

**A COMPARISON STUDY OF VISUALIZATION  
METHODOLOGY FOR TRAFFIC ANALYSIS**

**THESIS**

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by

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## TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS.....	iv
LIST OF TABLES.....	vi
LIST OF FIGURES .....	vii
ABSTRACT.....	viii
CHAPTER	
I    RESEARCH QUESTION.....	1
II   INTRODUCTION .....	2
III  LITERATURE REVIEW .....	8
IV   PROBLEM STATEMENT .....	25
V    METHODOLOGY .....	33
VI   CONCLUSIONS.....	58
APPENDIX	
I    SURVEY SOURCE CODE.....	62
II   PRINTED SURVEY.....	91
SELECTED BIBLIOGRAPHY.....	104

## LIST OF TABLES

Table	Page
1 Experience Level of Respondents.....	42
2 Education Level of Respondents .....	43
3 Accuracy of Answers for all Respondents.....	50
4 Accuracy of Answers for Traffic Professionals vs. Non Professionals .....	51
5 Confidence Level of Respondents .....	52
6 Comparative Preference.....	53
7 Comparative confidence level of answers given .....	54
8 Comparative speed with which the graph was understood.....	55

## LIST OF FIGURES

Figure	Page
1 Image Used to Describe Trajectory Graph .....	26
2 Image of the Trajectory Graph displaying four runs .....	27
3 Travel Time Stacked Bar Graph .....	29
4 Route of Test Vehicle .....	38
5 Image Used to Describe Trajectory Graph .....	45
6 Image Used to Describe Stacked Bar Graph.....	46
7 Image of Trajectory Vector Graph.....	48
8 Image of Stacked Bar Graph.....	49

## **ABSTRACT**

# **A COMPARISON STUDY OF VISUALIZATION METHODOLOGY FOR TRAFFIC ANALYSIS**

by

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Modern data collection and computer modeling techniques create an enormous volume of raw data that is available for evaluation by the scientific community. Traditional methods of analysis often sacrifice much of the robustness of detail in the original dataset in favor of parsimony of expression. Traffic analysis is one area in which analytical methodologies have failed to keep pace with the available data. Additionally the need for robust and intuitive explanations of traffic, congestion and travel time has

increased due to the growing trend to solicit more public involvement in transportation projects.

Traditionally, the trajectory vector diagram has been the preferred method of visualizing travel time and progress of individual vehicles in the traffic stream. This thesis has adapted the stacked bar graph methodology as a proposed alternative due to its simplification of presentation while retaining much of the richness of the original data that lies behind that information.

Using data collected during several traverses of a thoroughfare that experiences recurrent congestion, two graphic presentations were created and a Web based survey was conducted to evaluate these methodologies. Respondents, both traffic professionals and non-professionals, not only answered the questions more accurately using the travel time stacked bar graph than using the trajectory graph, but they also reported preferring the stacked bar graph format. These results demonstrate that simple graphical displays can be effective in increasing the comprehension level of travel time information and increase intercommunication between domain experts and the lay public.

## **RESEARCH QUESTION**

This thesis will develop a new approach for analyzing traffic patterns along urban routes that experience recurrent congestion during peak periods. The result of this analysis will be two visual displays that will be compared for comprehension, accuracy and user preference. The source of data for the analysis will originate from a test vehicle equipped with a Global Positioning System (GPS) receiver. Data reduction and management software will be designed to manage collected raw GPS data and will convert it into a form that is useful for the proposed research. The raw data collection process will be such that the test vehicle makes several journeys along a predetermined path as the GPS receiver passively records date, time, latitude and longitude every second to provide a detailed trace of vehicle trajectory. The chosen route will be representative enough such that results based on its analysis will be broadly applicable to other situations.

## INTRODUCTION

An article in the British journal *Nature* declared that geotechnology is one of the three important and evolving fields in the world today (Gewin, 2004). While modern data collection methods are providing enormous amounts of information about the world around us, the raw data can become profuse to the point that it threatens to overwhelm thoughtful analysis. The vast extent of available data masks a broader issue that the information that is available is often in a form that fails to match the needs of the researcher. Therefore, improved data collection and analysis techniques should be high on geography's research agenda (National Research Council, Rediscovering Geography Committee, 1997). It is important to collect not only good data, but also to process it into a form that is effective for solving problems under study (Decker, 2001). Of all methods for describing, exploring, analyzing and communicating information about large sets of data, well-designed graphics are usually the simplest and most powerful (Tufte, 1983).

The field of surface transportation is a prime example of this phenomenon. Interest in the collection of traffic data has proliferated since 1995 when Secretary of Transportation Federico Peña outlined a plan for establishing an Intelligent Transportation System (ITS) and Traveler Information System in the US. (U. S. Congress. House of Representatives, 1995). The following year in a speech before the

Transportation Research Board, Secretary Peña set a goal of deploying a metropolitan ITS infrastructure in the 75 largest metropolitan areas by the year 2005.

Because of this motivation, the amount of raw data available for traffic analysis has increased dramatically. In the year 2000, the most recent for which national records have been compiled, 70 of the 78 largest metropolitan areas are gathering at least some kind of traffic flow data (Meyer and Schuman, 2002). In addition 23 states have installed traffic surveillance systems in non-urban areas (Intelligent Transportation Systems, U. S. Department of Transportation, 2004).

While data are being collected at an ever increasing rate, the process of compiling and using those data to convey useful information to end users and stakeholders is failing to keep pace (Schuman, 2001). Few agencies have adequate real-time information to monitor or analyze their systems. Despite considerable demand, less than a quarter of the 75 largest metropolitan areas actually make this information available to the public or stakeholders (Canby, 2002). This deficiency suggests the urgent need for better data processing and display methodologies.

