

An Integrated GIS Solution For Estimating Transportation Infrastructure Needs: A Florida Example

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Abstract

In 1991, one of the most important pieces of legislation in history was signed into law. The Intermodal Surface Transportation Efficiency Act (ISTEA) requires traffic monitoring and systems management monitoring of pavement, bridges, safety, congestion, public transportation facilities, and intermodal facilities. These systems call for coordinated efforts to collect, manage, analyze and store transportation related data. With these new requirements come opportunities to use existing technologies and resources to develop state of the art information storage, retrieval and management processes.

GIS-T (GIS for transportation) is one of the tools that will be used extensively in upcoming years to manage the information requirements of ISTEA. More specifically, GIS coupled with an integrated server-client based information system will become the standard, replacing many existing stand-alone, subgroup level applications that do not reflect the overall goals and objectives of an organization.

This report discusses two current model architectures proposed and developed for GIS-T applications (several other models are discussed in less detail). The first model discusses a four tier architecture integrating data, activities, information technology and people into one integrated information system. The second model delves into more detail by discussing 15 different integrated servers combined into one GIS-T server-client architecture. These two models provide a first iteration of GIS-T applications. This report discusses a second iteration framework combining both of the above architectures to be used by Department of Transportations (DOTs) and Metropolitan Planning Organizations (MPOs). This framework combines the ISTEA management systems with attribute data, spatial data, transportation models, transportation analysis tools, procedures and people into one integrated server-client framework. Finally, a real-world application developed in one of the DOT districts in Florida using concepts of the enhanced framework is discussed. This system seamlessly integrates an ArcView GIS application with a knowledge based expert system (KBES) programmed in Visual Basic.

In 1991, one of the most important pieces of legislation was signed into law calling for coordinated efforts to collect, manage, analyze and store large quantities of transportation related data. The Intermodal Surface Transportation Act (ISTEA) required traffic monitoring and systems management monitoring of pavement, bridges, safety, congestion, public transportation facilities, and intermodal facilities. With these new management systems came opportunities to use existing technologies and resources to develop state of the art information storage, retrieval and management processes.

One of the state of the art tools used considerably in this arena is Geographic Information Systems or GIS. GIS, integrated with a Transportation Information System (TIS), more commonly called GIS-T¹, make up the foundation for current and future transportation management systems. These

integrated systems will become the standard, replacing many existing stand-alone, subgroup level applications.

More complex database and GIS applications are being used to manipulate and manage large quantities of data. These applications are being used for congestion management systems, level of service (LOS) analyses, traffic count databases, pavement management applications, and roadway characteristics inventories, to name a few. The purpose of this paper is to discuss the design and implementation of a GIS-T application that manages and maintains data used to determine LOS, road improvements and road improvement costs. This GIS-T application was developed for both Metropolitan Planning Organizations (MPOs) and Departments of Transportation (DOTs). The application has been implemented within the Florida Department of Transportation (FDOT) and a MPO within the State of Florida. This paper uses as an example the implementation of the application for the FDOT.

Background

The GIS-T application was designed by considering first the needs and expertise of the end-user. Based on this premise, several application objectives were developed. In order to meet the objectives, the application should:

- be a truly integrated GIS-T application based on the definition of GIS-T,
- calculate LOS for an entire urban area or DOT district by individual roadway segment,
- determine necessary road improvements based on deficient segments,
- cost the improvements based on current construction, right-of-way, and preliminary engineering and construction inspection costs,
- perform all calculations based on accepted practices and procedures,
- be able to use data that currently exists within the State of Florida, and
- be as user friendly as possible and easy to maintain.

These objectives were used to develop the application outlined in the following sections.

Application Framework

Several GIS-T frameworks have been developed and implemented ranging from simple to more complex. The simplest framework includes only a database and a GIS application. Most complex frameworks involve client-server technology where as many as 15 servers may be used for various purposes.² The architecture chosen for this application can be considered to be medium in complexity and includes a GIS application and a separate, yet integrated TIS. The client-server framework was not chosen due to limitations in hardware in most governmental agencies.

