Development of a Map-Based Transit Itinerary Planner

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ABSTRACT

One of the challenges in promoting transit is the presentation of service information and the relative complexity of trip planning on a transit system. Geographic Information Systems (GIS) has provided a platform to present information over the Internet to potential users of public transportation. Itinerary planning using GIS consists of a user selecting an origin and destination on a map as well as the time of travel, which are sent to a routing algorithm that selects the optimum path along the bus route system. The program presents the output both textually and graphically, giving the user specific directions for using the public transportation system. This paper describes the implementation of a GIS-based itinerary planner for the SunTran bus network in Tucson, Arizona. ArcIMS was used to create a website that presents the city's bus network as well as other spatial information relevant to bus travel and the user's origin or destination. This system provides the users the option of selecting their origin or destination on the map, manually entering an address, or selecting a landmark from a pull-down menu. The routing algorithm then finds the optimum path, and the output is presented to the user both in text and on the map. This is unique from other itinerary planners because it provides an interactive point-and-click map feature that can be implemented using existing GIS software. The development of an itinerary planner using GIS on the Internet increases the simplicity of using transit and thus increases the attraction of using public transportation.

INTRODUCTION

Transit agencies have always struggled to attract riders in a highly competitive transportation market. Potential riders have a large number of options available to them that would encourage them to use other modes of transportation. One of the major problems associated with transit ridership is the presentation of information. Abdel-Aty (*1*) performed a survey of the effect of advanced transit information and stated that "About 38% of non-transit users indicated that they might consider transit use if appropriate transit information was available to them" (p. 276).

Recently, transit agencies have made their service information available on the Internet, using maps, schedules, and on-line automated trip planners. Radin et al. (*2*) provides an excellent report on the current state of the practice of trip planners. There have been several approaches to creating on-line trip planners. One of the more advanced applications is the introduction of interactive maps using Geographic Information Systems (GIS) software. This software provides functionality that allows for a map to be created and accessed that is personalized to the user's preferences and route choices.

There have been several researchers who have described itinerary planning systems and have recommended functions and features that should be provided. Trépanier et al. (*3*) indicate that the itinerary calculation process includes:

1) origin, destination, and circumstance specification
2) access and egress calculation
3) path calculation
4) schedule integration

When developing a trip planner, the developer must consider the needs of the user and provide the tools that allow the user to plan their trip using the same decision making factors that they would use without the trip planner. Several authors have identified some options that mimic this decision-making process. Huang and Peng (*4*) identify that important trip-planning options should include the shortest travel time, the minimum amount of transfers, the minimum fare, and/or the least amount of walk time. Donovan (*5*) recommends allowing the user to choose which mode they prefer and allowing the user to choose their maximum walking time.

Text-based Trip Planners

Many times the input and output of the trip planner is a text-based interface. The user enters his or her address at the origin and destination, and time requirements including the day of travel, in text fields. These time inputs can include the time at the origin or the time at the destination (*6*). The information is sent to the web server, which sends it to a routing algorithm. The completed itinerary is returned to the web server and back to the browser. This has been the state-of-the-practice of on-line transit itinerary planners since their evolution from call-centers (*2*).

Peng and Huang (*7*) recognize some problems associated with text-based trip planners. One major problem is that many times, the user either does not know the exact address of both the origin and the destination or the user does not enter the address correctly. Another problem is that sketch maps often do not provide enough detail or scale to be useful when attempting to plan a trip. Peng and Huang state that a solution to this problem is to allow users to pick their origins and destinations from pull-down menus and provide interactive maps during the itinerary planning process. This is reinforced by a large literature on human-computer interface design (*8*, *9*).

Map-based Trip Planners

To incorporate maps into this process, Smith (*10*) identifies the two major functions of a map-based trip planner. The first function is that the planner must make spatial decisions. This function requires that a planner find all of the nearby transit stops within walking distance of a desired origin or destination. The trip planner must also be able to make temporal decisions; that is, the planner must be able to link schedule times to the origin and destination as well as to determine a total trip time and maximum time allowed for the trip. Smith (*10*) identified the goal of a map-based trip planner is to minimize total trip time subject to spatial constraints, temporal constraints, and system constraints.

Peng and Huang (*7*) indicate that on-line, map-based trip planners have a 3-tier architecture. The first tier of the architecture contains a user interface on the web browser, which is the client-server tier. The second tier is a web server, which is the server tier. The third tier is an application server that contains a GIS application server and/or a database server, which is the application tier.