Many of traditional methods for the communication of traffic conditions, congestion levels and travel time have their roots in an era when data was manually collected, logged, analyzed and displayed. For over 40 years, the manual floating car technique has been utilized to collect travel time data. In practice, the method was simple and direct. A driver kept the vehicle floating in the stream of traffic while a passenger

recorded time of passage of predetermined landmarks with a stopwatch (Bullock et. al., 1996). This method was labor intensive and prone to recording errors. Due to the cost of data collection, information was sparse and graphical displays concentrated on methods that would closely examine the details of each trip. Recently, a plethora of data collection techniques have come into common use with the result that the magnitude of raw data available to traffic researchers has increased dramatically (Meaker and Horner, 2004).

Analysis of congestion, travel time and highway speed data provide numerous examples of datasets with copious amounts of information that have many important but fine distinctions within the data. Details within these data are central to the understanding of the nature of the flow of traffic along the roadway. With the proliferation of information about traffic conditions becoming available from numerous sources, methodologies will need to be developed to analyze and present the information in a way that informs both traffic professionals and the public.

This thesis will analyze an approach to visualization of travel time studies that will encourage the viewer to examine the richness of patterns of travel time and travel time uncertainty across the data rather than accepting a single summary statistic for the dataset as a whole. To accomplish this, the study will adapt a method of visualization that depicts both travel time and the variability in travel time using a single, simple graphic display. This technique is based on visualization methodologies developed for display of both primary and secondary characteristics of spatial data. The paper will compare the

newly applied technique with traditional trajectory graphs to determine which technique conveys travel time information most effectively.

## RESEARCH METHODOLOGY

An identical dataset for both visualization methodologies was collected from a test vehicle equipped with a passive Global Positioning System (GPS) receiver. This method is similar to the floating car technique described earlier, with the exception that manual data recording is replaced with a GPS unit that automatically logs the position of the test vehicle every second. This provides for a much more detailed track of vehicle trajectory and eliminates data entry and transcription errors.

### **Data Collection and Management**

Data were collected using a relatively inexpensive recreational GPS receiver from Garmin. In order to provide a detailed record of the track of the test vehicle, the GPS unit was programmed to record latitude, longitude, altitude date and time each second. A freeware software program called MyGPS written by Paolo Faure Ragani and Pier Paolo Colombo was used to download the data from the GPS and output it to a data log file (Ragani, 2004). The file format consists of plain text in a comma delimited format that is capable of being imported into several programs for information processing.

Due to the nature of this study there is no suitable off the shelf software capable of using the raw data and creating the charts and reports required for this project. Therefore, custom data management and reduction software was used to convert the data from the log files into a usable form for producing run summary information and charts. Primary languages used for this purpose include perl for the extraction of information from the data and PHP for the creation of the charts. In addition, Linux utilities and scripting languages were used to manage, store and retrieve information from the data logs.

### **Data Collection**

Collection of the raw data required the test vehicle to complete several journeys along a predetermined route while the GPS recorded position and other information each second to provide an extremely detailed trace of the trajectory for each trip that the vehicle completed. The methodology used for data collection and the quantity and quality of information collected is consistent with that of other similar research.

The path of the test vehicle was selected to provide an environment comparable to that of other analogous research projects. A section of highway in south Austin, Texas, was chosen because it contained several characteristics of thoroughfares that are commonly studied for travel time analysis. The designated route begins in a suburban area and ends in a downtown area and includes a traffic control device, a work zone and several areas of recurrent congestion as well as areas of free flow. At several points

along the selected test course, physical bottlenecks occur where the capacity is restricted, but flows from major feeder roads with relatively large capacities intersect with the route. In addition, there is a closely spaced series of interchanges with local streets that causes recurrent congestion resulting in an entire highway corridor where a system of bottlenecks and recurrent congestion exists.

## **LITERATURE REVIEW**

Increase in the magnitude and extent of traffic congestion and the resultant direct and indirect costs of reduced mobility have fueled the demand for more efficient, automated data collection methodologies that can monitor changes in urban roadway conditions. The data collected from these sources result in exceptionally detailed measurements from roadway surveillance equipment installed for congestion monitoring purposes. In order to make the greatest use of these data sources, better methods will be required communicate highway performance in a manner that is meaningful to the stakeholders and users of the road network (Northern Great Plains Initiative for Rural Development, 2005).

### **TRAFFIC CONGESTION**

Congestion on our nation's highways is increasing in both scope and duration as rush hours are becoming longer and congestion is plaguing more rural areas (Quiroga, 1997). The problem is perhaps an intrinsic part of the need for human interaction and the fact that most business establishments usually begin and end their workday at the same time as other similar businesses to allow for efficient commercial exchange between them (Downs, 1992).

While some congestion on our nation's highways may be inevitable, it is also expensive in terms of wasted time, money and fuel. The Urban Mobility Report has been conducting an ongoing analysis of roadway congestion levels since 1982 and has reported that that congestion levels have increased in each of the regions studied since analysis began. The report concludes that congestion currently extends through longer periods, affects more roads, impedes more traffic and creates more extra travel time than at any point in the past (Schrank and Lomax, 2003).

While congestion is increasing in magnitude and extent in metropolitan areas, it is also extending to more rural regions making it no longer merely an urban issue. In rural areas of the United States congestion becoming an increasing problem due to the growth of rural bedroom communities, seasonal residences, increasing tourism and special events (Fitzpatrick et al, 2000). Areas that experience elevated rates of growth are more likely to experience congestion problems because transportation demand tends to increase faster than roadway construction and public transportation services in these areas (Schrank and Lomax, 2003). Because of this, methods analyzing of roadway congestion should be flexible enough to follow development trends. The methodology presented in this paper is extremely portable and can be used anywhere that a GPS can receive signals.