The GIS-T framework chosen consisted of a GIS interface and TIS (sometimes called a knowledge based expert system or KBES³). This framework is illustrated in Figure 1. The most important feature about this framework was that both the GIS interface and the TIS interface had access to the same attribute data at the same time, therefore edits in one interface were carried over into the other. This eliminated the possibility of having two databases with different sets of data.

Application Design

After a framework was developed, the design of the application ensued. Figure 2 illustrates the general design of the application. As can be seen from this figure, ArcView (by ESRI) was selected as the GIS interface and Visual Basic (by Microsoft) was selected as the TIS interface. ArcView was selected since the roadway network obtained from the FDOT-Transportation Statistics Office (TSO), which is used by many agencies in Florida, was in Arc/INFO format. Also, ArcView is fairly easy to use and is widely used by the FDOT and local agencies within Florida. Visual Basic was chosen since it is easy to use and program. Visual Basic also contains the Microsoft Access database engine allowing it to handle large quantities of data efficiently and effectively. The integration of this application can be seen in the figure by the arrows going from the attribute data to both the GIS and TIS interface.

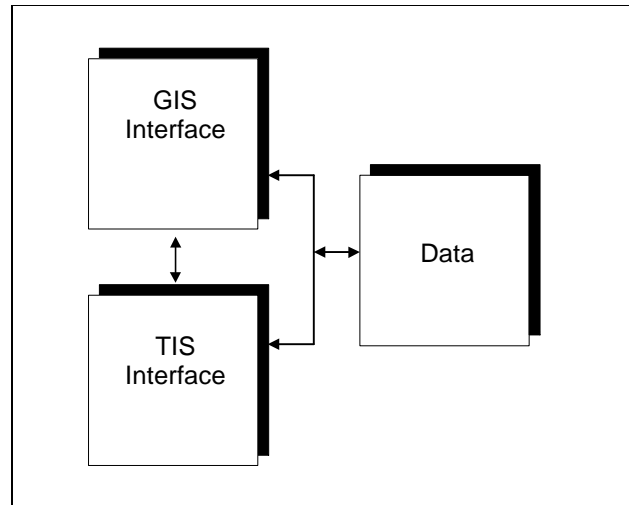


Figure 1: GIS-T application framework

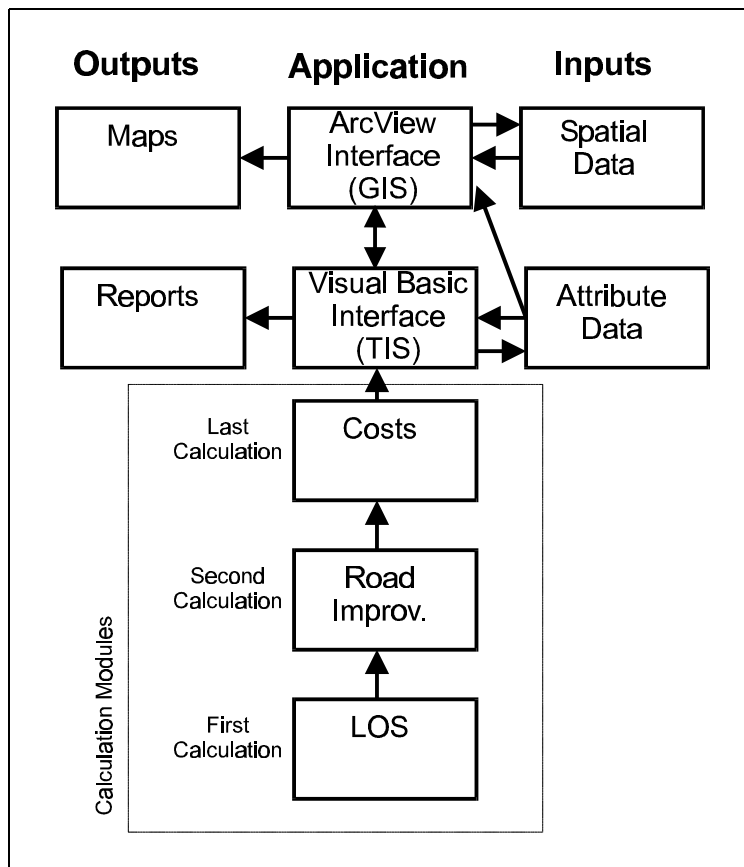


Figure 2: GIS-T application design

The calculations are included in the calculation modules section of the application. This module section can be considered like an electrical outlet in that new modules (such as future expansions to the application) can be “plugged in” with little or no disruption to the application. The calculation procedures are in order based on processing sequence. The LOS calculations must be completed first in order to estimate roadway deficiencies. After deficiencies are determined, the alternative improvements to mitigate the deficiencies are evaluated. Finally, after improvements are selected, they are evaluated for costs.

