Geographic Information Systems for Transportation Asset Management

A Project and Report in Partial Fulfillment of a Master’s of Science Degree in Civil and Environmental Engineering

Emily A. Prince
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Committee
Adviser: Dr. Jesus de la Garza, Civil and Environmental Engineering.
Professor: Dr. Anthony Songer, Civil and Environmental Engineering.
Professor: Dr. Michael Vorster, Civil and Environmental Engineering.
Professor: Dr. Randel Dymond, Civil and Environmental Engineering
Abstract

Data visualization can have a profound influence on the effectiveness of data communication. Visualizing information allows users to easily inspect, analyze, and draw conclusions from the data. The construction industry has used data visualization tools in planning, designing, and building structures and infrastructures around the world. Geographical Information Systems (GIS) is one visualization tool that has great potential to improve construction and civil engineering practices. The implementations for GIS visualizations are extensive.

One research project currently using GIS software is the Highway Maintenance Monitoring Program, a contracted project between Virginia Polytechnic Institute and State University (Virginia Tech), and the Virginia Department of Transportation (VDOT). The project tracks the effectiveness of VDOT in maintaining the interstates of Virginia. With field inspections, a statistical analysis, and an enormous database, this program accurately illustrates and compares the level of maintenance of VDOT to private contractors each year. The assessment is performance-based, evaluating the existing conditions for specific areas against a specified goal set by VDOT.

This project report tracks the history of GIS visualization, focusing on its use in the VDOT Interstate assessment project. While the VDOT project does have a GIS component that provides a data visualization component, it contains many drawbacks. The major limitations of the current process are that there is no capacity for data interaction, the data is only available through a yearly CD submission, and the creation process is tedious and susceptible to errors.

Three new GIS visualization tools, ArcExplorer, Map2PDF, and WebGIS, present the potential to solve the current problems with the GIS component of the project. An analysis of these three programs answers the question, “To what extent can new GIS tools further develop the visualization and utilization of the transportation data currently collected for the VDOT project?” This project evaluates the benefits of each program and determines that WebGIS is the best option. The second phase of the project is the actual implementation process of incorporating WebGIS into the overall VDOT research project.
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I. Introduction

Data visualization has had an enormous impact on the history of science and engineering. Attempting to bring the user to a deeper understanding of the information, data visualizations can aid in decision-making and planning (Bajaj 1999). Effective visualizations provide a clear and easily understood depiction of even complex data sets. By providing insight into the meaning of unorganized data, visualization techniques allow innovation and development of countless realms. One tool that has greatly influenced visualization practices is the developments of Geographic Information Systems (GIS).

The potential implementations for GIS visualizations are extensive. One research project currently using GIS software is the Highway Maintenance Monitoring Program, a contracted project between Virginia Polytechnic Institute and State University (Virginia Tech), and the Virginia Department of Transportation (VDOT). The project tracks the effectiveness of VDOT in maintaining the interstates of Virginia. With field inspections, a statistical analysis, and an enormous database, this program accurately illustrates and compares the level of maintenance of VDOT to private contractors each year. The assessment is performance-based, evaluating the existing conditions for specific areas against a specified goal set by VDOT (Piñero 2003).

This project report tracks the history of GIS visualization, focusing on its use in the VDOT Interstate assessment project. While the VDOT project does have a GIS component that provides a data visualization component, it contains many drawbacks. The major limitations of the current process are that there is no capacity for data interaction, the data is only available through a yearly CD submission, and the creation process is tedious and susceptible to errors.

Three new GIS visualization tools, ArcExplorer, Map2PDF, and WebGIS, present the potential to solve the current problems with the GIS component of the project. An analysis of these three programs answers the question, “To what extent can new GIS tools further develop the visualization and utilization of the transportation data currently collected for the VDOT project?” This project evaluates the benefits of each program and determines that WebGIS is the best option. The second phase of the project is the actual implementation process of incorporating WebGIS into the overall VDOT research project.
II. Background

A. History of GIS Visualization

A Geographic Information System, or GIS, is an organized collection of computer hardware, software, and geographic data designed to capture, store, update, manipulate, analyze, and display all forms of geographically referenced information (ESRI 2005). Though spreadsheets and databases can graph simple geographic points, a true GIS is capable of linking spatial data with geographic information about a particular feature on the map. This allows the user to draw conclusions from the data with reference to the location (ESRI 2005).

GIS has evolved out of a long tradition of map making. Though many of the attributes used are innovative and new, the basis of GIS reaches back to the roots of navigational maps. Before computers became widely available, cartographers would lay plastic Mylar sheets on top of each other, revealing more information about an area than was possible with any single paper map (James 2001). GIS digitalizes this process to create computer maps with multiple layers, each containing unique data. In the 19th century, maps developed from single diagrams of geographical features to comprehensive atlases that portrayed statistical information relative to the location (Friendly and Denis 2004). In 1855, John Snow created a dot map that discovered the source of a cholera epidemic. He plotted the location of cholera cases within a community and found that they concentrated around a contaminated well used as a water source. This discovery brought a great deal of attention to the benefit and use of geographic visualizations in areas other than geography (Tufte 1983). Since then, geographic referenced maps have become widely used in almost all industries.

The development of modern GIS visualization began in the 1950s, with use primarily in the public sector. The creation of the GBF-DIME files by the U.S. Census Bureau in the 1960s marked the first large-scale adoption of digital mapping by the government. This system led to the production of the Census TIGER files, one of the most important socioeconomic geographical data sets in use today (Mark et al 2004). In the 1970s, private companies began offering GIS packages to public and private entities. Environmental Systems Research Institute (ESRI) emerged as the leading vendor of GIS software. In 1981, ESRI released Arc/Info, a standard package that ran on mainframe computers. As computing power increased and hardware prices plummeted in the 1980s, GIS became a feasible technology for state and municipal planning (Mark, 2004). In 1992, ESRI released ArcView, a desktop mapping system with a graphical user interface that marked a major improvement in usability over Arc/Info’s command-line interface. Since the release of ArcView, ESRI released ArcGIS 8.3 and Arc 9.0 as updated versions.

The release of ArcIMS in the mid-1990s enabled the distribution of GIS maps and spatial data over the Internet, eliminating many of the hardware and licensing expenses of a full software package (James 2001). This program uses a server software product, ArcSDE, to access large amounts of data and to provide access to clients via the Internet (ESRI 2005). The development of GRASS (Geographical Resources Analysis Support System) was introduced in the late 1990s. This program, based on an open source system, allows users to obtain free access to the source code of GIS programs. This permits the
technology to develop much more rapidly than traditional software progression (Neteler and Mitasova 2002). A third advancement, ArcExplorer, provides a lightweight GIS data viewer. Developed by ESRI, this freely available software offers an easy way to perform basic GIS functions. By linking ArcView programs to the ArcExplorer system, users can view the data on computers without having the sophisticated ArcView software. ESRI provides a free, downloadable version of ArcExplorer on their website (ESRI 2005). Systems such as ArcIMS, GRASS and ArcExplorer, that promote progression as well as the need for GIS components in business, municipalities, and government, allow GIS to be a rapidly growing and advancing field.