### **Cost of Congestion**

A study for the American Highway User's Alliance concluded that improvements to the 167 most serious bottlenecks in the nation would prevent 287,200 accidents, 1,150

deaths, and 141,000 injuries. Additionally CO<sub>2</sub> emissions would be reduced by 71 percent, volatile organic compound emission would drop 41 percent and carbon monoxide would be reduced by 45 percent. Drive time delays could be reduced by 71 percent saving affected drivers an average of almost 40 minutes a day or over 160 hours a year (Cambridge Systematics, 1999). In 2002, congestion cost about \$63 billion and 5.7 billion gallons of fuel were wasted due to vehicles trapped in traffic (Schrank and Lomax, 2004).

A survey by the Texas Transportation Institute revealed that the majority of drivers (57.3 percent) described driving now as more stressful than in the past. Merge related behaviors and highway construction zones were cited as being the most likely conditions that induced stress (Walters and Cooner, 2001). In some cases, congestion leads to aggressive driving behaviors that tend to exacerbate and perpetuate roadway congestion. Drivers frustrated by congestion may take excessive risks such as tailgating, cutting across traffic lanes, excessive acceleration and using shoulders as traffic lanes. These practices have the direct impact of increasing congestion and may cause additional accidents that cause even more congestion (Kockelman, 2004). In a recent survey of aggressive driving behaviors, motorists listed bottlenecks as a significant source of frustration and stress. The authors noted that feedback from commuters revealed that a majority realized reduced aggressive behaviors after improvements were made at a recurring bottleneck location and noted that almost half of those surveyed indicated reduced stress levels after bottleneck improvements had been completed (Walters and Cooner, 2002).

## **The Nature of Congestion**

Essentially, highway congestion is caused by the existence of delays along a roadway due to the presence of other users. Any time two users want to use the same space at the same time a delay will result because one user must relinquish the space to the other (Kockelman, 2004). When travel normal demand exceeds highway capacity, recurring congestion can develop at approximately the same time of day and in the same location on a regular basis. Non-recurring congestion results from unexpected or unpredictable incidents such as accidents, highway obstructions or adverse weather conditions (Kockelman, 2004). Non-recurring congestion by its very nature is difficult to analyze. Many traffic engineers and planners agree that congestion measurements should distinguish between congestion caused by incidents and that caused by inadequate capacity. Thus, instances of non-recurrent congestion such as accidents, stalled vehicles, obstacles on highway and other sporadic traffic disturbances can be analyzed to study the effects of intermittent capacity reduction on traffic flow. Models of these sporadic incidents and their effect on traffic flow can be verified and fine tuned in a real world environment. With improved models that are refined for individual networks, specific problem areas can be identified and corrected (Meaker, 2003). Data from vehicles equipped with passive GPS systems can provide a source for this information.

In addition, with traffic models prepared for a region, significant differences between expected and current conditions should become apparent when a real-time

monitoring system is established. Incident severity can easily be evaluated by comparing current speed and travel time data with historical data (Meaker and Horner, 2004)

### **Quantifying Traffic Congestion**

Measurement of traffic congestion has traditionally been the bailiwick of engineers and other experts in the field of traffic engineering (Transportation Research Board, 2000). Over the years, these specialists have developed their own methodologies and technical jargon. Members of the public who travel the roadways experience traffic congestion on a regular basis are well aware of the nature of traffic problems, but are unfamiliar with the language and methodologies of the domain experts. This has caused a breakdown of communication between members of the public and traffic engineers. Improved communications between these groups can lead to a more thoughtful discussion of the problems and ultimately to making more optimum expenditures for improvements in the transportation infrastructure. Simple, easy to understand graphics for public information materials may help with this process.

Part of the problem is that engineers and other domain experts use technical jargon that seems incomprehensible to the lay public to describe traffic conditions. These experts typically describe traffic conditions using a level-of-service (LOS) rating from “A” through “F.” As defined in the Highway Capacity Manual (HCM) (TRB, 2000), LOS is a qualitative measure describing conditions within a traffic stream and provides for standard estimates of speed and capacity for various roadway configurations and LOS

levels. One issue with LOS is that the definitions of the levels are not intuitive for the average commuter because HCM uses such abstract metrics as the number of passenger cars per lane mile (pc/mi/ln) and passenger cars per hour per lane (pc/h/ln) (TRB, 2000). Travel time measurements provide almost the same information about the underlying traffic conditions in a form that is more intuitive to the lay public since the purpose of the transportation network is to move people, goods and services. Travel time and Level of Service are highly correlated such that travel time can be considered an average LOS (Chen et al., 2003).

Thus, travel time and mean speed on major highway systems have become a common standard measurement of the performance of our nation's traffic networks (Dahlgren et al, 2002; Dailey and Cathey, 2002). These measurements can be obtained from several sources including inductance loop detectors, fleet Automatic Vehicle Location (AVL) operations and the use of computer vision techniques applied to in place traffic cameras mounted along major arterials (Cathey et al, 2002; Kogut and Trivedi, 2002). In addition, several technologies use probe vehicles in the traffic stream to collect travel time data. Automatic Vehicle Identification (AVI) systems, such as those used for automated toll collection, can measure travel time between tollbooths or other measurement points imbedded in the roadway (Turner et al, 1998). Signpost based and GPS systems used by transit agencies for tracking bus locations in real time have successfully been used to determine travel time for general traffic along urban roads (Chakroborty and Kikuchi, 2004; Bertini and Tatiyanugulchai, 2004). Cellular phone tracking has also been successfully demonstrated in a pilot project intended to derive

travel time estimates for vehicles traveling major roads (Lovell, 2001). All of the techniques outlined above have the potential be used for real time analysis of traffic conditions along sections of major highways.

Some of the techniques outlined above, such as fleet AVL and cellular phone tracking can be utilized to determine travel time on rural highways that have no imbedded sensors in addition to those major roads that are outfitted for speed or travel time measurements. Meaker and Horner describe a technique that utilizes remotely sensed GPS data that is available in real time for many roads, including rural highways (Meaker and Horner, 2004). In addition, the passive GPS technique used for the data collection for this paper can be used to measure travel time between points anywhere.