To date, there are very few map-based, interactive trip planners (*11*) (*12*), and none that use commercial off-the-shelf GIS tools. As a result, the objective of this research is to implement a GIS map-based itinerary planning website for a transit network using readily available software. This software can be adopted by public agencies integrated into their existing GIS websites. This website would contain functionality that allows users to point-and-click their location on the map. This paper documents the development of this website. The second section gives more detail to the design of the proposed trip planner. The data acquisition and development are discussed in the third section. The steps to create a basic website using ArcIMS with the available data are then outlined. The fourth section presents the different tasks performed to create the functionality and look of the basic ArcIMS package. These new functions are modifications of existing tools within ArcIMS that will aid in the usability of the site as well as create some functions that are essential to the implementation of the itinerary planner. In the fifth section, the routing algorithm is discussed and its connection to the website is presented. The modifications made to get the final display and functionality of the website are also presented. Finally, the sixth section offers conclusions and recommendations to improve the performance of the website.

SYSTEM DESIGN

The goal of this system is to provide the transit rider with an interactive, easy to use, powerful trip planning application on the Internet. This system must be GIS map-based to provide interactivity, the tools must be intuitive and easy to use, yet it must include powerful GIS functions to perform the analysis. This section will give an overview of the design of the user interface and the functions that must be included to meet the goals of the project.

Display Properties

Since most GIS software contains a large amount of complex analysis tools, many of these tools must be eliminated if they are not needed, or simplified, so that the user can easily use them if they are unfamiliar with GIS software. When designing the display of the system, consideration must be made to determine what cartographic information should be presented that is relevant to trip planning. The two types of cartographic data that are included in the map are landmark data and intermodal data. The intermodal data contains map features that would aid in the orientation of the users. The user can also determine what modal options they have inside or outside of the transit network. The landmarks are provided to show the user points of interest or large trip generators served by the transit network. The landmarks can also aid the user in orienting themselves on the map. Overall, all features of the map must have some purpose that will aid the rider when determining the trip plan.

Routing Algorithm Requirements

When developing the trip planner, one important element in the design is to determine what input from the GIS is needed for the routing algorithm and then decide how to provide the data to the routing algorithm. In the proposed routing algorithm, it is necessary that the user enter an origin, destination, and time of travel. More specifically, the algorithm requires that the user enter in unique locations, in the form of land parcels, addresses, or landmarks, as origins and destinations. The GIS analysis must then deliver nearby bus stop identifiers to the routing algorithm.

Key Functions

When deciding how users will determine the origin and destination bus stops, the developer must provide the options that the rider normally uses when planning a trip. Many people desiring to use transit either know the address of their origin or destination, or they know the name of a large landmark where they would like to leave from or go to. However this does not constitute all of the ways that a transit rider would plan a trip. Many riders plan trips by looking at maps and identifying their approximate location based on street intersections or other orientation landmarks. From that point, they decide which bus route to take. In the case of this project, all of this functionality for identifying the origin and destination bus stops is included: an address search function, a landmark search function, and a function that allows the user to click any point on the map. The features on the map that must be included for all of these functions are the individual land parcels, so the user can search addresses and landmarks. Since the parcels contain a fairly complete coverage of the area, this feature can also be used for the point-and-click functionality.

Figure 1 displays the series of events that occur when a user runs this application. Upon opening a web browser, the user is able to choose their maximum walking distance from a pull-down menu. The user then has three options to select the trip origin and destination. If the user knows the address or landmark, he or she can enter that into the appropriate field, and the GIS system queries that feature in the parcel database. Once the feature is found, it is selected on the map and the buffer GIS tool finds all of the bus stops within the maximum walking distance. Those bus stops are then sent to the routing algorithm.

If the user does not know the address or landmark, he or she can utilize the point-and-click capability. With this feature, the user can simply click a point on the map and the address of the selected parcel will be displayed in the field. When they accept that location, the system identifies the same buffer around that parcel and the bus stops are sent to the routing algorithm.

The final input required by the routing algorithm is the time of departure. This information can simply be input by using a form with fields indicating the time, whether the rider is traveling in the morning or afternoon, and whether the rider is traveling on a weekday, Saturday, or Sunday. These variables are required to accomodate variations in the local transit agency's (SunTran's) schedule. All of this information is sent to the routing algorithm, and the routing algorithm returns an itinerary to the viewer, in the form of text directions and a highlighted route map.

The main function of this website is to provide an interface that can be accessed through a standard web browser, allowing everyone who has Internet access to use the system. It is also designed to provide all of the functionality of the system through a single, easy-to-use interface. All of this functionality is provided by modifying the tools of existing GIS software to create a custom application.

