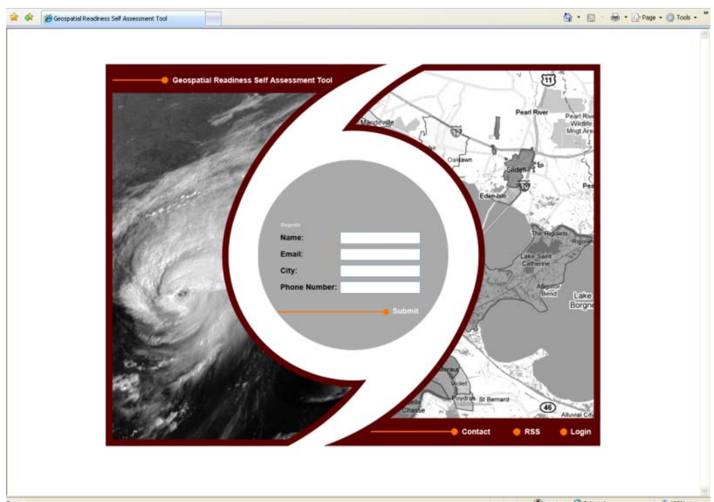

Figure 4.1 GRSAT registration page.

The login page enables users and the GRSAT administrator to access the GRSAT or administrator page, respectively. The user enters his username and password, and if it is correct, that user is redirected to the assessment page. If the administrator logs in, he is redirected to the administrator page. If the user fails to enter the correct credentials or if the user does not exist in the system, he will be denied access. The login page can be seen in Figure 4.2.

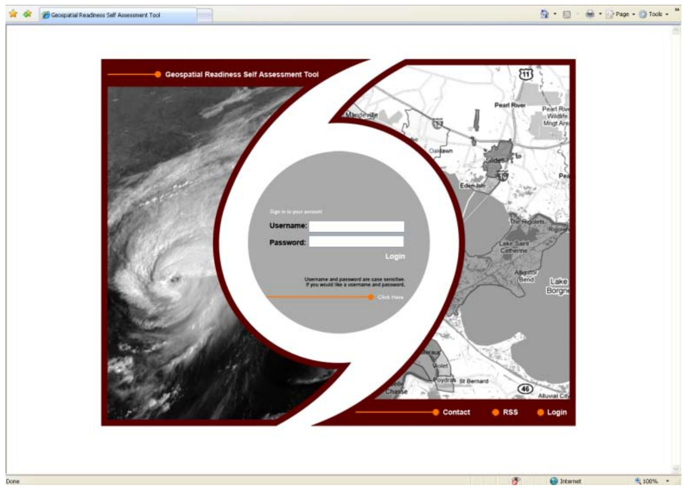

Figure 4.2 GRSAT login page.

Assessment for Gathering Data from the User

The assessment page is used to ask the user about his jurisdiction's GIS data and capabilities. The input forms were designed to allow the user to select only one answer for each question. The assessment page, when loaded, gave the user instructions for completing the assessment. The assessment page also provided the user a guide for answering the scale component for GIS layers. The user can also provide feedback on the assessment page. Figure 4.3 shows the assessment page, and Figure 4.4 shows the assessment page with the scale-help tab being displayed. Upon completion and submission of the assessment, the user is directed to the results page.

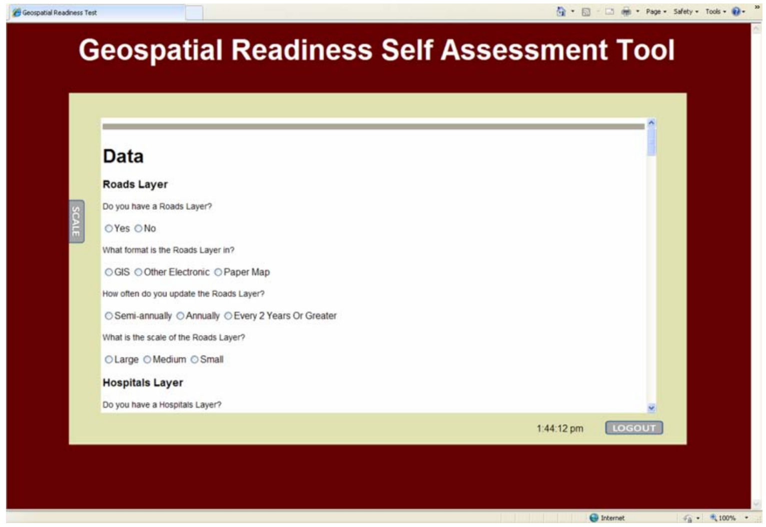

Figure 4.3 GRSAT assessment page.