Methodology for LOS, Road Improvement, and Cost Calculations

The methodology for LOS used the procedures and guidelines outlined in the 1995 FDOT LOS Manual,

which was developed from the 1994 Highway Capacity Manual (HCM). The FDOT has developed table generating spreadsheets based on procedures outlined in the 1994 HCM that estimate maximum service volumes for each LOS possibility (LOS A, B, C, etc.). The maximum service volume can be defined as the maximum hourly rate at which vehicles can be reasonably expected to traverse a uniform section of a lane or roadway during a given period under prevailing traffic, roadway, and control conditions at a designated LOS.⁴ There are currently several different types of spreadsheets for facility type (arterials, freeways, and uninterrupted facilities) and area type (urban, transitioning, rural developed and rural undeveloped). Each of the facility types correspond to a chapter within the HCM. Each spreadsheet has the capability to analyze only one roadway segment at a time.

All of the spreadsheets were broken into components and re-programmed into the Visual Basic interface. An extensive quality check was done to ensure that the results from the application matched those of the spreadsheets and ultimately, the HCM. Each roadway segment record within the database had a field designating which LOS procedure (arterial, freeway, or uninterrupted) was used. From this, the program calculated service volume thresholds and compared the threshold to the actual peak hour volume on the roadway segment to determine a LOS letter grade. This letter grade along with the thresholds were stored into the database.

If a roadway operated below the LOS standard, the next road improvement that met or operated above the standard was calculated. For example, if a road operated at a LOS E and the LOS standard is D, the application found the next upgrade (e.g., a 2-lane to a 4-lane) that made the road segment operate at or above the LOS standard. Several assumptions were made during the upgrade process. For example, all of the improved roads were considered to be divided facilities with turnbays since this is common practice in the field assuming right-of-way is not constrained. Road upgrades were calculated by starting at the existing road type and progressing to facilities within the same class (e.g., arterials) with a greater number of lanes. If the maximum number of lanes was attained and the facility still operated below LOS standards, the next facility type with greater capacity was used. For example, if an 8-lane divided interrupted arterial did not operate at or above the LOS standard, the next upgrade would be a 4-lane uninterrupted facility. Eight-lanes were considered to be the maximum number of lanes for an urban arterial. It should be noted that the system does not take into consideration physical, policy, funding, or other constraints that may decrease the feasibility of an improvement. Therefore, careful consideration should be given to the outputs.

After improvements were estimated, costs were then calculated. The cost calculation included construction costs, preliminary engineering costs, construction engineering and inspection costs, and right-of-way costs. Figure 3 illustrates the general cost calculation procedure. The construction costs were estimated by obtaining a cost per centerline mile for the particular upgrade (e.g., 4-lane undivided to a 6-lane divided) as documented in *1994 Transportation Costs* produced by the FDOT Office of Policy Planning. This publication has generalized construction costs per centerline mile for several road improvement options. The preliminary engineering and CEI costs were taken to be a percentage of the construction costs. This is a common planning technique used within the State of Florida. Right-of-way costs were calculated by estimating the number of acres needed for the improvement and multiplying the acreage by the predominant land use cost (on the segment) per acre. The land use categories initially selected were residential, commercial and industrial. Although there are many different land use types, the three chosen typically repre-