Insert Figure 1 here

SOFTWARE AND DATA REQUIREMENTS

The software used for this project was ArcIMS (Internet Map Server) distributed by the Environmental Systems Research Institute (*13*). ArcIMS provides the functionality to present GIS information on the Internet or an intranet, allowing users who do not have GIS software or who are not familiar with GIS operations to use the system. For this application, ArcIMS is implemented over the Internet using a simple browser interface. This interface must be powerful enough to perform complicated analysis yet simple enough to be accessed by individuals with limited experience with computers. ArcIMS provides a simple interface with potential for customization that will allow both users and developers to easily use the system. On the development side, ArcIMS consists of three components: Author, Administrator, and Designer. Author allows the developer to design maps, using spatial data; Administrator allows the developer to create a service to send those maps to a browser; and, Designer allows the developer to customize the browser interface.

In a GIS-based itinerary system, spatial and temporal decisions are required and likewise, spatial and temporal data are required to make those decisions. The spatial data required for this project are shapefiles with associated database files. The temporal data required are schedule data for the bus stops. With these data, the GIS software, and a routing algorithm, an itinerary planner can be developed.

Spatial Data

The data used to create the map was developed by Pima County for the Pima County Land Information System (PCLIS). This system was prepared by the Pima County Department of Transportation and the data was compiled from various federal, state, county and municipal agencies. The files provided by the PCLIS are in ESRI's shapefile format. All of the shapefiles used can be categorized into three groups: those required for routing functionality, those complimenting an intermodal transportation network, and those landmarks that might aid in the use of the program. The shapefiles for these data are listed below.

Temporal Data

The other major component of the trip planning data is the temporal data. Schedule data is an essential component of the trip planning system. The schedule information gives the departure time at each time point, along each route, for each run. There are no schedule data available for the intermediate bus stops between time points. For this reason, the preceding time point is used when determining a passenger's departure time from the origin, and the subsequent time point is used when determining a passenger's arrival time at the destination. The schedule data for each route are in Excel spreadsheet format and can be accessed directly by the routing algorithm.

DEVELOPING A CUSTOM WEBSITE

To develop a website using ArcIMS, the developer must go through the three stages of site development. The steps within ArcIMS are:

1) ArcIMS Author-develop an initial GIS map
2) ArcIMS Administrator-create a map service using the map created in Author
3) ArcIMS Designer-create a web browser interface in which to display the map

This section discusses the development of the basic SunTran GIS website using the ArcIMS software package.

Authoring a Map

The first step of developing a website is creating a map using Author. This is the step that allows the most customization of the map display. Once all of the shapefile data are collected, the desired layers are added to the map, and displayed on the map and in a list. The layers are essentially stacked on top of each other; because of this the developer must take care to order the layers to avoid obscuring an important layer. There are also many view attributes that can be associated with each layer that change the visibility of the feature. The features can be displayed at different scales so that there is minimal clutter at a large scale, and as the user zooms in, more detail is shown.

Besides visibility, the order of the layers defines some of the parameters of the website. For this custom application, the user will not be able to change the "active" layer. For example, the default active layer is the first layer in the Author layer list. This project contains 15 shapefiles that are ordered according to desired visibility. Those shapefiles, in order, are:

- Parcels
- Bus Routes
- Bike Routes
- Major Streets
- Minor Streets
- Bus Stops
- Park & Ride Lots
- Public Trails
- Schools
- Post Offices
- Parks
- Malls and Colleges
- Libraries
- Lakes
- Hospitals

Once these layers are added to the map, the map is made into a map service through Administrator. For this application, an additional overview map was created displaying only the bus routes layer; this was added to simplify presentation of the bus network. This can be seen in **Figure 2**.

Insert Figure 2 here

Administering a Service

The next step for the creation of this website is to create map services. This step is done through the Administrator component of ArcIMS. In the case of this website, two map services must be created: one for the main map and one for the overview map. After these map services are administered they can be accessed by the web server and displayed on a web browser. The next step is to develop a website that can reference these map services and display them within a general web browser.

Designing a Website

Developing a browser interface that displays the map services is done through the Designer component of ArcIMS. The developer must choose the map service that will be used in the website. The HTML browser only allows one map service to be used in the main map display. Separately, the HTML browser can include the overview map as well. See **Figure 2** for a display of the main map and the overview map. One of the goals of this project is to make a powerful yet simple interface in which a user, who has no GIS experience and does not understand the use of GIS tools, can easily navigate through the system without confusion. Because of this, we have to customize the interface to eliminate or combine some of the advanced GIS tools so that the user only needs to perform the least number of steps. The customization of the interface is described in the following section.

CUSTOMIZATION OF THE WEBSITE

The GIS interface provided by ArcIMS is very powerful but is also too complicated for the average Internet user. This project therefore requires that the interface be simplified in such a way as to provide all of the functionality required for the trip planning application, yet not so complicated as to discourage use of the system. The simplification must occur in the interface of the browser as well as the functionality of several of the tools provided by the software. The first part below describes the layout changes in the viewer, including the moving, resizing, creation, and elimination of several frames. The second part discusses the changes in the tools that are provided by ArcIMS.