Those travel time measurement techniques that are not directly linked to the infrastructure of a specific highway are flexible enough to measure congestion in rural areas and during seasonal or special events. This added flexibility can augment planning efforts and allow transportation professionals as well as the public to gain a more regionalized picture of highway system performance.

### **Travel Time Variability**

In addition to travel time, the variability of system delay is an important measure of network performance for many users. In fact, the variance in travel time has been referred to as the reliability of the travel time estimate (Dahlgren et al, 2002). Travel time

variance affects a traveler's ability to make accurate predictions of arrival time which can be important for example, to business travelers and others who must arrive at destinations at an appointed time. If driver assumes that a trip will take the median travel time, he or she will be late for half of his or her trips (Schrank and Lomax 2002). If a traveler has the need to arrive on time for 95% of her journeys, she needs to budget the difference between the mean and the 95th percentile trip into each trip. In some instances this time variation is so large that the additional buffer time can actually exceed the mean travel time (Schrank and Lomax, 2002).

Improved transportation reliability reduces the costs of delivery for goods and services thus reducing production costs and decreasing overhead in inventories, spare parts and finished goods (ICF Consulting and HLB Decision-Economics, 2002). According to studies by the Federal Highway Administration (FHWA), industry can benefit from increased transportation reliability by substituting better transportation for increased warehouse space. By reducing the dependence on warehousing, savings can be realized through lowered inventory carrying costs, reduced insurance premiums and decreased labor costs (FHWA, 2004). With smaller inventories in warehouses, production and transportation must become better coordinated and thus placing greater demands on the transportation system to deliver goods in a narrower time window than in the past (Lakshmanan and Anderson, 2001).

The volume of freight shipped on the nation's highways has grown significantly over the past few decades. Between 1975 and 1997, domestic intercity shipping grew by

approximately 60 percent (Eno, 2002). In 1997, 11 billion tons of freight valued at \$7 trillion was shipped in the U.S. (American Association of State Highway and Transportation Officials, 2002). Shippers and freight carriers value transit time in the range of \$25 to \$200 per hour and the costs of unexpected delay for trucks can add 50 percent to 200 percent (U. S. Department of Transportation: FHWA, 2002). Increasing volume of freight on the highways means increased costs for delays.

Increasing trip reliability and predictability requires much broader use of information than is currently available (Schauman, 2001). Building greater reliability and better service will require a method to monitor and communicate performance in a manner that is meaningful to the freight community (Northern Great Plains Initiative for Rural Development, 2005). A graphical display that allows the viewer to judge not only the travel time, but also the variability in travel time can benefit users, such as the freight industry, who seek travel time reliability.

### **Involvement by the Public in Transportation Planning**

There is a developing trend on the part of departments of transportation to engage the citizen more actively in the decision making process. This requires the transportation agencies to solicit citizen involvement in all phases of transportation system planning from program development, project planning and design and even including implementation and monitoring. This stems from a growing belief among policy makers that the real experts on local transportation needs are those daily commuters and the

members of the community who are most impacted by traffic congestion and must ultimately pay for the mitigation measures (Charlier Associates, 2004).

The process of soliciting public input for transportation projects and responding to citizen and end user input regarding transportation department projects can be complicated, challenging and often intimidating for all involved, however, when it is done properly, it is also a rewarding and meaningful experience that leads to better decisions on the issues (Minnesota Department of Transportation, 1999). Increasing public participation in the development and implementation of transportation infrastructure improves the local democratic process and increases early acceptance of projects. Stakeholders and members of the public expect to see and understand proposals before spending millions of public dollars on major transportation projects (Keister and Moreno, 2002). Making good investment choices in the transportation system will be critical to enhancing America's economic productivity and global connectivity (FHWA, 2004).

There are, however, numerous barriers to public involvement including cultural, ethnic and language issues. Additionally, large meetings intimidate many members of the public (Minnesota Department of Transportation, 1999). Adding to traditional language barriers, there is the issue that domain experts and engineers often have difficulty communicating effectively with stakeholders and members of neighborhood associations or citizen groups (Minnesota Department of Transportation, 1999). However, with a

shared sense of public purpose, participants work toward common goals to bridge traditional, institutional, functional and technical boundaries (Dean, 2004).

Public information materials often rely on graphics and other visual aids making it possible to reach busy people or people who have difficulties in reading. The significance of visualization is increasingly being recognized within the transportation field as an essential part of the solution to communications problems because it improves the collaborative, decision driven aspects of transportation system planning and design (Hughes, 2004). Even technical and planning staff that have access to full technical documentation realize the benefits of concise and easily understood nature public information materials and visual aids. (Howard/Stein-Hudson Associates, 1996).

There is the concern that public information materials may prove ineffective if the information is too technical for lay people to grasp and this may cause the loss of goodwill that a public information campaign was designed to create (Howard/Stein-Hudson Associates, 1996). The visualization techniques presented here may help to reduce the reliance on the highly technical aspects of presentations and serve to eliminate these language barriers and ultimately improve communications between domain experts and the lay public.

## **Internet**

Information technologies are offering administrators of public agencies numerous effective ways of sharing information with their customers and the Internet was one of the most commonly used technologies (Zimmerman et al, 2001). Many state departments of transportation as well as numerous Federal agencies have discovered that the use of the Internet works well to overcome obstacles to gathering input from citizen groups. Public information materials published on the Web can also benefit stakeholders by enabling the public access to information on their schedule without having to attend public meetings.

Many public agencies recognize that websites are a cost effective method distributing information and gathering input from the public (Keister and Moreno, 2002). Use of the Internet and Web sites to communicate information to the public is especially attractive to agencies in small and medium sized communities because a relatively small commitment of resources allows the agency to reach a large audience and to receive feedback on an ongoing basis. (Schutz, 2000).