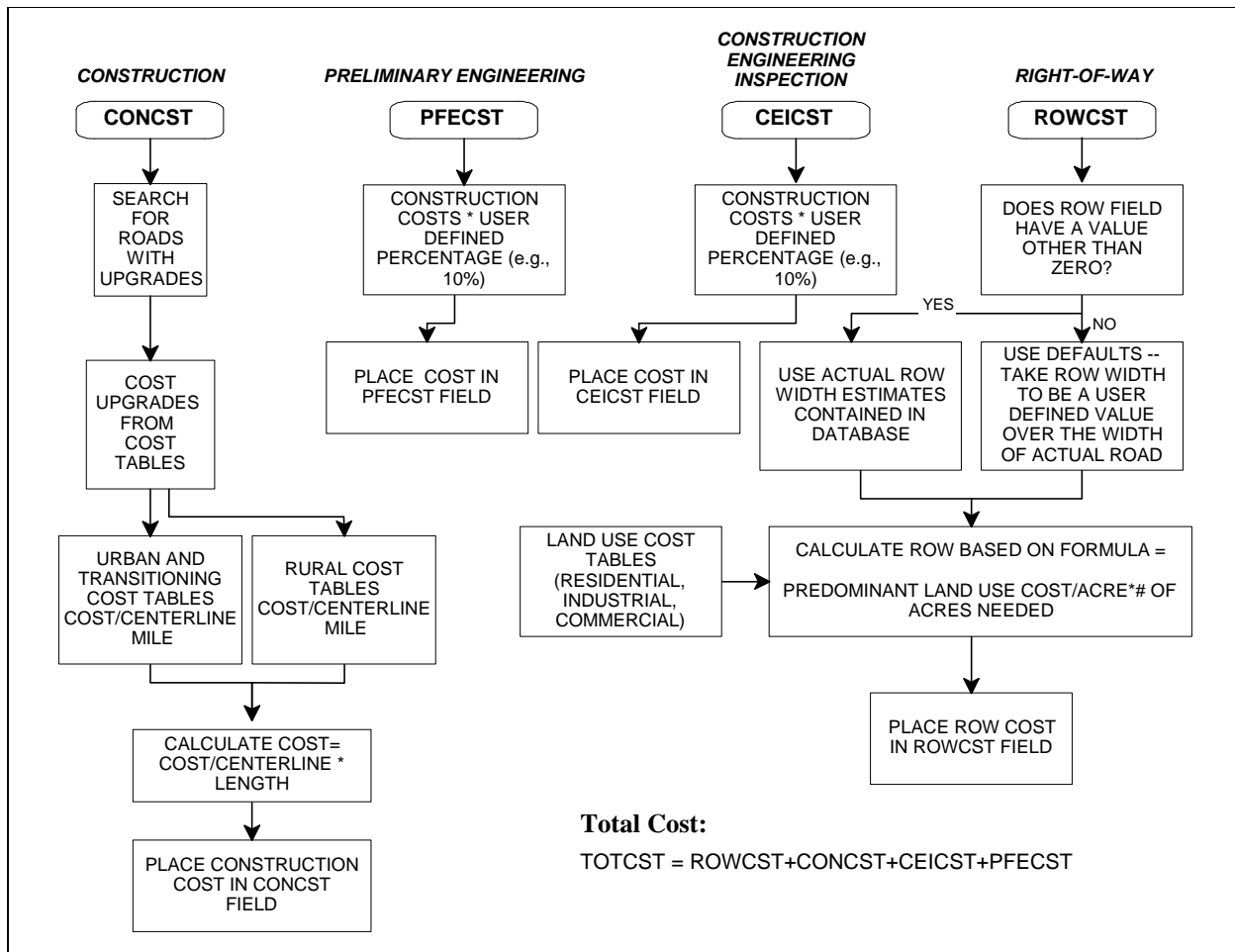


Figure 3: Cost calculations

sent the majority. However, further consideration should be given to areas with rural and urban areas. In these cases, land use categories should be added to reflect the difference within each area type. The right-of-way needed was estimated using a default cross-section width for each improvement or by actual right-of-way widths determined in the field. All of the costs were added together to estimate a total cost for the improvement per roadway segment.

User Interfaces

A graphical user interface (GUI) is the interface between the user and thousands of lines of programming code. The GIS-T application was designed to utilize GUIs for all of its screens. To minimize learning curves, the application only utilizes two main GUIs. The first GUI is the GIS interface and the second GUI is the TIS interface. Both GUIs are illustrated in Figures 4 and 5 respectively.