In the last five years, the implementation of GIS visualization tools has become evident in nearly every sector of business. GIS programs can locate areas, populations, or resources with respect to a physical space. Driving directions found on the Internet, storm watch equipment, Global Positioning System (GPS) units in automobiles, and census bureaus across the world all use GIS systems. Developing countries are using GIS tools to track the populations and development that the government would like versus the actual data. These comparisons can visually show officials the problems that exist and the areas in which they are excelling. Forestry organizations also use a great deal of GIS technology to determine what wildlife resides in their forests and where these animals typically roam. Another interesting application of GIS is for new businesses entering an area. GIS can map out target clients and show strategic locations for a business with a certain specialty. Emergency Services and Police use GIS to determine how to reach someone in trouble via the fastest route (ESRI 2005). GIS can also help with crime analysis or search and rescue operations. The applications for GIS reach to almost any vocation in any location. In 2001, analysts estimated that the GIS software, data, and services were a two billion dollar industry (Mark 2004).

B. Implementation of Data Visualization in the Construction Industry

The opportunity for implementations of visual displays of data in the construction and civil engineering sectors is vast. Currently the main visualization tools used are computer aided design (CAD) programs, production simulations, scheduling software, and geographic information systems (GIS) software. Data mining, spreadsheet, and asset management software programs work with the visualization software to organize, analyze, and visualize the data (Bajaj 1999). Several visualization tools have also been developed through research projects that can greatly increase daily processes and productivity.

The most widely used visualization tool in design and construction is computer-aided design. CAD is an automated system for the design, drafting, and display of graphically oriented information. The development of CAD began in the 1960s, revolutionizing the design industry. Nearly all architects, engineers, and construction firms now use CAD capabilities to create, alter, optimize, update, and view drawings (Autodesk 2005). In addition to plan and profile drawings, CAD can also create 3-dimentional (3D) renderings of the final project before any construction starts. A shown in Figure 1 below, these visualizations give the owner and public an idea of what the finished product will look like (Post et al
The data visualizations and drawings that CAD programs produce play a major role in the development of the construction industry.

Figure 1: Example of a 3D CAD rendering of a neighborhood

While CAD software has reformed the design phase of construction, simulation and scheduling software have modernized construction managing and planning stages. Simulations allow the user to experiment and evaluate different scenarios during the planning phase of a project (Kamat, 2000). Construction processes, resource allotment, and building stability in earthquakes, are all areas where the use of visual simulations indicate relationships relative to time. Construction personnel, owners, and design professionals all can use simulation programs to predict the outcome of an activity or optimize a process. This allows the parties involved to make decisions before the construction phase, minimizing lost time and maximizing efficiency.

Scheduling software, the most prominent program being Primavera, also allows project managers to optimize a project’s duration and resources during the planning and development stages (Primavera 2005). Visualizations portray the schedule or resources in the form of bar charts, histograms, and precedence diagrams as. With scheduling software, interested parties can track the project through a critical path. In the event of a delay or change to the project, updated schedules are easy to obtain if scheduling software is being used (Primavera 2005).

A more recent development combines the use of 3D CAD and project scheduling to provide a 4-dimensional (4D) tool. 4D planning allows the user to see the project drawings with respect to the planned time schedule for the project. This provides a visual indication of when a specific component of a project is not completed within the allotted time. A Stanford study confirmed that a 4D model communicates a schedule more clearly and enables even relatively inexperienced construction professionals to identify problems that can be overlooked by experienced personnel in the traditional schedule formats (Koo et. al, 2004).

Numerous studies have been conducted evaluating the programs used for construction data visualizations. Benjamin Hays, a Virginia Tech alumnus, studied graphical representation for construction control information, such as scheduling, budgeting, and correspondence. Though a great deal of
technology does exist, the construction industry has not created a formalized method for most processes. Hays concludes that data visualization tools must be linked or integrated to each other and must follow guidelines in order to be effective for the overall industry (Hays 2002). If CAD software, simulation systems, scheduling software, and GIS programs can establish a standard, they are more likely to be implemented into construction practices and have more potential to integrate with each other.

Another study by Munish Kapoor assessed the use of visual displays of quantitative data in the construction equipment and accounting realms (1996). Kapoor’s research of construction equipment fleets lead to the use of color-coded pictorial representations, termed small multiples, to easily indicate the condition each piece of equipment in a fleet. This visualization tool uses a common picture with colors indicating the condition of individual parts. This tool, modeled after visualization specialist Edward Tufte (1983), is easy to understand and maintain. Kapoor also analyzed the use of a color-coded system to indicate if a project is above or below the proposed budget. This system again provides the means for analyzing a large volume of detailed data quickly (Kapoor 1996).

Each visualization tool, ranging from CAD to small multiple drawings, provides benefits to the construction industry. Time and money can be saved, errors can be identified, and plans can be made in advance to improve the flow of a project. Graphical tools do not replace numerical tables and spreadsheets, but add value by clearly representing quantitative data to improve the construction industry (Tufte, 1983).

C. Implementation of GIS in the Construction Industry

GIS is a continually developing technology that has been integrated into many industries, as well as in everyday life. The construction field has begun to use GIS tools and is working to implement the technology to its full capacity. Companies such as Trimble have recently put a heavy focus on implementing GPS and GIS systems into the heavy highway and earthmoving sector. The excavating and grading machines are equipped with GPS receivers that allow machine to excavate to the precise elevation. The GPS signals are then implemented into a GIS mapping program that displays the data for the operator. Thought the technology has been developed, components such as industry culture and conversion complications are inhibiting the full implementation of GIS, yet progress has been made.

Currently one of the main construction and civil engineering divisions using GIS systems is transportation. All fifty departments of transportation across the country have begun to implement GIS systems to maintain and assess the roads they build (GIS-T 2005). Every state Department of Transportation currently has state shape files and base-map coverage with feature data sets available to the public through the Internet. Any user can download the information and view the highways and collected data. Many states also provide interactive GIS maps that display major routes, county zoning, resident boundaries, advisory areas, distinct topography, and bridges (GIS-T 2005). Some of these interactive websites serve as a clearinghouse for distributing statewide maps while others are only informative or used for internal processes. Figure 2 shows a breakdown of state Department of
Transportation’s applications of GIS in 2004. Feature inventory, asset management, safety management, and highway project locations are the major uses.

![Current GIS Applications in Transportation](image)

Figure 2: Breakdown of GIS applications in transportation in 2004 (GIS-T 2005)

The Virginia Department of Transportation (VDOT) has implemented GIS technology into numerous divisions. In 2003, VDOT was a recipient of ESRI’s Special Achievement in GIS award, which recognizes outstanding work in the GIS field (VDOT 2005). The received the award for the development of the Online Transportation Information Center, or “GIS Integrator Project.” This tool allows users to locate roads, rest areas, alternative transportation options, pictures of each area, and numerous other features. The site also indicates the proposals for road expansion and construction in the next six years (VDOT 2005).