There is a drawback to publishing information on the Internet. This mode of broadcasting public information materials is likely to target computer oriented people to a greater degree than others. Those who are comfortable with the use of computers are more likely to participate in Web based activities. In the long term, this may no longer be a significant issue as the use of computers by the public continues to increase and on-line services become more ubiquitous (Howard/Stein-Hudson Associates, 1996)

## **Abundance of Data**

With the increase level of data collection since Secretary of Transportation Peña's speech before the TRB in 1996, the number and types of data sensors available for the analysis of traffic conditions has increased rapidly with no end in sight. Inductance loop detectors and fixed radar systems are being installed in highways at an increasing rate. The use of traffic cameras is becoming more common as technology improves and cameras are able to track vehicles in areas without complete sensor coverage (Kogut and Trivedi, 2002).

Automatic Vehicle Identification (AVI) systems such as those used for automatic toll collection are a potential data source for real time traffic monitoring that has not yet been used to its full potential (Turner et al, 1998). Signpost based systems such as those used by transit agencies for monitoring mass transit vehicles are gaining wider use and as research continues will provide another source of raw travel time data (Bertini and Tatiyanugulchai, 2004).

While several fleet Automatic Vehicle Location (AVL) systems are currently in place and capable of collecting travel time data, few if any actually do so (Dailey and Cathey, 2002). Cellular phone tracking has also been successfully demonstrated but there are no reported systems currently in place (Turner et al, 1998). Passive GPS techniques used for the data collection have been demonstrated but are not currently in use (Meaker and Horner, 2004)

With this increase in raw data, methodologies will need to be developed to analyze and present the information in a way that informs both traffic professionals and the public.

### **Historical Data**

Traffic information need not necessarily be current to be useful. Historical travel time data may be helpful for forecasting mean travel times for differing periods of the day and week but also for establishing confidence intervals around those predicted values based on historical variances. Such an analysis would produce estimates of travel conditions for various times in the future given current conditions.

Researchers can then incorporate data from earlier periods of time to investigate instances of persistent congestion to identify areas of reduced capacity and decide how to alleviate apparent bottlenecks. In addition, planners can use this information to assist in designing future roadways that are less beleaguered by congestion issues. Similarly, non-recurrent congestion (accidents, stalled vehicles, obstacles on highway and other sporadic traffic disturbances) can be studied to enhance research seeking to determine the effects of intermittent capacity reduction on traffic flow. Models of how these sporadic incidents affect traffic flow can be created, analyzed and verified in a real world environment using historical traffic information. Simulation modeling of such scenarios is routinely done with GIS computer software (Miller and Shaw, 2001) and could be validated against

historical data. Once these models are in place, highway systems can be designed to be more forgiving in cases of minor traffic anomalies and disturbances.

## SCIENTIFIC VISUALIZATION

With the advent of computer modeling techniques and electronic data collection methodologies there was an enormous increase in volume of data available for scientific analysis. While this inundation of data was a windfall for analysts, it also called attention to some of the shortcomings of traditional statistical methods. Exploratory data analysis (EDA) is an approach to analysis of data established by John Tukey in his pioneering work *Exploratory Data Analysis* (1977). Tukey used more robust statistical methods, model fit indicators and graphical summary methodology to discover unexpected structure and provide rich descriptions for large and complex datasets (Tukey, 1977; 1980; 1986a; 1986b; 1986c; 1988). The term “scientific visualization” was coined to describe the use of computers to transform large datasets into images or other graphic representations of the data to aid in the understanding of the complex relationships within the data (McCormick et al., 1987). Scientific visualization and EDA provide the means to understand the complexity of information and study relationships linking the big picture to the details.

Estimates suggest that 80 percent of all digital data generated today include geospatial referencing such as addresses, postal codes or other geographic coordinates

(MacEachren and Kraak, 2001). Therefore, the merging of EDA and scientific visualization approaches with techniques developed for analytical cartography may become an ideal alliance.

According to Waldo Tobler, geographic cartography is one of the techniques used by geographers in analytical investigations. Many significant discoveries by such distinguished scientists as Alexander von Humboldt, Alfred Wegener, Walter Christaller and others have been facilitated as a result of the use of maps (Tobler, 2000).

In the period before World War II the Germans advanced the field of analytical mapping and analytical photogrammetry using state of the art optical equipment and precision mapping related hardware (Clarke and Cloud, 2000). By the end of the war, the preparation and use of map overlays that were composed manually on translucent media had become routine procedure (Clarke and Cloud, 2000). After World War II, many of the advances in analytical mapping were suppressed because of cold war concerns by the military and intelligence mapping community. This caused a situation in which academic cartographers were forced to play catch-up with two decades of intensive, but highly secret, analytical geography (Cloud and Clarke, 1999).

The first formal conceptualization of analytical cartography in academic circles originated with Waldo Tobler's PhD dissertation in 1961 in which he articulated his concepts of map transformations of geographic space (Moellering, 2002). These ideas were further refined and included in a course entitled "Analytical Cartography" at the