Interface Customization

The interface of the software provides some features that could be confusing to a casual user and might discourage use of the system. As shown in **Figure 2**, the original viewer contains three columns: the toolbar frame, the map frame, and the table of contents frame. The toolbar and the table of contents frame have fixed widths and the map frame fills the remaining width of the screen. The viewer also contains three rows: the title frame, the map frame, and the bottom frame. Again, the title frame and the bottom frame are fixed and the map frame fills in the remaining height of the screen. The text frame is contained within the map frame and is a fixed height. The map fills in the space above the text frame.

In order to make the website more user friendly, several of the frames were moved to aid in the simplicity of the interface. Several of the frames had little meaning to a user with no GIS experience so these were moved or modified to maximize the size of the map. A color-coded legend was included to ease the use of the map. Many of the tools were also taken out of the toolbar that are not relevant to the functions of this website. The toolbar icons were also changed to text to be more intuitive to a casual user. Finally, a simple HTML frame was included that contained all of the input fields for the user of the system. See **Figure 3** for a display of the modified viewer.

Insert Figure 3 here

Tool Customization

The main function required from the GIS software is determining the location of the bus stops surrounding the user's origin or destination on the map. In this case, since the user is looking for addresses, landmarks, and points on the map, the parcel layer is set to be the active layer and all of the analysis tools are used on the parcel layer. In order to provide the point and click functionality that is desired, the *Buffer* tool was used to find bus stops. Because of its complexity, this tool was modified in such a way as to automatically execute the buffer when the *Select by Rectangle* tool was used. The select by rectangle tool functions with a point-and-click, or it can be dragged to select everything inside of the rectangle. Once a parcel is selected, the address of that parcel is input into the user display. The user can then go to the next step or reselect a different parcel.

Since the only feature that the routing algorithm needs is the bus stops, the bus stops layer is chosen as the highlighted feature for buffering. The user is given the option of choosing an acceptable walking distance and the bus stops within that distance are selected. The display shows the highlighted parcel surrounded by a circle with a radius of whatever walking distance the user has specified. Within this circle, all of the bus stops are highlighted, and the resulting list of bus stops is displayed to the user.

A similar technique is used for the option of the user to enter an address or select a landmark. Instead of using the select by rectangle tool, the user can take advantage of the query tool. With the modified interface, the format of the query is automatically generated so that the user does not have to develop a query on their own. In the case of entering an address, the user enters his or her exact address in the field. The system then queries the address field of the parcel database for an exact match of that address. A similar function is performed for the landmark option. The user selects the radio button indicating that he or she wants to search for a landmark from a pull-down list. The pre-defined query then searches the landmark field in the database for a match of that landmark. So, the user will either enter an address or pick a landmark and go to the next step. At this point, the buffer tool is immediately run and the surrounding bus stops are selected. Again, those bus stops are used in the routing algorithm as potential origins and destinations.

ROUTING ALGORITHM

Transit routing algorithms are very different than standard street network algorithms. The main reason these algorithms are more complex is because they generally operate on fixed routes rather than standard street networks, as well as the complexity of the schedule timing, especially in the case of transfers. The scope of this project is to develop a map-based system that connects with a back-end routing algorithm and presents the results of that algorithm to the user. Therefore, the main focus of this project is to provide the existing routing algorithm with the information that it needs to find the shortest path, and, once the path is found, to present the path to the user. This section will briefly discuss the operation of the routing algorithm as well as the output of the routing algorithm and how it is displayed to the user as an end product.

Project Routing Algorithm

The itinerary planning algorithm of Hickman (*14*) was used for this application; a brief summary is provided here. This is a forward searching algorithm. It finds the shortest path between sets of bus stops, starting at the origin at a certain time and working toward the destination. It does this by tracing a minimum possible time path from node to node along the transit network; these nodes are time points in the SunTran schedule. If the system cannot find a path to the destination bus stop on the same route as the origin, it then looks for a transfer node. The transfer nodes are also schedule time points serving several routes. Once the algorithm finds a transfer node, it begins performing a similar search along the new route toward the destination. The algorithm repeats this process until it finds a path to the destination bus stop.

Once the algorithm finds a minimum possible time path from the origin to the destination, it must go through the process of finding the optimum path based on the travel times on all possible route combinations. All routes are considered and those routes with the possibility of having the minimum travel time are selected. If a transfer is considered, the optimum route would include the transfer that allows the rider to arrive at his or her destination at the earliest possible time.