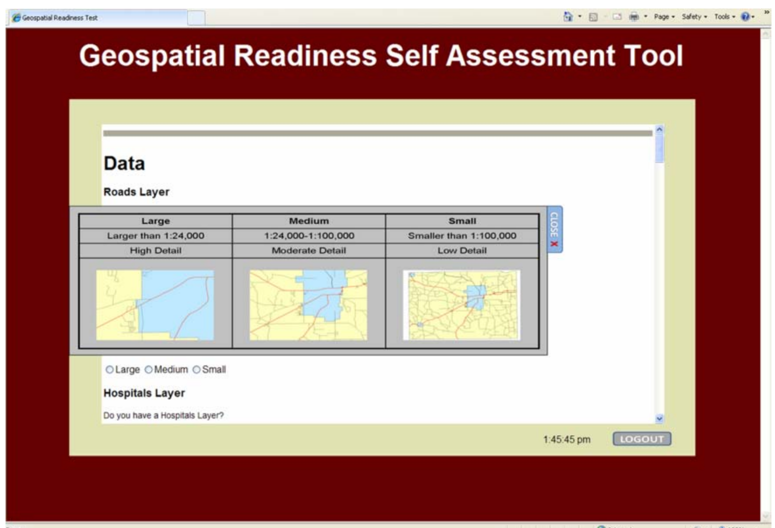

Figure 4.4 GRSAT assessment page with scale-help tab displayed.

Results Page

The goal of the results page is to process the answers submitted by the user and display the results in a diverging color scheme. Figure 4.5 is a screenshot of the results page using answers from table 4.1 and 4.3, and Figure 4.6 is a screenshot of the results page using answers from table 4.6 and 4.7. There are a couple of features offered to the user on the results page. One is a user can mouse over a component and the fix or fixes will appear within the “how to fix” box on the bottom right of the interface. For example, if the user moved the mouse over the overall geospatial readiness score component, the fix box would tell the user to fix the data and capabilities. The other feature allowed the user to click the polygon within the Google Maps display, and a box appeared within the map showing the jurisdiction’s name and score. The results page also sent an email to the user and administrator with the results from the assessment. When the user finished analyzing his results, he logged out by clicking the “Logout” button, and he was redirected back to the GRSAT home page.

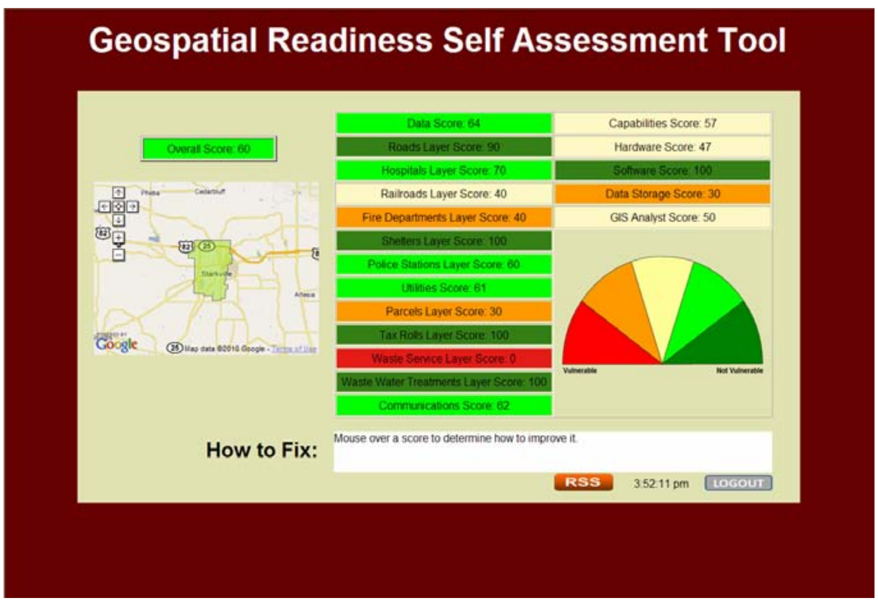

Figure 4.5 Results page with input from Tables 4.1 and 4.3.