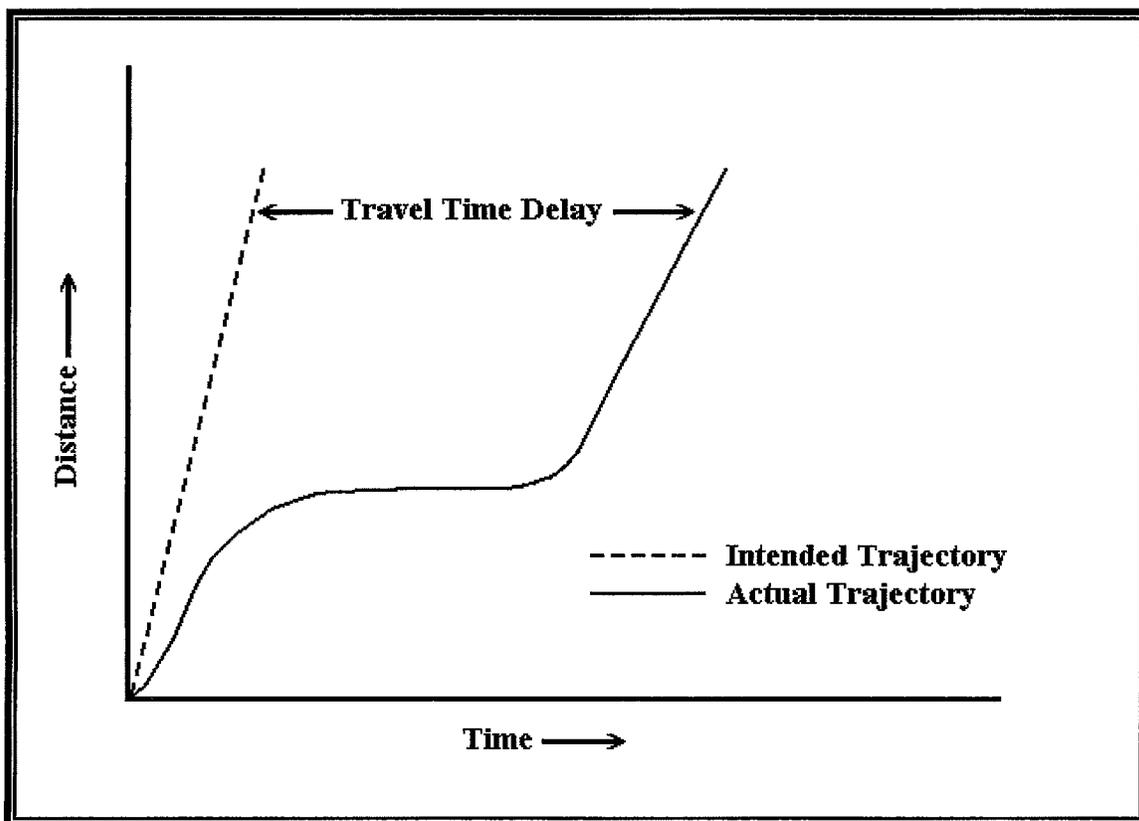
University of Michigan that was developed by Waldo Tobler in the late 1960s and described in an article in *The American Cartographer* (Tobler, 1976). In the years since these beginnings, analytical cartography has developed into a field that combines cartography, discrete mathematics, geography, computer science, and image analysis (Moellering, 2000).

## **PROBLEM STATEMENT**

Many current methods of conveying travel time information are derived from traditional paper and pencil practices without the benefit of the efforts of either Analytical Cartography or Scientific Visualization. The trajectory vector graph is commonly used as a visualization tool to convey a myriad of details about the travel times for individual trips (Quiroga and Bullock, 1999). Often they combine several trips into a single graphic, thus making the display more complex and difficult to understand. While these methodologies serve the needs of traffic professionals who work with these displays and are used to reading them, they fail to work well for members of the public who may have no training in traffic studies and little understanding of engineering principles.

Sometimes called the time-space diagram, the complexity arises from the sheer number of details that the diagram is designed to convey to the reader. In its simplest form, the trajectory graph is a plot of the distance and travel time of a vehicle along a route. Often, there will be several trajectories on a single graph in order to depict several runs over the course of interest at different times. Sometimes, an intended trajectory line will be added to provide a reference for the speed limit or preferred speed for the highway of interest. Occasionally, travel delay will be represented for critical points in the journey. If a grid is added, the diagram becomes even more busy and difficult to read.

The general layout of the trajectory graph has the vertical axis depicting distance traveled along the route while horizontal axis represents travel time. Figure 1 illustrates an extremely simple trajectory graph for a single vehicle in the process of stopping for a traffic control device. The in this illustration the intended trajectory, actual trajectory and travel time delay are depicted in a relatively straightforward and easy to understand display.

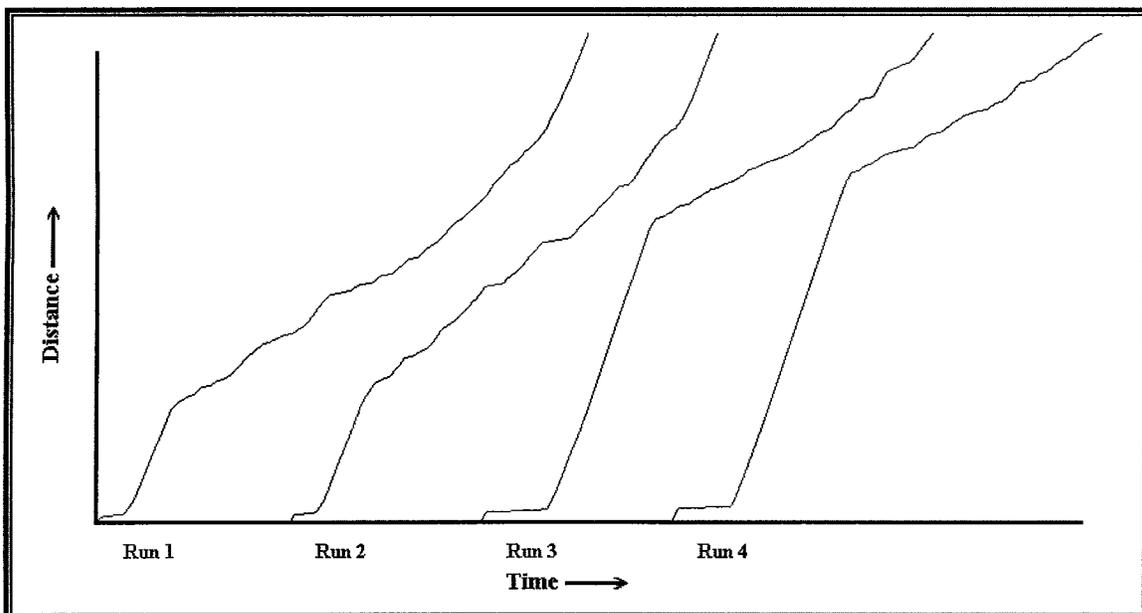


**Figure 1** Image used to describe the Trajectory Vector Graph

Intended trajectory is the path of the vehicle at the desired speed under free-flow conditions without the influences of traffic, signals or other sources of delay. The actual

trajectory is a plot of the progress along a defined route verses true time of travel and includes delays from all sources. Note that the vehicle begins to slow to join the traffic queue and additionally takes time to accelerate to highway speed after clearing the intersection. A user can evaluate travel time delay for any point along the route by determining the difference between the intended trajectory and the actual trajectory. Note that a horizontal line denotes that the vehicle has stopped and increasing speed is portrayed increasing slope of the actual trajectory line.