Environmental programs and safety studies for VDOT have also used GIS tools to analyze and display data. The Virginia Transportation Research Council has done a great deal of research and studies to determine the advantages for GIS. By tracking collisions and accident reports, VTRC is developing ways GIS can improve highway safety. They have also indicated numerous other implementations (VTRC 2005).

D. VDOT/VT Highway Maintenance Project Overview

As mentioned earlier, the Virginia Tech and VDOT Highway Maintenance Monitoring Program currently uses GIS software as a visualization tool. The project tracks the effectiveness of VDOT and Virginia Maintenance Systems (VMS) in maintaining the interstates of Virginia. VMS is a private firm that has been contracted to maintain a selected portion of Virginia’s Interstate system. Based on the doctoral
thesis of Juan Piñero, the Virginia Tech team implemented a performance evaluation program in 2000. With field inspections, a statistical analysis, and an enormous database, this program accurately illustrates and compares the level of maintenance of VDOT to VMS each year. The assessment is performance-based, evaluating the existing conditions for specific areas against a specified goal set by VDOT (Piñero 2003).

The main asset groups are shoulders, roadside, drainage, traffic, bridge structures, pavement, and timeliness of response to road incidents. The amount of data collected is immense, with over 7000 sites inspected each year in 38 different asset items. Once the raw data is collected, the Virginia Tech team works to analyze and report the results of the study. VDOT and VMS receive a final report each year that includes an overall “report card” for that year along with the data in the form of spreadsheets, trend analysis bar graphs, individual asset item bar graphs, and written descriptions (Piñero 2003).

In 2002, the Virginia Tech team used ArcGIS 8.3 to implement a GIS component to provide a visual tool for the report. While the graphs and tables included in the report do communicate the data, they do not show a clear illustration of the specific conditions on each road segment. GIS software has the ability to plot maps of each individual stretch of highway with the pass and fail areas indicated by green and red marks as seen in the above Figure 3. These maps provide an easily understood and accurate illustration of the data. The project encompasses both individual asset item maps, as well as trend analysis maps. The trend analysis maps allow the reader to see the change in performance of sites inspected over the course of the project. Currently contracted to continue until 2007, this project still has several years to be improved. In addition to this project, the Virginia Tech team has recently become involved in other VDOT evaluation projects. One project is focusing on the maintenance level of Interstate-64 and another is evaluating the quality of inspections across the state. Each of these projects also has the potential to implement GIS components.
III. Problems with Previous GIS Deliverables

Though the GIS visualization did greatly improve the project by adding a visual display of the data, potential for improvement does exist. Over the past year, the visual aspects of the GIS display have been improved. Research in the science of visualization, particularly works by Edward Tufte, indicated several problems with the visual display of the data. By adding items such as a scale, legend, and overview map, the overall visualization improved. The orientation of the data was also evaluated to maximize the amount of space used for data and lessen empty space. In 2004, over twenty templates were created to assess how people viewed the data and what orientation is the most effective. The Virginia Tech team held a survey of the twenty options to determine which template was the most effective, and later implemented this new template into the final report. Although these advancements have improved the project, there are still a number of key problems with the current system.

The first drawback is that the creation process is tedious and very susceptible to errors. Each link and textbox used is hand-linked or typed into the GIS software template. In addition, each asset item under each section of interstate must have its own template. This requires a great deal of tedious template creation and increases the likelihood of simple typing and human errors. The time-intensity of the process also limits the functions that the Virginia Tech team can incorporate.

A second problem is that the CD created in the current process is only sent to VDOT once a year. The data sent to VDOT is only available after crews have inspected all of the segments for that year. By the time VDOT receives the CD, the data may be six to eight months old. VDOT may not know of major problems or changes until the end of the process when they receive the CD.

The final, and most substantial limitation in the current system is that it does not allow the user to interact with the data. When using the ArcGIS software, the user can select each data point (represented by red or green dots seen in Figure 3) to view the background information of that point: location, pass or fail criteria, and segment information. Yet, in order to view the maps, the user must have a GIS software program and be familiar with the components involved (ESRI 2005). Many of the target audiences at VDOT and VMS do not have this computing capability. In order to convey the visualizations to these parties, the Virginia Tech team converts each map into an Adobe Portable Document Format (PDF). At the end of each yearly cycle, the Virginia Tech team creates a disk for interested parties with each of the PDF maps copied and indexed. Though the disk does provide a visualization of the data, the PDF documents are not interactive.

The GIS component is a great asset of this project, but these limitations lessen the value. The CD created with the PDFs illustrates the abundant value that GIS systems can provide, but without the interaction between the user and the data and the timeliness of the data to the user, a great deal of the benefits of GIS is lost.
IV. Description of Project Proposal

A. Objectives

The major objective of the research component of this project is to answer the question “To what extent can new GIS tools further develop the visualization and utilization of the transportation data currently collected for the VDOT project?” The primary objective of the overall project is to implement the best program into the project. Many sub-objectives exist within these goals. Some specific objectives include:

- Discover software and systems available to improve the project
- Learn how to use each program to create useful and efficient maps
- Provide VDOT with an improved GIS tool that will more efficiently illustrate data
- Shorten the time needed to create the GIS component each year
- Make the final deliverable more interactive
- Allow the program to be easily updated in subsequent years

These objectives promote learning and improving on the current process. If each objective is met, this project will illustrate how the VDOT project can benefit from each program, which program provides the most benefit, and how it has been implemented.

B. Scope

This project will be a comprehensive study of three programs that each have the potential to benefit the VDOT Highway maintenance project. These programs are ArcExplorer, Map2PDF, and WebGIS. Each of these options will be evaluated and tested to determine the usefulness for this project. After the evaluation, one program will be chosen and will be integrated into the VDOT project as the GIS deliverable for 2005. The project scope also encompasses documenting the evaluation process and documenting the steps to integrating the chosen program.

C. Limitations

Hundreds of software packages exist that have GIS capabilities, but only a limited number of these programs can solve the existing problems with the GIS component of this project. Though other options do exist, ArcExplorer, Map2PDF, and WebGIS will be the focus of the project.

A second limitation is in the data set explored. The VDOT highway maintenance project contains thousands of data points for each year. The templates will be created for one section of data that is representative of the whole state. These sample templates will illustrate the capabilities of each program without dealing with an overwhelming amount of data. Once the ideal program has been determined, that program will be implemented into the VDOT project using all of the collected data.
D. Proposed Method of Investigation

ArcExplorer, Map2PDF, and WebGIS all have the potential to enhance the GIS aspect of the VDOT project. The questions addressed in this project are, “how does each program benefit over the current process,” and “which program provides the best solution for the current problems.”