From review of Figure 4, it can be seen that two new menu items were added to the basic ArcView GUI: Transportation Analysis and Mapping. The menu item Transportation Analysis, when selected, executed (or loaded) the Visual Basic interface. This link made the application an integrated GIS-T application. The other menu item, Mapping, provided a fast, efficient way to create a map in ArcView. A series of questions were asked that when answered by the user, automati-

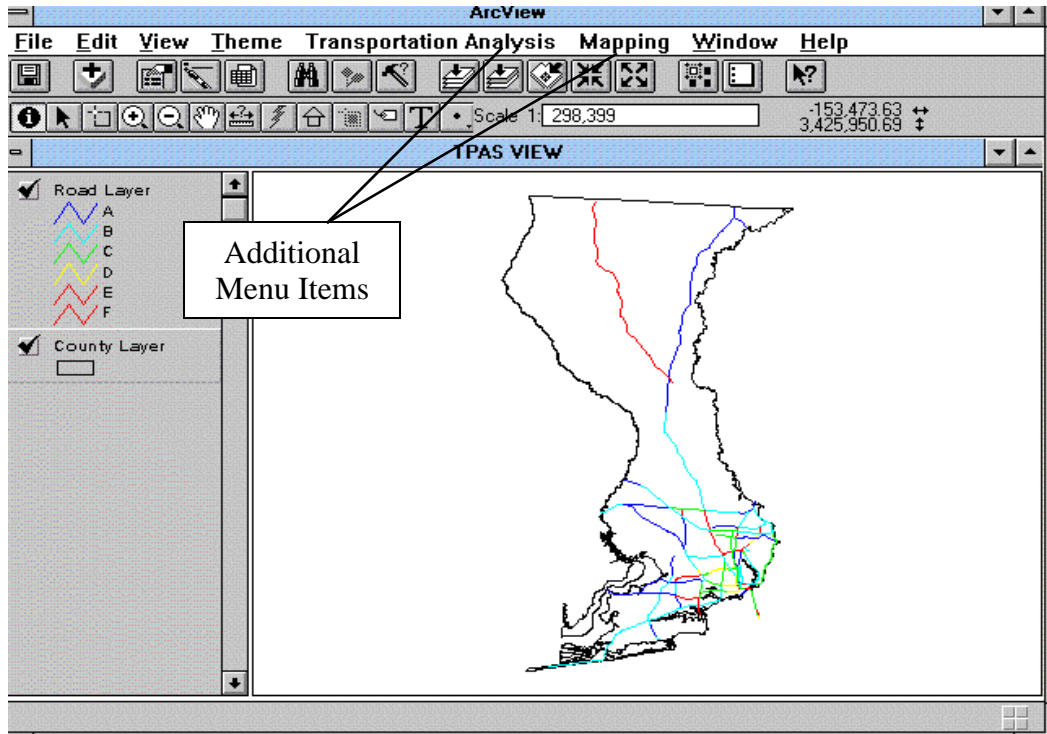


Figure 4: GIS (ArcView) interface

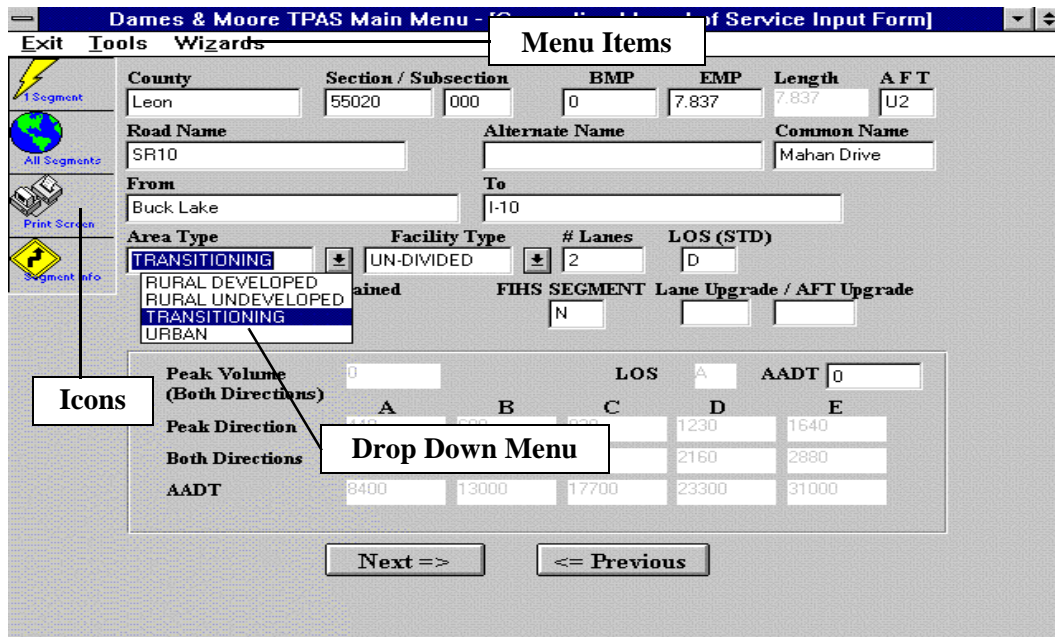


Figure 5: TIS (Visual BASIC) interface

cally generated a GIS map. A user who was not proficient in ArcView was able to generate maps quickly and professionally.

The Visual Basic interface contained three menu items: Exit, Tools, and Wizards. The tools' menu item contained several tools that performed various functions such as printing tabular reports and searching for specific records. The Wizards menu item contains two wizards: a LOS Wizard and a Data Warning Wizard. These Wizards quickly, easily and efficiently guided the user through processes that may be complicated for first time users. The Visual Basic interface contained all of the data for each segment. The LOS, road improvement and cost equations are calculated in this interface. Data were editable by entering the information directly or by clicking on drop-down menus as illustrated in Figure 5. One record at a time could be calculated or the entire database could be calculated at one time. The program took approximately three to five minutes to calculate 600 records on a Pentium based computer.

GIS-T Application Comparative Analysis

Implementing the GIS-T application for the FDOT involved collecting and analyzing data for approximately 600 roadway segments traversing 16 counties. The GIS-T application was not only used to manage FDOT data but was also used by the FDOT to verify the data and calculations used for long range plans developed for state roads by the local agencies. Considering this use, the newly developed application was validated by applying it to estimate improvements and costs developed for the *2020 Panama City Long Range Plan* completed in 1996.