This routing algorithm gives the user the option of determining whether to determine the optimum path from the schedule data or from historic arrival data. The historic bus arrival and departure data is used to find the optimum path based on the total trip time as well as the probability of the passenger arriving at the destination by a particular time. In this way, reliability of service can be considered. Alternately, the user may choose to use the schedules directly in finding a path. The user then has the choice to choose the deterministic schedule-based shortest path or the non-deterministic, reliability-based shortest path.

Data Input

For this routing algorithm, the data input required is the time point that the rider would like to board and the time point that the rider would like to alight. SunTran only has schedule information for the time points. Between each time point can be several intermediate bus stops. The problem with the existing system is that the bus stops within the buffer distance of the origin or destination parcel are found and many of those bus stops that are found are not actually time points for the routing algorithm. Therefore, there is no way to reference the intermediate bus stops when they are selected from the map. Rather, a text file was developed that contains each route in the network and the bus stops that the route serves, in order of service. From this file, a column is made for each bus stop, referencing the immediately preceding time point and the immediately following time point.

When a bus stop is selected using the map-based system, the nearest time point is referenced. In the case of the origin bus stop, the nearest upstream time point is found. In the case of the destination bus stop, the nearest downstream time point is found. The program then runs the routing algorithm. By using these time points, the algorithm delivers a conservative itinerary. However, since the time taken for a bus to traverse between time points is often rather small, this overestimation should not make a large impact on the overall travel time.

Data Output

The output of the routing algorithm must be presented to the user in a manner that is clear and easy to understand. Once the routing algorithm has determined an optimum path between time points, the application lists the arrival time at the originating time point, and the probabilities of the bus arriving at that time. It also lists the transfer nodes that are required and the bus stop where the rider will alight. For this, the process of sending bus stops to the routing algorithm is reversed as the time points are delivered from the routing algorithm to the bus stop. From the time point in the routing algorithm, the system finds the actual bus stop number from the group of bus stops that the user originally selected. The name of the intersection where that bus stop exists is sent to the display and presented to the user. This is done for the origin and destination bus stops as well as the transfer points in the itinerary. The time that the bus arrives at each of those stops is also displayed. Presenting this information gives the user complete and specific directions on where to go to catch the bus, what time to arrive to catch the bus, the location and time of transfers, and the location and time of arrival to the destination.

Map Display

The map display is one of the unique features of this application; it includes a display of a personalized map of the highlighted transit routes that will be taken. This highlighting process is done by using the existing functionality provided by ArcIMS. The query tool automatically highlights all of the features that have been queried. The query is run on the bus routes and they are highlighted on the map. **Figure 3** shows the final output screen, displaying the map and the text directions to the user. The user then has the option to zoom to those bus routes to determine the path that it takes and present useful information to the rider about where to transfer and in which direction the buses will be going. It also provides a spatial representation of the length traveled by each leg of the trip.

Overall, this application performs the appropriate function of finding those bus stops within a predetermined distance from a parcel and converting those unique stop identification numbers into a format that could be used by the routing algorithm. The routing algorithm then finds a set of optimum routes based on the total travel time, and, if desired, the reliability of the travel time. The route is delivered to the user in text format and the routes are highlighted on the map. This map gives the user the same functionality as the original interactive map; the only difference is that the routes are highlighted, giving the user the option to identify landmarks nearby the origin, destination, or along the route.

CONCLUSIONS AND RECOMMENDATIONS

Transit has been attempting to overcome tremendous obstacles to become a viable transportation solution in many urban areas. One of the major obstacles associated with transit is the complexity of trip planning. The goal of this project was to use and modify existing GIS tools and software to create an on-line map-based trip planner for the SunTran transit agency of Tucson, Arizona. This trip planner contains much of the functionality that is currently available in the state-of-the-practice websites, but it also contains an interactive map. The interactive map also provides the functionality to point-and-click a location for the origin and/or the destination, thus eliminating the need for the rider to know exact location information. The trip planner also includes a routing algorithm incorporating service reliability, using historical route performance data.

System Development

One of the main objectives of this research was to develop this system using only the tools that are provided within the readily available GIS software. This would aid future developers of similar projects by simply using a customized application of an available software package. In the case of this project, ArcIMS 4.0 was used. This application was developed beginning with the standard steps through which to create a GIS website in ArcIMS, but the interface had to be customized to make it more intuitive. Many of the tools that allow the user to change settings were removed and many of the tools were automated. For trip planning, a new input frame was added to allow the user to select their origin, destination, and desired departure time and sends those data to the routing algorithm. The routing algorithm finds the optimum path and sends the output to the browser, in the form of text-based directions and a highlighted route map.