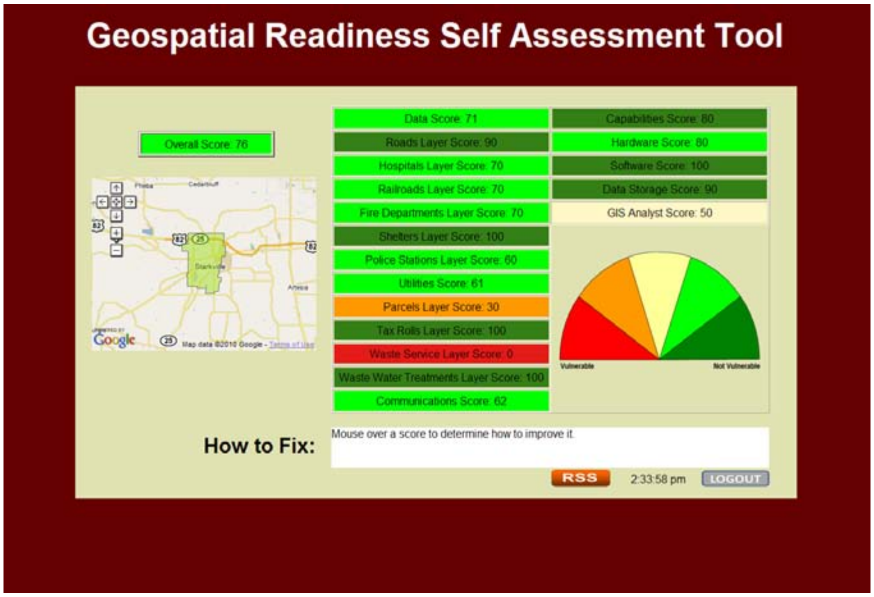

Figure 4.6 Results page with input from Tables 4.6 and 4.7.

Administrator Page

An administrator page was available within the GRSAT. Administrator credentials were used to access this page. The administration page provided several important features which were creating user accounts, adding jurisdictions to the system, and displaying the scores of jurisdictions in a table and map format. Each will be discussed in detail in the following paragraphs.

Creating a user account was done by creating a username and password and clicking "Register User." These fields and button can be seen on the upper portion of the administration page in Figure 4.7. The user account needs a corresponding jurisdiction so to accomplish this process 6 responses are required. The first two responses require the name of the jurisdiction and the username that corresponds with that jurisdiction. The next two responses require data from a KML file. KML files are generated by downloading a jurisdictional boundary ESRI shapefile from a state's GIS clearinghouse and converting the shapefile to a KML file within ESRI's ArcMap. Each jurisdiction in the KML file had tags for CD Data and Polygon Coordinates. The data between these two tags are placed in the “First CD Data” and “Polygon Coordinates” fields, respectively. The last two responses needed are latitude and longitude data. These are needed to provide a point to center the map for each jurisdiction’s results page. When the “Add City” button is clicked all input is inserted into the MySQL database. The next feature discussed offers the administrator the ability to analyze jurisdictional scores.