This Plan was chosen since an integrated GIS-T application was not utilized during its development. Also, Panama City is one of the larger urbanized areas within the FDOT District that the application was installed. Data was obtained from the Panama City MPO and entered into the application. The data used for this comparative analysis reflected the data used for the development of the Plan except for future volumes. The Plan used 2020 model volume projections which were not obtained during this comparative analysis. Instead, historical growth rates were used to estimate 2020 volumes. This will introduce some differences between the improvement estimations, however, still will provide a good validation procedure.

The first element to be compared was road improvements. The Plan used LOS thresholds to determine road improvements. These thresholds were obtained from the FDOT *LOS Manual* using default input values for PHF, K-factors, D-factors, etc. Road improvements were estimated based on the next facility improvement that had a maximum volume threshold that was greater than the actual volume of the roadway. Only state roads were considered in this comparative analysis since the data obtained for state roads were more accurate than for off-system roadways. The results of the analysis concluded that out of the 26 roadway segments, the application estimated the correct road improvement 17 times, or 65 percent. Most of the road improvements not designated by the application were in rural areas of the county. This can be attributable to the fact that in most rural areas, adequate data is not available to determine traffic growth patterns. Therefore, the rural traffic counts used to estimate the 2020 volumes may have been somewhat inaccurate, thus introducing error in the future year volume estimates.

The second element to be compared in this analysis was cost of the road improvements. The methodology used to estimate costs in the Panama City Plan Update was different from what was used in the GIS-T application. The major difference was in the right-of-way costs. The Panama City Plan Update took the right-of-way costs to be a percentage of the construction costs depend-

ing on area type. In less developed areas, the right-of-way costs were taken as one-half of the construction costs. In highly developed areas, right-of-way costs were taken to be 125 to 150 percent of the construction costs. As mentioned earlier, the GIS-T application estimates right-of-way costs by first estimating the acres need for the improvement and multiplying it by a generalized cost of the most predominant land use adjacent to the roadway. A general cost per acre for all land uses in Panama City was used for this analysis. This data was obtained from the Panama City MPO.