Potential Improvements

This project was developed as a prototype of a trip planner that could be implemented by transit agencies. There are several issues related to performance and user features. The main problem with the existing system is that the processing time to perform one trip calculation is rather slow. Most of the processing occurs on the server, so increasing the processor speed and efficiency of the server would increase the processing times of each of the steps. The current server is operated on a Windows NT operating system with a Pentium III 600 MHz CPU and 128 MB RAM. An upgrade in this server would surely improve the processing speed of this application.

Much of the processing speed issues revolve around the very large parcel file that must be visible for many of the functions to work, particularly the point-and-click function. This results in the slow generation of thousands of polylines every time the map display is redrawn. Also, the processing time increases as the zoom level increases for many of the tools. Finally, because of the large number of parcels, a lot of time is spent querying the parcel database for an address or landmark.

One of the tools that takes the most time to use is the buffer tool. When an address or landmark query is implemented, the program directly queries the parcel database for those text strings. Once it finds the text string, it creates a buffer around that feature and finds the nearby bus stops. This is a rather quick process because it does not require that the parcel layer be visible and it does not display the selected parcel, buffer region, and selected bus stops on the map. When the point-and-click function is used, the parcel layer must be visible, and when that parcel is clicked, the program performs a buffer and displays the buffer region with the bus stops.

This is useful and interesting output, but it takes a long time for the buffer function to perform and the map to regenerate. A more practical solution would be to select the bus stops surrounding a point on the map directly, without first clicking a parcel. In fact, it would be optimum to not even display the parcel layer so that the navigation of the map could be quicker. This can be done by setting the active layer to bus stops and developing a function that sets the pixel tolerance as a function of scale. With a high pixel tolerance, the user can select any point on the map and the program will find any bus stops within that specified pixel tolerance to the cursor. This eliminates the need to display the parcel layer at large zoom levels and greatly decreases the map regeneration time.

There are some improvements that could be made to enhance the user features. One improvement would be to provide an alternative text based trip planning site that is accessible to those with visual impairments who utilize screen reading software. This could be an alteration of the existing site, prompting the user to use the text based fields only, or it could be a completely alternate website that executes the routing algorithm with only a text-based interface.

Some improvements can also be applied to the routing algorithm. Many users are interested in different search parameters when determining the optimum path. The current algorithm is forward searching, meaning that you enter a time to leave and it starts at the origin and finds a path to the destination. People might be interested in a backward searching algorithm or a minimum transfer algorithm. These capabilities are currently being added to the system. It would also be beneficial to incorporate a routing algorithm to provide walking directions.

Another optimization that could be included is a more detailed map output. Currently the map simply has the routes highlighted that will be used. A more desirable output would be to highlight the route from the actual origin to the actual destination, graphically displaying relevant bus stops and transfer nodes as well as relevant times along the route.

All of these improvements have great implications. The current system has some limitations, mostly with processing times, but it is a successful prototype and provides exceptional functionality that is rarely found with other on-line trip planners. This trip planner provides current state-of-the-practice functionality with its text-based search capability, but it also includes a point-and-click functionality that is very rare with other trip planners. By optimizing some of the functions, display attributes, and layers, this system could be a robust itinerary planner for SunTran transit agency and it could be easily adapted to other transit agencies as well.