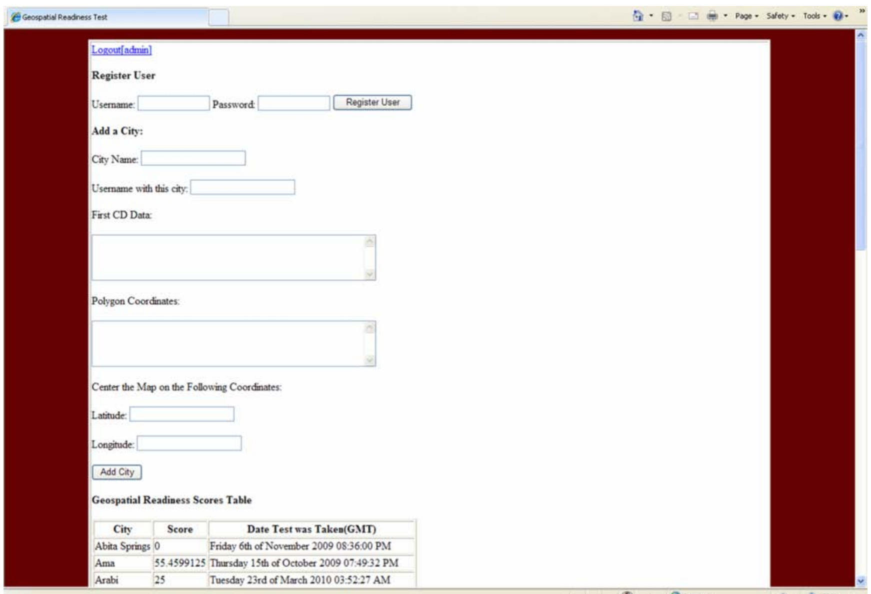

Figure 4.7 Administrator page with the creation of users and jurisdictions features being shown.

The scores are displayed to the administrator within a table and an interactive map. The table contains three fields which are jurisdiction name, score, and date the GRSAT was last run. This table is populated by jurisdictions that run the GRSAT. The table enables the administrator to view every jurisdiction’s score in alphabetical order by jurisdiction’s names. The other method for viewing scores is through the Google Maps interface. A KML file created a polygon overlay of all jurisdictions. The PHP code that builds the KML file examines a jurisdiction's score within the database and assigns a color to that polygon based on the color ramp from Table 3.9. Each polygon is clickable, and when clicked, a window displays the name of the jurisdiction and the score. Figure 4.8 is a screenshot of the administrator page showing the jurisdictions scores table and interactive map. All scores used in the table and map are trial runs of the GRSAT and are not a jurisdiction's actual score. This section and the previous section provided a discussion of the whole GRSAT system, more specifically the web component. These sections demonstrate the completion of objective three.

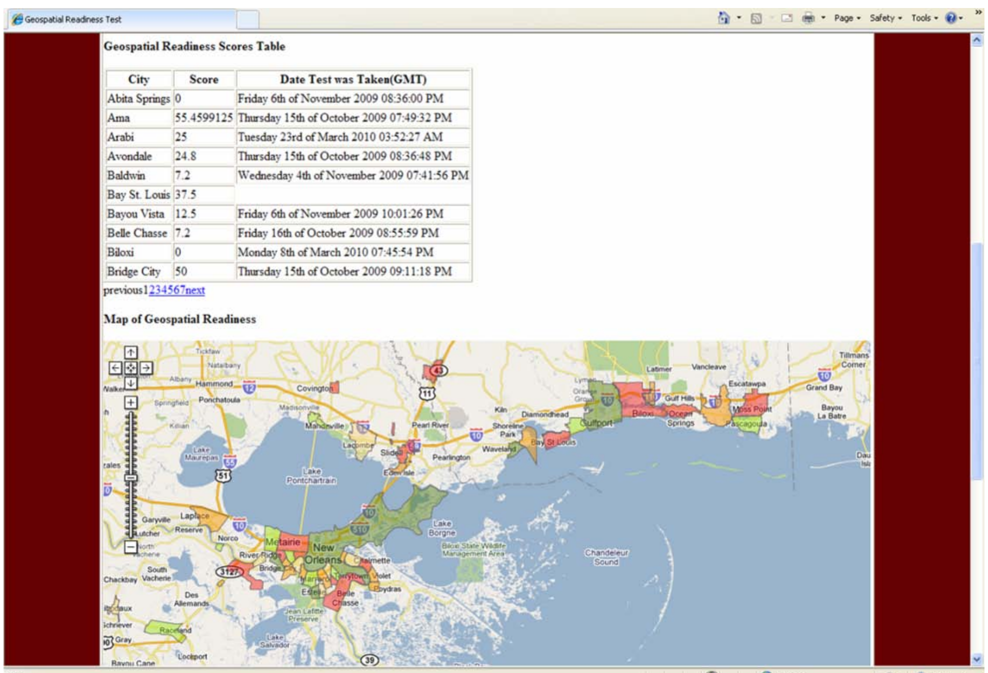

Figure 4.8 Score examination features shown on the administrator page.

GRSAT Beta Testing

The GRSAT was extensively tested by the developer. Furthermore, the GRSAT was sent to GIS professionals for testing. This was done for two reasons which are GIS professionals can make recommendations for improving the GRSAT, and they can catch and report potential errors within the application. A few of the suggested improvements made by the GIS professionals have already been taken into consideration and were applied to the GRSAT. These changes are located in the Modifications section within the methods portions of this paper. Some suggestions have not been taken into action yet, but in the future, the GRSAT can be modified to accompany these changes.