The project is comprised of six major steps:

1. Further research the potential programs
2. Obtain access to the necessary software
3. Learn the computer skills needed
4. Create templates with each program to compare the systems
5. Assess each program based on the rating criteria
6. Implement the most effective program.

The ultimate goal is simply to make progress in developing an enhanced process for visualizing the GIS data associated with the VDOT maintenance project.

E. Criteria of Evaluation

The following five criteria serve as the program evaluation areas. They provided a uniform comparison between each method and against the current method.

- Ease of use
- Data Interaction
- Creation Complexity
- Visual display
- Cost

Table 1 below explains the components of each category. These specific components will each be considered in assigning the rating for each group.

<table>
<thead>
<tr>
<th>Ease of Use</th>
<th>Data Interaction</th>
<th>Creation Complexity</th>
<th>Visual Display</th>
<th>Cost</th>
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<tr>
<td>Intuitiveness</td>
<td>Ability to identify and query data</td>
<td>Manual formatting required</td>
<td>Visually stimulating</td>
<td>Overall price</td>
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<tr>
<td>Number of steps to see data</td>
<td>Ability to zoom and highlight data</td>
<td>Tediumness of creation</td>
<td>Familiarity with visual display</td>
<td>Future expenses</td>
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<tr>
<td>Complexity of program</td>
<td>Ability to show multiple components of data</td>
<td>Time required</td>
<td>Ability to have multiple display options</td>
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<tr>
<td>Requirement of GIS knowledge</td>
<td>Ability to indicate passing percentages</td>
<td>Ease of future implementation</td>
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Ease of use is an important component because the ultimate users, VDOT workers, private contractors, and the general public, most likely do not have background in using GIS. If the interface is difficult to use then the entire project is made in vain. Creating a user-friendly, easily understood template is one of the goals of the project. The intuitiveness, complexity, and requirement of GIS knowledge will all be considered in this group.

Increasing the level of data interaction is a primary goal for this project. The current process does not allow for any data interaction. Providing identification information such as location, reason for failing segments, or crew number gives the user a better understanding of the data as well as a reference. Ideally, users will be able to analyze the data by showing different combinations of data across the state and in varying asset groups. The ability to show the passing percentages is also important. Data interaction also includes the ability to query, identify, highlight, and zoom-to data.

The third criteria, Creation Complexity is important on the Virginia Tech side. One of the current problems is that the creation process is long, manual, and tedious. If a less manual process can be determined, more time and effort can go into improving the system and the potential for error is substantially reduced. The ease of future implementation and updates is also considered in this category.

Having an effective visual display is another important component. A great deal of work went in to improving the current visual display, so the new option needs to be at least as visually useful as the old version. Visual display includes the way the data is references, the options to view or compare the data in different ways, and the overall atheistic look of the program. The notion of familiarity will also affect the ratings in for the visual display component.

The final criterion for evaluation is the cost of the option. While cost is not the driving force of the decision, it is important to consider. The upfront investment for the program will be calculated and rated based of a comparison to the other options. In addition, future costs of updates or training will be considered.

The rating system used for this project is modeled after the system used by Consumer Report for evaluating computer programs. As Figure 4 illustrates, a score of excellent, very good, good, fair, or poor ranks each criterion for each template (Consumer Report 2005).

![Figure 4: Possible Evaluation Scores](image)

This system is used so that each criterion can be looked at separately rather than giving the overall template one score. Some criteria may be more important than others, so an overall value may not indicate the best program. The final results table allows each criterion to be assessed for each program, and for the best program to be selected.
F. Schedule of Work

The schedule of work for this project is shown in Figure 5 below.

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Figure 5: Schedule of work for project running from proposal to final defense
V. Description of each Program Assessed

In researching visualization programs, the major goal is to find potential tools that can improve the GIS component of the VDOT project. Three programs, ArcExplorer, Map2PDF, and Web GIS, each have the potential to address many of the current limitations. Each program is different, addressing different issues, yet all have the ability to benefit the project.

A. ArcExplorer

ArcExplorer is a free software interface that users can download from the ESRI website and copy onto a CD. While the program does not have the capability to create the data sets that ArcGIS can generate, it does provide an interface to communicate the data to parties without access to expensive ArcView software. Once set up with the VDOT data, ArcExplorer can be copied onto a CD and sent to participants. One major benefit is that ArcExplorer is interactive, allowing the user to click on failing points and view location, type, and reasons why the point failed. ArcExplorer also has a query function that could be set up to show all points that fit a certain description. For instance, the user can create a query to find all points inspected in 2003 that failed in the area of landscaping. This tool could prove to be extremely useful. ArcExplorer also has measuring tools, scales, and different display capabilities (ESRI 2005). In addition, this program would not add any expense to the project. Some potential downfalls of this program are not being able to show multiple years, educating the client on how to use the program, and organizing the data in an easily understood way.

B. Map2PDF

The second program that this project will research is a Layton Graphics product called Map2PDF for ArcGIS. This product claims to have the ability to display graphical layers and feature data in a GeoPDF that can be viewed with any Adobe Reader software. The GeoPDF is an intelligent PDF program that allows users to interact with the data, query attributes, manipulate map layers, zoom to points by coordinates, display locations, and print. Several other tools are included that may prove to be useful for this project. The PDF maps can be posted to the Internet or distributed on a CD for easy viewing. Layton Graphics provides a free trial for the Map2PDF software, downloadable from their website (Layton Graphics 2005). If this program proves to be the most efficient, a full license can be purchased. The tools and access to this program make it a very promising option, but one obstacle does present a challenge. Map2PDF is only compatible with ArcGIS 9.0, and the current project uses ArcGIS 8.3. The university does provide access to ArcGIS 9.0 software, but compatibility issues may arise. ESRI claims that the programs will be compatible and that the data can easily be converted from 8.3 to 9.0 (ESRI 2005). Although they do not anticipate any complications, many risks are involved. If the implementation of ArcGIS 9.0 is successful, the Map2PDF program is a viable option.
C. WebGIS

The use of GIS systems on the Internet is the third visualization technique this project will assess. This technology is a link of the previously discussed ideas of GIS visualizations and the Internet. Melissa Scott, an employee of Anderson & Associates in Blacksburg, Virginia, works in the WebGIS department. According to Scott, an Internet based GIS system can allow users to access GIS visualizations such as photographs, queries, data references, and data comparisons without having to purchase the software (Scott 2004). VDOT, VMS, and the general public could all view the data online and have the ability to interact with the data to determine what caused failure, where the site is located, and historic performance. Capabilities also exist to automatically notify the appropriate party if severe maintenance problems exist (Scott 2004). ESRI, the leading provider of GIS software, offers ArcWeb services as well as ArcSDE and ArcIMS programs. These software systems are the basis for the WebGIS program.