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LIST OF FIGURES

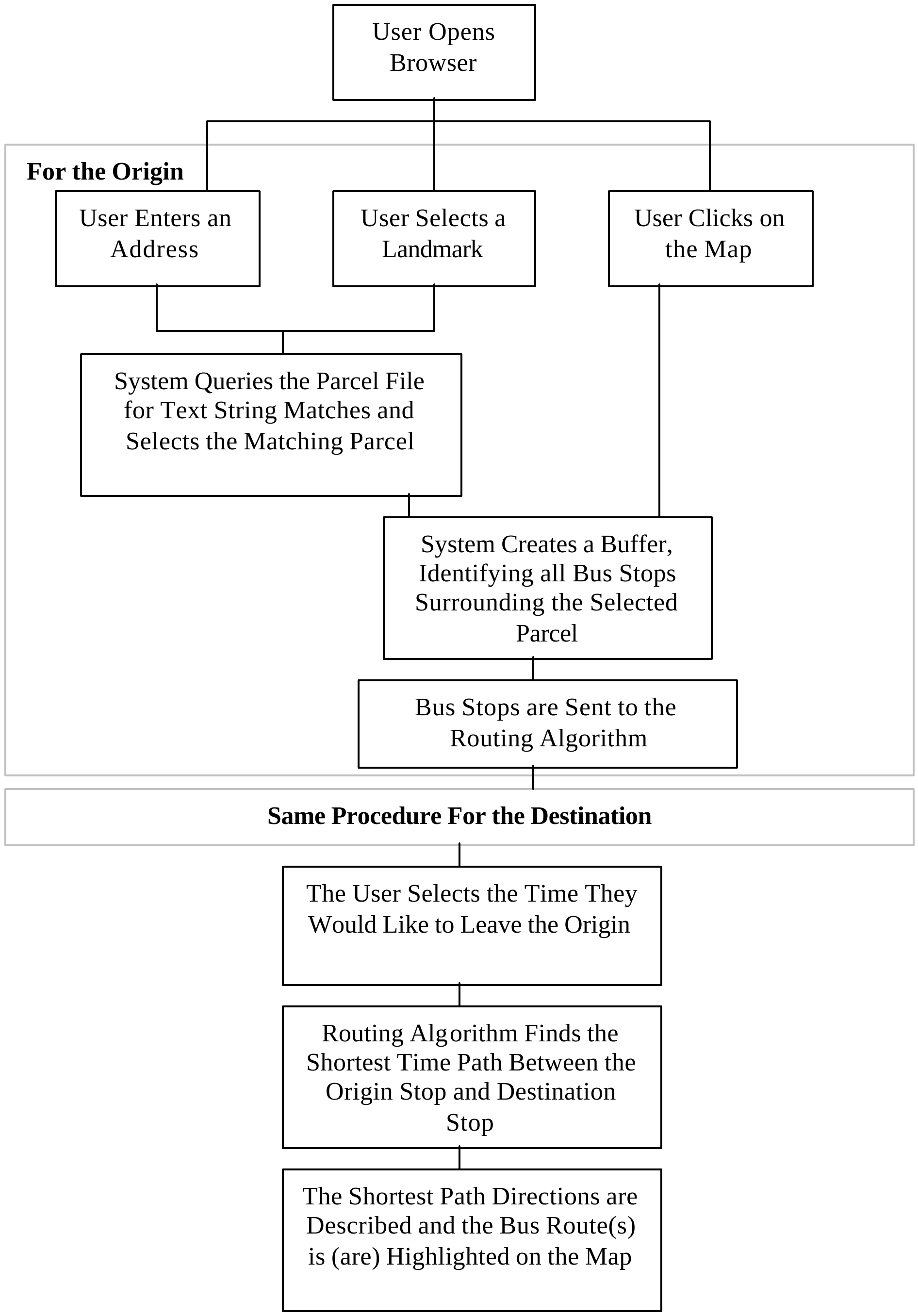

FIGURE 1: Flowchart of Events Required for the Trip Planner