The suggestions made by GIS analysts from various jurisdictions are beneficial to the advancement of the GRSAT. These GIS analysts have invaluable experience and know how GIS systems operate at the jurisdictional level. The following suggestions were made by GIS analysts:

- Make the "Update Frequency" component easier to understand.
- Possibly make a question about a GIS director, programmer, or even a Technician.
- Possibly add components to the Hardware Section about GPS units, servers, large format.
- Possibly ask about GIS internet mapping applications in the capabilities section.
- Define the utilities layer in more detail.
- Make the communications layer more understandable.
- Possibly ask the user if he or she has a centralized GIS depot.

All suggestions are important to the GRSAT development team. The two suggestions that were addressed were defining the utilities layer in more detail and making the communications layer more understandable. Another benefit from beta testing is the ability to examine a small sample of jurisdictional scores.

When each jurisdiction completed the assessment, an email was sent to the administrator with all of the scores and fixes. Table 4.10 shows the overall geospatial readiness scores for four jurisdictions involved in the beta testing. Table 4.11 and Table 4.12 show the overall scores for data and capabilities, respectively. The city names were withheld due to confidentiality restrictions. The mean overall geospatial readiness score for these four jurisdictions was 79.55. The mean overall data score was 75.66, and the mean overall capabilities score was 83.44. Three out of four jurisdictions were geospatially ready. The jurisdictions appeared stronger in capabilities compared to GIS data. This data shows that the GRSAT appears to be a fair assessment, meaning that it is not impossible to achieve a geospatially ready score.

Table 4.10 Overall geospatial readiness scores for four separate jurisdictions.

Jurisdiction	**Overall Score**
1	80.31
2	94.84
3	61.50
4	81.53

Table 4.11 Overall data scores for four separate jurisdictions.

Jurisdiction	**Overall Data Score**
1	70.61
2	94.69
3	63.01
4	74.31

Table 4.12 Overall capabilities scores for four separate jurisdictions.

Jurisdiction	**Overall Capabilities Score**
1	90.00
2	95.00
3	60.00
4	88.75

CHAPTER V

SUMMARY AND CONCLUSIONS

A geospatial readiness self assessment tool was developed to enable jurisdictions to assess its geospatial readiness. Accomplishing objective one was done by using multi-hierarchical linear weighted equations which generated scores for all components of geospatial readiness. Geospatial readiness was broken into two main components which were data and capabilities. The data component was created to assess a jurisdiction's geospatial data, and the capabilities section was created to assess a jurisdiction's hardware, software, data storage, and GIS analysts. Following the quantification of all components previously mentioned, the GRSAT would recommend fixes to the user.

Artificial intelligence methods were used to accomplish objective two. A fix algorithm was developed using rule-based programming. Through an iterative process, the fixes were determined by substituting in fix values, and the fixes yielding the greatest change were recommended to the user. The final objective in this research was to bring objectives one and two together into a web application with a friendly user interface.

The GRSAT was built using HTML, PHP, Javascript, KML, MySQL, and Google Maps API. The web application enabled the user to login, take the assessment, and examine the results. Results were emailed to the user and also to the administrator of the system. The GRSAT also provided geospatial readiness scores to the administrator of the system in table and interactive map format. The administrator also had the capability to add jurisdictions to the system. Following the completion of objective three, a test run was performed by the developer and also by several GIS analysts.

The goal of trial run was to demonstrate the completion of objectives one, two, and three. The trial run did in fact show that the GRSAT can quantify geospatial readiness, recommend optimal fixes to the user, and offer these features to the user in a friendly web interface. The beta testing performed by several GIS analysts helped identify weaknesses within the GRSAT. The beta testing has already led to a couple of improvements, as well as guidance for future improvements. Following the completion of all objectives and testing, several conclusions were drawn from this research.

Completion of objective one helped show the importance of linear weighted models. The models developed for the GRSAT allowed for the quantification of geospatial readiness. A benefit of these models was the ability to make variables more important than other variables because in reality in a GIS system some features are more critical than others. However, this can also be a limitation, and it will be discussed further in the limitations portion of this chapter. Conclusions were also drawn from objective two.