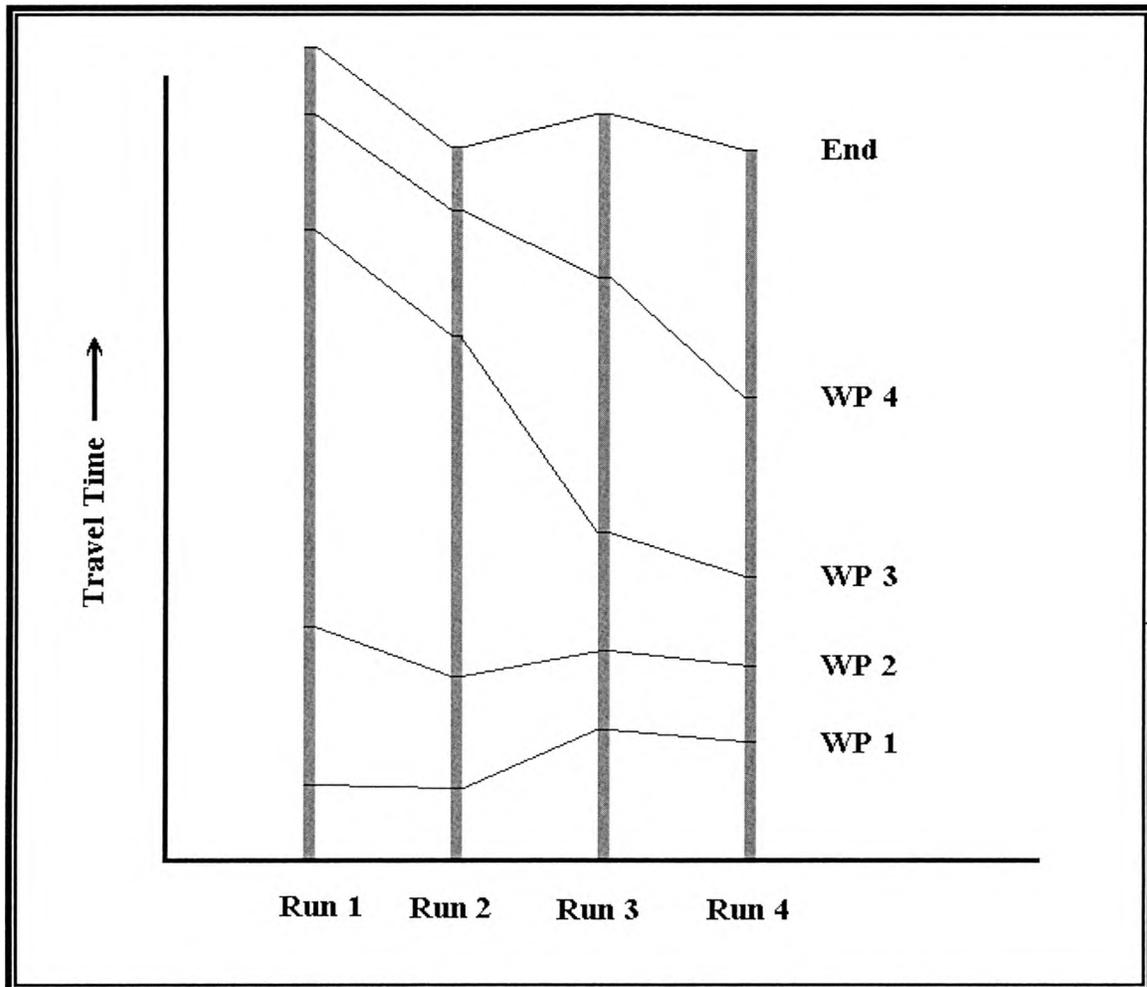
This style of display works well for analysis of a single run, but can quickly become busy when depicting multiple runs. Figure 2 shows the effect of displaying four runs on a single chart without intended trajectories, delay factors or grids marked. This is the image used in the survey and contains actual data from four separate runs.



**Figure 2** Image of the trajectory vector graph displaying four runs

The travel time stacked bar graph shows travel time along the vertical axis and each run will become a separate column in the horizontal axis. This makes it much easier to compare travel time between different runs. While details of speed variations within each segment are lost, it is hoped that the travel time graph will allow a novice reader to compare a series of trips and evaluate not only the overall travel time, but also travel time for various segments.

Figure 3 uses the same data as was used in Figure 2, but makes a direct comparison of travel times for the four trips while maintaining information about the overall travel time of each of the segments. In this case, the segment is considered to have been completed only when it has been totally cleared and in the case of an intersection when the vehicle reaches the far side of the junction. In cases that the vehicle must wait in queue for multiple cycles of a traffic signal, only the total time in queue will be observable.



**Figure 3** Travel time stacked bar graph depicting the same data as was used in figure 2

One drawback of the vehicle trajectory graph is that it will work well with only a relatively small number of runs. As the number of runs to be displayed on the graph increases, the complexity likewise increases. Conversely, the comparative travel time graph can effectively compare as many runs as can fit along the horizontal axis of the graph.