Preliminary engineering and CEI costs were estimated in the Panama City Plan Update by using a variable percentage of construction costs. If the construction costs were less than \$500,000, 18 percent was used; between \$500,000 to \$2,000,000, 14 percent was used; and greater than \$2,000,00, 10 percent was used. As mentioned earlier, the GIS-T application also calculates CEI and preliminary/final engineering costs. For this analysis, CEI costs were taken to be 5 percent of construction costs and preliminary/final engineering costs were taken to be 10 percent of construction costs.

Construction costs used in the GIS-T application for this analysis were taken from the FDOT *1994 Transportation Costs* publication and from the Panama City Plan Update document. The comparative results concluded that the overall percent difference of the total costs was six percent. The largest percent difference was -59.3 percent and the smallest percent difference was 1.9 percent. Considering the two different methodologies used to estimate the costs, they were relatively similar. Most of the error was attributable to the variation in lengths of the segments. It was difficult to geographically reference the Plan Update network to a GIS. There were several inconsistencies with the lengths of the segments in the Plan Update and with the geographic file. Also, there were several roadway lengths in the Plan Update that did not correspond to the straight line diagrams. Variations in roadway length will affect the construction cost estimation, which will affect CEI and preliminary/final engineering costs. Also, the variable percentage of costs for CEI in the Plan Update also added to the variation in costs between the two methodologies.

Conclusions

This new application provided an efficient and effective alternative to current analysis techniques. This application transformed spreadsheets into a fast database program that was able to process hundreds of records in a fraction of the time. Also, this application provided an integrated geographic reference to easily map the data immediately after the database had been updated and recalculated.

This application can also be used as a tool to quickly and effectively develop or validate the highway element of long range transportation plans. From the Panama City example, it can be seen that the application can automate part of the long range transportation plan process and still be accurate. If model volumes had been used in the validation procedure instead of historical growth rates, the differences between the application and the Plan would have decreased further.

Considering the above, it was the conclusion of this research that the new application was an effective and efficient tool to be used in determining LOS, road improvements and road improvement costs. These procedures can be done as a stand alone process or as part of a long range transportation plan. Not only did it drastically reduce the time spent on tasks, but it accurately calculated road improvements and costs based on applicable procedures and guidelines. This application can free-up precious transportation agency resources to perform tasks of greater

importance. With the funding shortfalls of most agencies worsening, it is imperative that remedial or repetitive tasks are streamlined so that minimal resources are devoted to them. GIS and data-base management tools are the only effective way to streamline these types of tasks.

Future Enhancements

There are several enhancements to this application that will make it more effective. The following list several enhancements that are being further studied to improve the application.

- Transportation Model Interface - the application should have the capabilities to interface with the local (Florida) FSUTMS models as well as to TRANPLAN or MINUTP.
- Traffic Counts Database and Calculations - the application should have the capability to project, either by historical growth rates or model volumes, traffic volumes into the future to estimate long range needs. This should be completed automatically with the modeling interface.
- Multi-Modal Compliant - the application should be able to manage and maintain attribute and spatial data for multimodal features such as bicycle paths, sidewalks, transit, and park-n-ride lots. Queries and other reports should be produced showing this data.
- Road Improvement Alternative Selection Process - a prioritization procedure should be in place to estimate, after road improvement alternatives are estimated, which roadway segments should be improved first. The prioritization procedure may include levels of congestion, multimodal service, regionally significant roadway, etc.
- Internet Link for Public Involvement - an Internet link should be established illustrating goals and objectives, short-term, intermediate, and long-term roadway improvements, costs of needs plan, revenue shortfalls, etc. Since, this technology is changing rapidly, it is imperative that one constantly stays abreast of the latest developments.
- Linkages to Other Management Systems - the application should be able to share data between the safety, pavement and other management systems.

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