Completion of objective two shows the benefit of recommended fixes. In the test run, the score was not at an optimal level. However, the fixes that the GRSAT recommended were made in the second trial run, and the score was improved to the desired level. This is important to the end user because if he is looking to improve his score it is important to make the changes that will yield the greatest result. This takes out guessing on the user's part, so he can now focus more on making the fixes. Another conclusion reached is that the fixes recommended to the user are dependent upon the linear weighted models. If weights are changed within the models, the recommend fixes will be different. Following objective two, the results from objective three were analyzed.

The results from objective three show that the GRSAT is best served to the user through a web interface. The web interface gives the end user access anytime and at any location that has an internet connection. The web application also enables real-time analysis of results for the end user and the administrator of the GRSAT. This is a benefit because there is no waiting time. The simplicity of the web application also creates less ambiguity for the user. Therefore, there is less of a chance for an error when the web application is simple to understand. Following the examination of the results, several limitations were discovered.

One limitation was the determination of the weights used in the scoring process. Weights were heuristically determined. As a result, people will weigh variables differently. For example, one user may see a roads layer as the most important, weighing it the highest while another user may see the roads layer as of third importance weighing it accordingly. If the weights are changed, scores will be completely different for the same answer set. Another limitation was discovered when an optimum level was implemented.

The developer of the GRSAT chose an optimum level of 70. However, some may think this score is too high or low. Heuristically deciding an optimum level is an issue because it can lead to different fixes for the same answer set. If the optimum level is higher than 70, more fixes are recommended to the user. If the optimum level is less than 70, fewer fixes are recommended to the user. However, future modifications are in the process of being made to enable the user to decide the optimum level. Another limitation was discovered that dealt with user input.

A limitation existed with the accuracy of the user's input. The GRSAT relies only on user input. If the user does not answer the assessment truthfully or does not understand the question, a problem arises, and a false score and wrong fixes maybe shown to the user. Creating an easy to understand assessment is important because it will minimize error during the input acquisition phase. Another step taken to counter this limitation was reminding the user to answer the assessment truthfully. Ultimately, the user controls whether or not his answers accurately represent his geospatial data and capabilities. After beta testing, another limitation was discovered.

The GRSAT is limited to jurisdictions that are located along coast lines and are at risk of being struck by a hurricane. A low score was seen in the beta testing phase for a jurisdiction that was not located in a coastal area. The GRSAT used Katrina Lessons Learned Research Phase 1 results as guidance. As a result, this assessment is not applicable to non-coastal jurisdictions. For example, an inland area may not have a shelters layer. Nonetheless, although several limitations existed, the GRSAT has proven to be useful.

The GRSAT, when answered truthfully, will provide a community with accurate scores and fixes. This was proven in the test run performed in the results section. This tool can be implemented along coastlines that are at risk of land-falling hurricanes. All coastal jurisdictions can benefit from the GRSAT. Even jurisdictions that are geospatially ready (scores of 80 – 100) are able to diagnose minor problem areas that can be improved. Making improvements to a jurisdiction's geospatial data and capabilities will enable better implementation in the four phases of disaster management.

In the future, the methods used to develop the GRSAT can be applied to other natural disasters. Since the GRSAT focused on the geospatial requirements for

Hurricanes, the GRSAT is not valuable for assessing the geospatial readiness for jurisdictions threatened by other natural disasters. However, by varying the weights, data layers, and capabilities components, a different version of a GRSAT can be created to fit another type of disaster. The scoring techniques and fix-searching methods are flexible and can be applied to a completely different set of input. Another future improvement that needs to be addressed before the GRSAT becomes publicly available is improving security. The GRSAT will need stronger security before it becomes publicly available to ensure complete protection of jurisdictional data. Nonetheless, the GRSAT has met the need of providing methods for improving a jurisdiction's geospatial data and capabilities.

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APPENDIX A

ASSESSMENT FROM THE GRSAT

Data

Roads Layer

Do you have a Roads Layer?

Yes

No

What format is the Roads Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Roads Layer?

Semi-annually

Annually

Every 2 Years Or Greater

What is the scale of the Roads Layer?

Large

Medium

Small

Hospitals Layer

Do you have a Hospitals Layer?

Yes

No

What format is the Hospitals Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Hospitals Layer?

Semi-annually

Annually

Every 2 Years Or Greater

Railroads Layer

Do you have a Railroads Layer?

Yes

No

What format is the Railroads Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Railroads Layer?