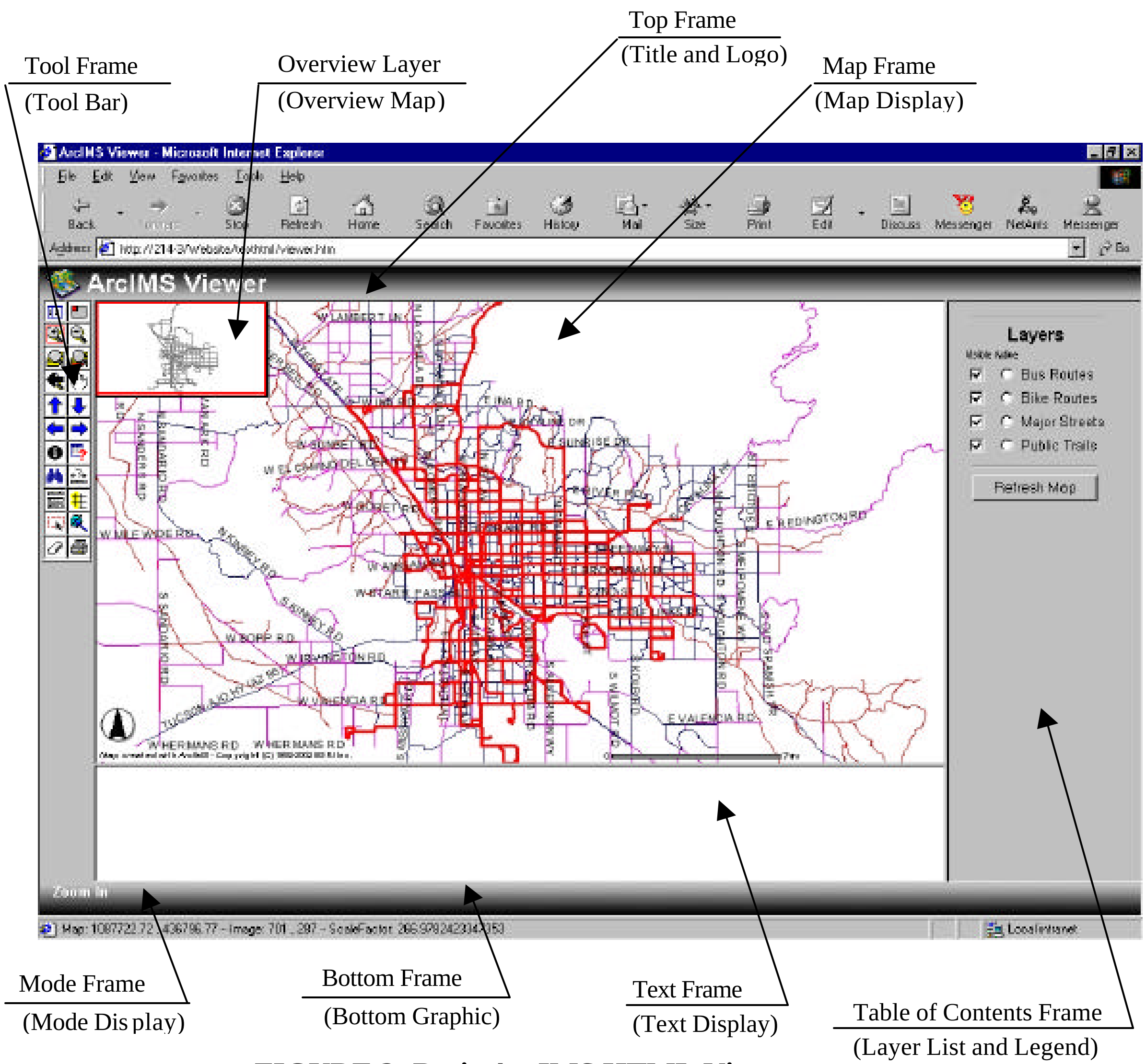

FIGURE 2: Basic ArcIMS HTML Viewer

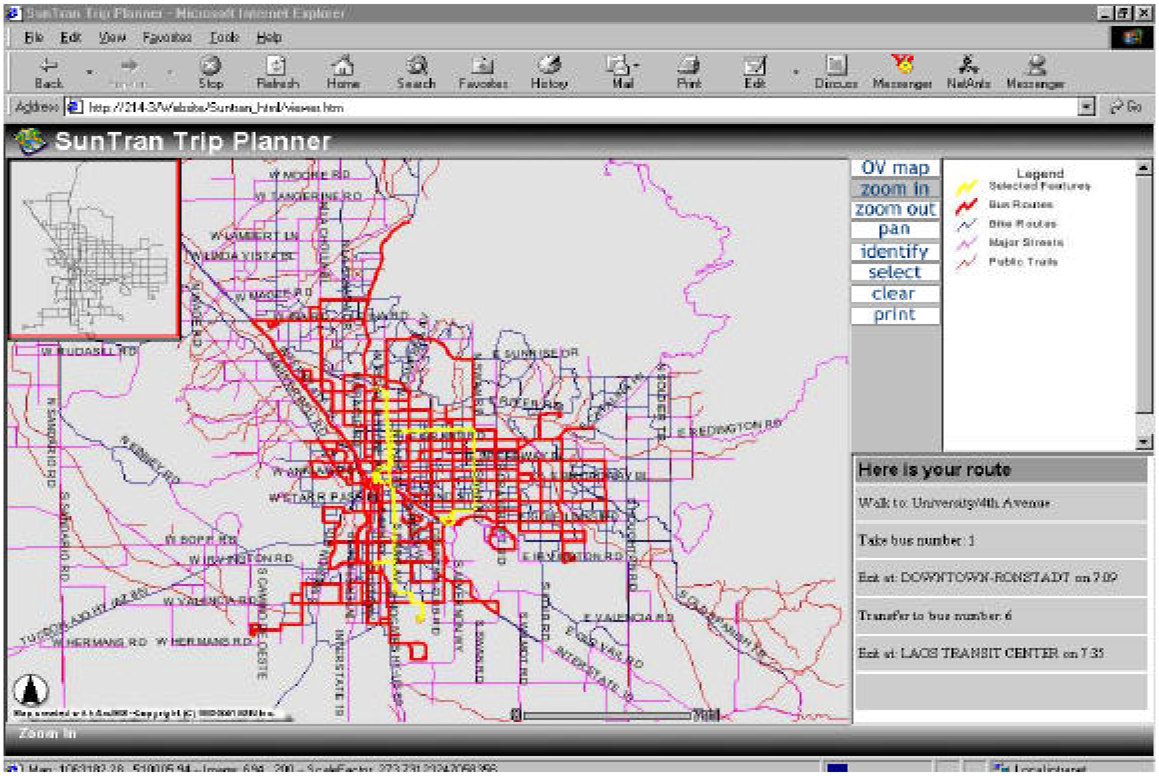

FIGURE 3: Final Output Including Text Directions and Highlighted Map