From the initial descriptions, WebGIS seems to be an ideal visualization tool for the VDOT project. The system allows users to interact with data, uses the basic template that the Virginia Tech team has already created, and allows users access to the site from any computer that has Internet capabilities. The major drawbacks of online GIS programs as a whole are the cost and software complexity. Each software package is extremely expensive, over $1200 per year, and it is not feasible to upkeep the server and system. The programs also require a great deal of training and expertise in GIS software.

The online GIS option explored for this evaluation is Anderson & Associates’ WebGIS program. By using their program, the expense of purchasing the software and providing an Internet server is eliminated. A contract with Anderson & Associates will allow access to the software and servers, but the actual work and development will not be included. Employees of Anderson & Associates will simply provide guidance. Additional guidance and education can be obtained by taking the GIS Applications in CEE course offered at Virginia Tech. The WebGIS program has a great amount of potential, but the possibility for problems does exist.
VI. Actual Method of Investigation

The actual research process did not differ much from the proposed method of investigation. A flowchart of the project process can be found in Appendix A. As previously mentioned, the six main steps were:

1. Further research the potential programs
2. Obtain access to the necessary software
3. Learn the computer skills needed
4. Create templates with each program to compare the systems
5. Assess each program based on the rating criteria
6. Implement the most effective program

Research for this project began in the fall of 2004. The Virginia Tech team noticed the limitations of the current GIS output and began researching alternative options. Experts in visualization, specifically Edward Tufte, provided information on the effective use of space and data density. The second research component was simply to learn what GIS systems exist and how each of them work. Becoming familiar with the products, capabilities, and limitations was an important aspect of the project that had to be completed before moving on to other steps. One of the most important components of research was meeting with professionals at Anderson & Associates as well as with expert professors in the geography and GIS programs. The final component of research was looking at previous research projects and at current Department of Transportation projects. This allowed for brainstorming on how the elements of those ventures could be used to improve the VDOT project.

The second step involved obtaining access to the appropriate software. ArcExplorer is free and was easily downloaded onto the project computer. Map2PDF for ArcGIS also provides a free trial that was easily obtained, and the require ArcGIS 9.0 was obtained under the civil engineering ESRI license. An agreement was made with Anderson & Associates to create the template in WebGIS for no charge. Although there will be a charge if this option is chosen, access to see what could be provided was free.

The learning process was primarily trial and error. The primary "learning tool" was simply using the software, creating test templates, and reading the help menus. ArcExplorer is set up with similar features to ArcMap and thus was not difficult to learn. Yet, for someone without GIS experience, the program would likely seem confusing. Layton-Graphics offered a free web-demo of the Map2PDF software to aid in the learning process. This involved talking with a representative on the phone while he mirrored his desktop and walked through the creation process. The Layton-Graphics representatives were also very open to questions and concerns. The programming skills needed to create the Web GIS template are immense, thus Steve Spillane, a Anderson & Associates programmer, joined the project to aid in programming the specific tasks for the project. Several meetings with the Spillane aided in learning simple programming skills as well as they theory behind the program.

Creating the templates also came about by trial and error. The data was formatted into the appropriate form, projects were created with that data, and tools were used within the programs to optimize data interaction and usability. ArcExplorer is a very simple program and does not offer many
template options. Thus, the template was set up with the default tools. Map2PDF offers a few variations, but is a new product that is still being upgraded. The main decision for the Map2PDF template was how to reference the data. The options were to show the entire state of Virginia, show each section of interstate, or show the trend analysis. The decision was to incorporate both the interstate sections as well as the trend analysis. Web GIS offered the most options in creating a template. The A&A system has a default template that can be edited based on the client’s need. The query tool was chosen as the main means for data interaction. A hyperlinks section was also added to allow the user to access other relevant information. Many tools were assessed, and the ones that best serve the needs of the project were incorporated.

The five criteria previously mentioned were used in evaluating the templates. Upon investigation, it was determined that having a user-friendly, interactive program was more important than the cost or creation complexity. These considerations were taken into account with evaluating the programs.

The final step in the actual method of investigation was to implement the best program into the VDOT project. The 2005 data collection process was completed in September 2005. The implementation involved using this newly collected data, as well as the historic data collected since 2000. Section IX describes in detail the implementation process and challenges. The following section includes a snapshot of each template along with a description of the capabilities and limitations. Appendix B contains more printouts of the templates in varying situations.
VII. Description of Findings

Each of the templates created had positive and negative attributes, and each had strengths in different areas. Each program's template is described below with the positive and negatives of each explained.

Template 1: ArcExplorer

ArcExplorer has several useful tools as well as the potential for a nice visual display that can be seen below in Figure 6. The program includes identify, zoom, find, and query tools that allow adequate interaction with the data. The identify tool allows the user to click on any point to see the asset data base information for that segment. The query tool, shown in Figure 7 is also useful. Once setup, the visual display can compare data across the entire state, or the user can zoom to a specific section to see the data more closely. In the lower left corner, an overview map of Virginia will highlight the area that the user zooms to for reference. Each year is set up as a layer within the program, allowing the user to see historic data as well as the current year. This template could be updated before the end of the cycle as long as the crews provided the GPS coordinates with the sites. The final obvious advantage of this program is that it is free.

Although there are several useful tools, ArcExplorer is more difficult to use than it may seem. In the template shown above, all the data has been pre-set to show [BRUSH] data, meaning brush and tree control. If users want to see any other asset item, they must go to the properties menu, seen in Figure 8.
This menu requires knowledge of GIS to use. The user must first select the field, which is in a somewhat coded language and cannot be changed. Once a selection is made, the user must know if the asset item is a “Class Break” item or a “Unique Value” item; from here the user must select the number of classes and the color breakdown. In short, the data tools are useful if data is already set up, but selecting data is extremely confusing and complex for a non-GIS user. This display also does not have the ability to show the percentage passing for each section or asset item. Overall, ArcExplorer does provide tools that could be extremely useful, but if the user cannot set up the tool, it cannot be used.

![Figure 7: ArcExplorer Query Option](image)

![Figure 8: ArcExplorer Theme Properties-very difficult to use and necessary to set up data](image)

**Template 2: Map2PDF**

The second program evaluated is Map2PDF for ArcGIS. Figure 9 is a template for an individual section while Figure 10 illustrates a trend analysis template. The main advantage of Map2PDF is the familiarity of PDFs and the familiarity of the data format. Since the current method involves making PDFs of the data, those same templates can be used in Map2PDF, with the same ledged, scale, overview map, and data frames. In addition, almost all users are familiar with PDFs. The advantages that these geoPDFs have over regular PDFs are that the asset table is actually embedded in the file. This allows the user to see the available layers and turn them on and off. One layer in these templates is set up as the “comment” layer. This turns on a series of “post-it” notes for each segment in the map. As shown in Figure 9, a comment box will pop up with all of the segment data when the curser is brought over a segment. The templates can be set up to include or exclude any asset item in the original file. The proposed solution with Map2PDF would include 25 PDF maps; the 12 individual sections, 12 trend analysis maps, and 1 overall Virginia map. All of the maps would be linked together into one file and indexed. The user could move from page to page within the “Pages” tab on the left side. This is a huge improvement over the current 915 PDF maps created, and has the added benefit of having interactive data comments. Like ArcExplorer, this map could be updated within the collection process as long as the crews provide the appropriate information.
The main disadvantage of Map2PDF is that the user cannot query the data or view the actual percentage passing within a specific section. A search tool is available that allows the user to search for words within the comments, but it proves useless for this data set. Another disadvantage in Map2PDF is that the comment notes are limited to 1000 per PDF. Two sections within the project contain around 1500 segments, and thus need 1500 comments. The program did allow all the comments to be inserted,
but it greatly slowed down the computer. The professional version of this software is $995 for a full educational version. Although this is a reasonable price, it is a negative compared to ArcExplorer, which is free.