Semi-annually

Annually

Every 2 Years Or Greater

What is the scale of the Railroads Layer?

Large

Medium

Small

Fire Departments Layer

Do you have a Fire Departments Layer?

Yes

No

What format is the Fire Departments Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Fire Departments Layer?

Semi-annually

Annually

Every 2 Years Or Greater

Shelters Layer

Do you have a Shelters Layer?

Yes

No

What format is the Shelters Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Shelters Layer?

Semi-annually

Annually

Every 2 Years Or Greater

Police Stations Layer

Do you have a Police Stations Layer?

Yes

No

What format is the Police Stations Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Police Stations Layer?

Semi-annually

Annually

Every 2 Years Or Greater

Utilities

Water

Do you have a Water Layer?

Yes

No

What format is the Water Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Water Layer?

Semi-annually

Annually

Every 2 Years Or Greater

What is the scale of the Water Layer?

Large

Medium

Small

Gas

Do you have a Gas Layer?

Yes

No

What format is the Gas Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Gas Layer?

Semi-annually

Annually

Every 2 Years Or Greater

What is the scale of the Gas Layer?

Large

Medium

Small

Electric

Do you have an Electric Layer?

Yes

No

What format is the Electric Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Electric Layer?

Semi-annually

Annually

Every 2 Years Or Greater

What is the scale of the Electric Layer?

Large

Medium

Small

Parcels Layer

Do you have a Parcels Layer?

Yes

No

What format is the Parcels Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Parcels Layer?

Semi-annually

Annually

Every 2 Years Or Greater

What is the scale of the Parcels Layer?

Large

Medium

Small

Tax Rolls Data

Do you have Tax Rolls data?

Yes

No

How often do you update the Tax Rolls Data?

Semi-annually

Annually

Every 2 Years Or Greater

Waste Services Layer

Do you have a Waste Services Layer?

Yes

No

What format is the Waste Services Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Waste Services Layer?

Semi-annually

Annually

Every 2 Years Or Greater

Waste Water Treatment Layer

Do you have a Waste Water Treatment Layer?

Yes

No

What format is the Waste Water Treatment Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Waste Water Treatment Layer?

Semi-annually

Annually

Every 2 Years Or Greater

Communications

Telephone

Do you have a Telephone Layer?

Yes

No

What format is the Telephone Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Telephone Layer?

Semi-annually

Annually

Every 2 Years Or Greater

What is the scale of the Telephone Layer?

Large

Medium

Small

Cell Tower

Do you have a Cell Tower Layer?

Yes

No

What format is the Cell Tower Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Cell Tower Layer?

Semi-annually

Annually

Every 2 Years Or Greater

Internet

Do you have an Internet Layer?

Yes

No

What format is the Internet Layer in?

GIS

Other Electronic

Paper Map

How often do you update the Internet Layer?

Semi-annually

Annually

Every 2 Years Or Greater

What is the scale of the Internet Layer?

Large

Medium

Small

Metadata

Do all of the data layers mentioned above meet the minimum requirements specified by the FGDC Metadata Standards?

Yes

No

Capabilities

Hardware

How many computers do you have?

More than Five

One to Five

Zero

If your answer to this question is zero, choose "Does Not Apply" for the next question.

How current are your computers?

New (Less than Two years old)

New to Old (Two to Five years old)

Old (Greater than Five years old)

Does Not Apply

How many printers do you have?

More Than Three

One to Three

Zero

Software

What type of GIS software do you run on your computer?

ESRI Related Software

Purchased Software other than ESRI

Open Source Software

I do not have GIS software

If your answer to this question is "I do not have GIS Software", choose "Does Not Apply" for the next question.

How current is your software?

Latest Version

Lacking Updates

Beta Version

Does Not Apply

Data Storage

How often do you archive your data?

Weekly or More often

Monthly

Annually or Greater

Never

Where is your data archived?

Archived at Multiple Locations

Archived on Location

Archived off Location

Does Not Apply

What is your storage capacity for your data?

Greater than 5 Tb

Between 500 Gb and 5 Tb

Less than 500 Gb

Does Not Apply

GIS Analyst

How many GIS analyst work at your facility?

Three or More

Two

One

None

If your answer to this question is "None", choose "Does Not Apply" for the next question.

What is the average years of experience of your GIS analyst/analysts?

10 Years or Higher

5-9 Years

0-4 Years

Does Not Apply