Template 3: Web GIS

The final template assessed is one created with Anderson & Associates using their Web GIS program. The template, Figure 11 below, was custom created, so it contains nearly every feature desired for this data. The overall visualization is similar to ArcExplorer with an overview map that can be zoomed in to see the individual interstate sections. The toolbar includes zoom, pan, identify, and measure tools. A quick zoom box allows the user to zoom to a specific county, district, or section. Below the Quick Zoom is a space that initially has instructions for the user. Once a segment is selected, the space is used to display the segment asset data.

The most useful tool on this template is the query tool on the left of the screen. This query allows the user to select the year and asset item they would like to display. Some data points are strictly Pass or Fail points while others pass based on a percentage set by VDOT. This template differentiates the two types of data and is set up to know if the asset item selected is a Pass/Fail or percentage item. Further, the template is set to know the VDOT requirement if it is a percentage item and will show this value as a default in the “% Results” table. The user has the ability to view Pass, Fail, NA, or any combination of these data types. Another strong advantage of this template is the “Required and Actual Rating” table below the query table. This box is linked to the asset tables to display the required value for each item and calculate the actual rating.

The final advantageous tool on this template is the “More Information” section. This hyperlinks section gives the user access to other related data. The old trend analysis PDFs would be posted to the Internet so they could be viewed from this page. Other links include the actual data webpage, VDOT webpage, an asset item index, and more. Since Web GIS is an online service, access is continually available. The data could be updated as it came in from the field. In addition, once the initial site is created, the data can easily be updated from year to year. The program is set up to automatically change when the asset data file is updated. This template also offers the option to enhance the system with time. Because the template is custom created, it can be changed to meet the user’s needs.
The major disadvantage of this system is cost. Although A&A allowed the template to be created without any charge, actual cost for implementation is significantly more than the other options. Despite the fact that the data would be updated and maintained by the Virginia Tech team, A&A charges $280 per month to serve the data and for the rights to use the software. This equals $3360 per year, over three times as much as Map2PDF for the first year alone. Upon discussion with A&A management, a deal was made to cut the price in half. This deal was possible because A&A is already involved in the project and is paid for their other work as well. The final contract cost for implementation would be $140 per month for the first year of the project.

The second disadvantage of the WebGIS program is that the trend analysis data cannot be viewed in parallel as it was in the old process. Although the user can check different years and view the data for that year on screen, the program cannot show all the years at the same time. The solution for this was to have the “Trend Analysis” hyperlink in the More Information Section and the PDFs for trend analysis will be created in the old way. The only other disadvantage of WebGIS is that the creation process requires a great deal of programming, yet this can be overcome.
VIII. Analysis of Findings

Using the previously referenced rating system, each progress was assessed for each criteria was assessed and given a score of poor, fair, good, very good, or excellent. Table 2 below summarizes the findings, while Table 3 includes descriptions of the assessment.

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<thead>
<tr>
<th></th>
<th>Ease of Use</th>
<th>Ease of Creation</th>
<th>Data Interaction</th>
<th>Visual Display</th>
<th>Cost</th>
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<tbody>
<tr>
<td>ArcExplorer</td>
<td>Poor</td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>Map2PDF</td>
<td>Very Good</td>
<td>Good</td>
<td>Fair</td>
<td>Very Good</td>
<td>Good</td>
</tr>
<tr>
<td>WebGIS</td>
<td>Excellent</td>
<td>Good</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor</td>
</tr>
</tbody>
</table>

ArcExplorer received a poor mark for *Ease of Use* and *Visual Display* because the data and display is completely useless if the user cannot set up the data. Although the program does have numerous visual tools, they cannot be used until the data is selected and put into the proper form. *Data Interaction* was given a rating of fair. The program does allow users to zoom, highlight, and query data, but it requires knowledge of GIS and cannot show the actual percentage passing. *Ease of Creation* was rated as good because no data needed to be reformatted and the previous files can be used, but all of the old steps will also have to be completed in order to have the data in the proper form. Finally, *Cost* is rated as excellent because the program is freely available.

Map2PDF was given a rating of very good for *Ease of Use* and *Visual Display*. This is because the interface is familiar and user-friendly. The user can also easily change layers and see comments. In addition, the final PDF would include a trend section and an individual section. *Ease of Creation* and *Cost* were given a rating of good. The creation process, like ArcExplorer’s, does not require rework of the data, but will still require the majority of the previous steps. The cost is reasonable. Because there is no query function and the comments are limited, *Data Interaction* was given a rating of fair.

WebGIS was given a rating of excellent for *Ease of Use, Data Interaction, and Visual Display*. The program is user-friendly, visually stimulating, and includes nearly every tool though to be useful for this data. The query function, hyperlinks, passing criteria, quick zoom function, and many more all allow the user to effectively interact with the data while showing an effective visual display. *Ease of Creation*, like the others, was given a rating of good. The initial template requires programming and expertise, yet once set-up, updating is easy. *Cost* is given a rating of poor because of the larger cost of serving the data.

Each program, ArcExplorer, Map2PDF, and WebGIS, provides improvements over the current process, yet the benefits provided differ. ArcExplorer would not enhance the current project because users would have difficulty understanding and using the program. Map2PDF does provide improvements over the current process, yet several limitations still exist. Essentially the Map2PDF program is the same as the current process, but the final PDF product has additional capabilities. The one component that would not be possible with Map2PD is having the passing percentages for each asset item visible. In the current process, these values are typed in, but that would not be possible with Map2PDF. The WebGIS
option unquestionably enhances the visualization of the data compared to the current deliverable and the only real limitation is the cost.

<table>
<thead>
<tr>
<th>Ease of Use</th>
<th>Ease of Creation</th>
<th>Data Interaction</th>
<th>Visual Display</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArcExplorer</td>
<td>-Difficult to switch asset</td>
<td>-No data reformatting needed</td>
<td>-Requires GIS knowledge</td>
<td>-Free</td>
</tr>
<tr>
<td></td>
<td>-Not user-friendly</td>
<td>-Need to complete most steps of old process</td>
<td>-Cannot show percentage passing</td>
<td>-Can be distributed on a CD for no software cost</td>
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<tr>
<td></td>
<td>-Cannot rename assets</td>
<td>-Can use previous files</td>
<td>-Can zoom or highlight</td>
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<tr>
<td></td>
<td>-Cannot change asset increments or preset pass/fail criteria</td>
<td></td>
<td>-Can query data</td>
<td></td>
</tr>
<tr>
<td>Map2PDF</td>
<td>-Interface of any Adobe PDF (6.0+)</td>
<td>-No data reformatting needed</td>
<td>-No query function</td>
<td>-$995 for Full Educational License</td>
</tr>
<tr>
<td></td>
<td>-Very User-friendly</td>
<td>-Need to complete most steps of old process</td>
<td>-Can turn on and off layers</td>
<td>-Can be distributed on a CD or posted to the Internet</td>
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<tr>
<td></td>
<td>-Can easily change layers</td>
<td>-Must convert to 9.0</td>
<td>-Can view data information</td>
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<tr>
<td></td>
<td>-Same format as old GIS component</td>
<td>-Effective training and easy to get help</td>
<td>-Limited digital space for information</td>
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<tr>
<td>WebGIS</td>
<td>-Easy to understand website</td>
<td>-Must rely on A&amp;A for programming help</td>
<td>-Very interactive</td>
<td>-Have to pay $280 per month to A&amp;A for serving the data on the website and for the rights to use their software and system ~$4000/year</td>
</tr>
<tr>
<td></td>
<td>-Very User-Friendly</td>
<td>Once set up easy to update</td>
<td>-Query, search, zoom</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Simple query for data</td>
<td>-Can use previous files</td>
<td>-hyperlinks to other data</td>
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<td></td>
<td></td>
<td>-Ability to improve upon</td>
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<td>-Can view data information</td>
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<td>-Visualizing</td>
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<td></td>
<td>Comparisons on multiple levels</td>
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<td></td>
<td></td>
<td></td>
<td>-Can show values</td>
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Table 3: Summary of Template Evaluation including comments

When all attributes are considered, the best program for this project is WebGIS. Though the cost is higher than the other options, WebGIS offers countless benefits over ArcExplorer and Map2PDF. ArcExplorer is not a feasible option because the data interaction is too difficult. Map2PDF could be an option, especially if ArcGIS can be used to include the percentage passing criteria for each asset item. Yet, WebGIS offers a great deal more interaction, data comparison, and information than Map2PDF can offer. WebGIS also has the ability to be enhanced in future years. Furthermore, the data on this website can be viewed and used by the public as well as VDOT officials. Communication of data with the drivers of Virginia is one goal of VDOT. WebGIS provides VDOT with an elite tool to communicate the data for the project and inform drivers of the maintenance state of the highways. Table 3 above summarizes this data.
IX. Implementation process

Once the WebGIS program was chosen, the next step was to integrate the program.

A. Process Overview

An official contract was written with Anderson & Associates for them to host the site. The contract states that the Anderson & Associates team will provide “a simple graphic user interface for public access” and will serve the data on their website. Virginia Tech’s responsibilities include providing all the mapping data in the appropriate shapefile format, providing updates of the data, and making the key decisions for the design capabilities and creation of the interface. The Anderson & Associates employees associated with the project will provide guidance and programming assistance.

During the evaluation process, a template was made for the site, yet the final version was created in the implementation phase. Anderson & Associates has a standard programming script that was used as the basis for the program. The standard script was modified and customized to create the final site. Though many tools and options exist, only those that proved useful for the project were incorporated into the site. Because the server technology is located at the Anderson & Associates office, all data updates were done there. Figure 12 below shows the final screen setup for the program.

![Figure 12: Final WebGIS Screen Design](http://example.com/final_screen.png)
The initial site included data from 2000 through 2004 for each asset item. The data had to be formatted into the appropriate shapefiles to be applicable for the WebGIS program. As Figure 13 explains, the site is based off one file that has all the GPS points for each of the 9000+ interstate segments. This file locates each segment within the state. Each year is then a supplementary file that is connected to the base file by the “Segment Number” identity key. Once the 2000-2004 data sets were added, the testing phase was entered to trouble-shoot any errors in the program. Several issues were resolved including consistency of asset table headings, location of key tools, format of query function, and errors in the base GPS file. These issues are discussed in more detail in the following section.

![Data Displayed with location](image)

**Figure 13:** WebGIS process for creating visual data from asset tables

After the 2005 data collection process was complete, this data was configured into the correct shapefile format and added as an additional pull-down item in the WebGIS program. More testing of potential combinations of data followed. The trend analysis PDF files were created in the same way that had been in the past and were added as a link to the WebGIS page. Once the site was complete and tested, a Users Guide was written with detailed instructions on how to use the document. This document is in **Appendix C**. A CD was sent to VDOT with the WebGIS URL link (http://arcims.webgis.net/ns/hwyinv/default.asp), the Users Guide file, and a copy of the Trend Analysis PDF maps. All of the processes for creating the shapefiles of data were documented in the form of flowcharts and systematic instructions. The flowcharts can be found in **Appendix D** and the systematic instructions are in **Appendix E**.
B. Problems Encountered

While the overall implementation of the WebGIS project was successful, there were several problems encountered in the process. The first problem was an inconsistency in the headings of the asset table files from year to year. For the program to work, the headings of the yearly tables must match the headings written in the script. This problem was easily fixed by changing the inconsistent heading in the appropriate files.

The next situation that arose was the realization that the values given as passing percentages in the WebGIS program were not consistent with the values in the yearly reports. After some analyzing the differences, it was concluded that the variations were only in the percentage passing asset items. The differences were in how the GIS system and how the reporting system account for the data. The reports count each individual asset item while the GIS system looks at each segment as a whole. One segment may contain several asset items, yet the GPS points are from the start and ends of each segment, so individual asset items cannot be indicated. Both processes are correct, but a disclaimer was added to the WebGIS site that explains the statistical differences. An explanation of the difference in the calculation method is shown in Appendix F.

After all the data from 2000 to 2005 had been formatted and entered in the program, a major problem was discovered. The base file with the GPS location points had multiple errors. The file should have each tenth-of-a-mile segment in order for each section with a maximum of four ramps for each exit. Yet, the file had segments out of order, overlapping, and missing completely. Since the WebGIS program is based off this base GPS file (see Figure 15), errors in the data were prevalent. The GIS department of Anderson & Associates originally created the file, but the personnel who created the file were no longer with the company. Research was done to determine how the mistake was made, but the data errors appeared to be random and were scattered across the state. The conclusion was to pan through each of the twelve sections in ArcMap, and recreate the data correctly. This involves using the Editor Toolbar to redraw, rename, or create the correct segments in the correct locations. Appendix G shows the flowchart of the process for correcting the base file. In addition to the errors in the mainline segments, all of the ramps in the base file were created incorrectly and had to be fixed as well. The final GPS file consists of 9497 segments, only 63 less than the entire asset density for the project. These 63 sites are located in mountainous areas were GPS points are not accessible.

Once the corrected file was complete, the 2005 data was merged with the corrected GPS locating file. Since the base file is what the WebGIS draws the location key from, the 2000 through 2004 data sets were automatically located to the correct segment in WebGIS, but each of these years had less data than the year before because less GPS points were known at the time of creation. The process of recreating the 2000 through 2004 files became the final exam project and is discussed in Section XI.
X. Future Implementations

One of the significant positive qualities of the WebGIS option is the flexibility of future implementation. Once the VDOT personnel have had a chance to use the program, feedback will be collected and improvements can be made. Hyperlinks can easily be added, new tools can be implemented, and future data sets can be linked to the base file and added to the current pull-down list. Developing a way to incorporate the trend analysis component without the use of PDF maps would also be a significant contribution to the overall project.

A second idea for improvement is to incorporate a notification tag that would send an email to the appropriate party if an emergency or time-dependent situation were found while crews are inspecting the interstates. This would involve linking the system with their field computer tablets. Though further research and study are required, the technology is available for notification tools to be implemented into the project.

Another development for this project is to link this WebGIS site to the overall VDOT “GIS Integrator Project” that they have received awards for creating. This would combine the asset management component of this project to the overall VDOT online system. Rather than having several sites with GIS capabilities, one site would be easier to maintain and simpler for users to use. The execution of combining these programs would require relationships be built with the VDOT department. Research would also have to be performed to determine if the two systems can be merged.

In addition to the future improvements that can be made to this project’s WebGIS site, this information can also be applied to other projects that Virginia Tech is involved with. As mentioned above, flowcharts of the data creation, connection, and implementation processes have been created. These flowcharts are not only applicable to this project, but have been written so they can be use on other projects as well. Jenni Gray, a Virginia Tech student pursuing a master’s degree in Civil and Environmental engineering is currently a member of the Virginia Tech Highway Maintenance Monitoring Program. She has been taught how to use the programs and has been walked through each of the flowcharted processes. Therefore, the future implementations go beyond the scope of this project and reach into future projects for the Virginia Tech team.
XI. Final Exam Project

As mentioned in the “Problems Encountered” section, recreating the 2000 through 2004 datasets with the corrected base file served as the final exam for this project. When the GIS component was initially added to the VDOT project in 2002, the data from 2000 through 2002 was merged with the GPS points that had been collected in 2002. Although there were many segments without GPS coordinates, the visualization was a general representation of the data. Each subsequent year more GPS points were collected and the data from that year was merged to the updated GPS coordinate file, yet the previous years were not updated. This resulted in each year having a more complete representation of GIS data than the year before.

Upon discovering the errors in the base file, it was decided to not only correct the data that was erroneous, but to actually “draw” in the segments that were missing. Most of the missing segment were between two existing segments, so the snapping tool was used to “snap to” the exact coordinate that had be collected. With the exception of the 63 sites that are in blocks and cannot be accurately created, this file is now a complete GPS base file for the entire asset density for this project.

With the complete GPS base file, each of the prior years (2000-2004) could be updated to reflect all of the available points, rather than just the points that were collected in up to the individual years. This increases the density of data present in the GIS visualizations. To recreate the data set, the performance data for each year was merged with the now cumulative GPS file. The process for merging and creating the data is the same as for the general process shown in Appendix D. The process was repeated five times, once for each year. Table 4 indicates the changes in the data density compared with the total number of segments inspected. The percent improvement is much more drastic for the 2000 and 2001 data sets because these were created with only the first set of GPS points. In 2004 and 2005, the change is minimal because most of the GPS points had already been collected. The data for 2002 actually decreased from the old file to the new file. This is due to differences in the asset density from 2002 to now. Over a hundred sites that were included in the asset density study in 2002 have now been taken out due to overlap or changes in the project scope.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Sites Inspected</th>
<th>Number of Old GIS Sites</th>
<th>Number of New GIS Sites</th>
<th>Percent Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>2303</td>
<td>1385</td>
<td>2100</td>
<td>31.05%</td>
</tr>
<tr>
<td>2001</td>
<td>2301</td>
<td>1407</td>
<td>2113</td>
<td>30.68%</td>
</tr>
<tr>
<td>2002</td>
<td>5605</td>
<td>5622</td>
<td>5414</td>
<td>-3.71%</td>
</tr>
<tr>
<td>2003</td>
<td>7106</td>
<td>6427</td>
<td>7078</td>
<td>9.16%</td>
</tr>
<tr>
<td>2004</td>
<td>7921</td>
<td>7770</td>
<td>7903</td>
<td>1.68%</td>
</tr>
<tr>
<td>2005</td>
<td>6944</td>
<td>6857</td>
<td>6942</td>
<td>1.22%</td>
</tr>
</tbody>
</table>

Table 4: Site Statistics with New GPS base file
The completed files were formatted into a shapefile within ArcMap and implemented into the WebGIS program. Figure 14 compares GIS data that is based on the old GPS file and on the new GPS file. As shown, the new file includes segments that were not present in the old file. The addition of the new segments makes the visualization more accurate and more complete. These base files will be used in subsequent years for the trend analysis component and in the WebGIS program.

![Comparison of 2001 Data with Original and Updated Base Files](image)

Figure 14: Comparison of data before and after base file change

An added benefit of this final exam project is that there are now formatted excel files for each year’s data that are all structured the same. Prior to this project, the data from 2000, 2001, and 2002 was formatted differently than the data for 2003, 2004, and 2005. The first step in recreating the data was to arrange the data from each year into a consistent format. These files have been saved and will be used in future years to reference the data.
X. Conclusion

This project answered the question, “To what extent can new GIS tools further develop the visualization and utilization of the transportation data currently collected for the VDOT project?” ArcExplorer, Map2PDF, and Web GIS, were all assessed on the same criteria to determine the benefits and disadvantages of each. ArcExplorer was found to be too difficult for user practicality and therefore not a benefit over the current process. Map2PDF was seen as an improvement, but still lacked several necessary tools. The conclusion was that WebGIS is the best program to be implemented into the VDOT project because of its extensive degree of interaction and user-friendly interaction.

In addition to the program evaluation, this project encompasses the implementation of WebGIS into the VDOT Highway Maintenance Monitoring Program. Though numerous problems were encountered, each was solved and the program is now successfully visualizing the data to anyone with Internet capability. All of the processes have been documented with reports and flowcharts so that the project can continue in future years. In addition to this project, WebGIS has the potential to benefit many future projects the Virginia Tech team is involved in. The benefits of this program are immense and are still being discovered as more people use the program.
References


Appendices

A. Project and Report Flowchart
B. Additional Template Pictures
C. WebGIS Users Guide
D. Data Creation Process Flowcharts
E. Data Creation Process Systematic Instructions
F. Explanation and Example of WebGIS Calculation Method
G. Flowchart for Recreation of Data