## JUSTIFICATION

Perhaps the motivation for using the trajectory vector graph is that traditional statistical analysis is inadequate for reproducing the fidelity of the data present in even relatively simple datasets, such as the results of several traverses of a section of congested highway. Statistics give the impression of an authoritative number when the interesting information is imbedded in the details of how that number was obtained and the distinctive characteristics contained in the original dataset. This is especially true of travel time information because sources of delay may originate from different causes and occur at various points along any given route (Bertini and Tantiyanugulchai, 2004; Cathey and Dailey, 2003; Quiroga and Bullock, 1999).

The problem of visualization of the quality of data can be viewed with the goal of optimizing the representation of the data and the communication of that as information to the end user. If a display improves the understanding about the nature and reliability of the data, then communication is improved (Loftus, NCGIA 1991). Issues to be considered when designing a visual display include the nature of the data to be displayed as well as the context of the display. Additionally, approaches to presentation issues should be targeted to the level of expertise of the target audience.

A data display should exploit the power of visual comprehension and encourage the reader to evaluate patterns within the data that influence the nature and reliability of the prediction as well as promote the interpretation of raw data into useful information.

Many users of travel time information already possess an appreciation of the nuances of the traffic congestion problem. Users who make a daily commute during drive time, often experience variations in travel time caused by time of day, weather, accidents and other variables.

There should be a distinction made between displays that are intended to be mere illustrations and those whose purpose is analytical in nature. Intuitive understanding of the meaning of the display is important for a graphic designed to be used as an analytical tool by untrained readership. The goal of an analytical display should, at least in part, be to encourage the user to evaluate the underlying data, especially in datasets with a small number of observations. If a visualization methodology can induce the reader to more fully appreciate the strengths and weaknesses of the underlying data, then the communication of information is better served.

A good visual analytical tool should not only give an accurate representation of the data but also give a sense for the intangibles of the data while preserving the resolution of the data, if possible. Traditionally, travel time predictions are made from a small number of runs along the route.

From the perspective of the user, the tool should be intuitive and easy to understand, preserve patterns in the data, offer speed of cognizance, reduce cultural bias and decrease or eliminate language barriers. Additionally, the user should be confident that he understands the information presented.

One of the constraints on the design of a data presentation methodology is the maximum amount of visual complexity that a person can handle. Cognitive limits also apply to the quantity of information that a user can retain in the mind to interpret the display. Human information processing capabilities are a relatively inflexible limitation on the ability to use different dimensions of symbols to display different aspects of data (McGranaghan,1991). Since maps already contain a relatively high level of visual complexity, non-map representations of spatial data should be explored as John Tukey suggested in *Exploratory Data Analysis* (1977).

### **Proposed Improvement in Travel Time Presentation**

Newer, more easily understood and intuitive graphic representations may help establish a common language for engineers and policy makers to receive feedback regarding transportation problems from the community at large. This may help identify critical issues and opportunities related to development and implementation of traffic mitigation procedures. Increased intercommunication can also provide taxpayers with confidence that their voice has been heard thorough the process from the planning through the final implementation stages of traffic mitigation projects.

## **METHODOLOGY**

The object of this survey is to perform a comparative analysis of the effectiveness of two methodologies for presenting travel time information to the general public. One method is the traditional trajectory graph and the other is a modification of the stacked vertical bar graph. Virtually all papers that appear in transportation journals and discuss travel time comparisons use the trajectory graph. This thesis will evaluate the effectiveness of using a modification of the stacked vertical bar graph as an alternative for expressing travel time to non-technical individuals and groups. The expected benefit of the stacked vertical bar graph is that it will be more intuitive to the public at large and therefore represents better means of communicating travel time to ordinary people.

The stacked bar graph methodology simplifies the presentation of travel time by directly representing travel time over relatively small and fundamentally similar aggregations of the trip journey. Waypoints can be selected to assess travel time of free flow conditions along a corridor and compare this with areas of congestion. If waypoints are selected appropriately, the causes of congestion along a route can be isolated and compared. Thus different causes of congestion such as physical bottlenecks, restricted highway capacity and flows from major feeder roads can be compared to provide relative assessments of the impact of each on the overall situation. In addition, causes of delay such as intersections with traffic control devices and work zones can be compared across

different roadways to assess how improvements might be incorporated into traffic mitigation practices.

However, because travel time information is aggregated, there is a loss of minute measurements and factual details contained in the original dataset. This inevitable deficiency is a result of the simplification of the display. However, the graphical nature of the display allows the viewer to recognize the various underlying causes of the congestion problem under investigation and therefore more thoroughly understand the complex nature of the issues involved.

## SURVEY DESIGN

The survey was conducted as an open Web study with participants recruited from members of the general public, traffic professionals as well as Texas State Geography students. Any open Web survey is vulnerable to sampling issues that result in self-selection bias. In addition, sampling methodology did not take into account early withdrawal rates of respondents. It is therefore not possible to know why respondents decided to answer the survey or why they may have dropped out before completing the entire survey.

The survey sample frame tended to select individuals with greater than average computer knowledge and skills. Each of the recruitment methods either depended on use of computer to contact the potential respondent or selected individuals who used

computers as a tool in either work or studies. Additionally, computer use was required to complete the Web based survey. The graphic methodology under study is intended to be used as part of public information materials for Web and therefore differences between the sample frame and target population may influence the results of the survey.

## EXPERIMENTAL DESIGN

In order to achieve independent responses for each of the two visualization methodologies, the survey adopted two separate evaluation pathways. One path evaluated the trajectory graph followed by the stacked bar graph while the other evaluated identical data and presentations in the reverse order. Approximately half of the respondents were selected for each of these paths at random. This approach was an attempt to compensate for the phenomenon that those who take part in surveys learn during the short survey process. In this way, results of the learning phenomenon were intended to be distributed equally between the two presentation methodologies.

## DATA SOURCE

Data were collected using a test vehicle equipped with a passive GPS receiver that completed several traverses along a predetermined route. Each second the GPS receiver recorded position, date and time to provide a detailed trace of the vehicle track.

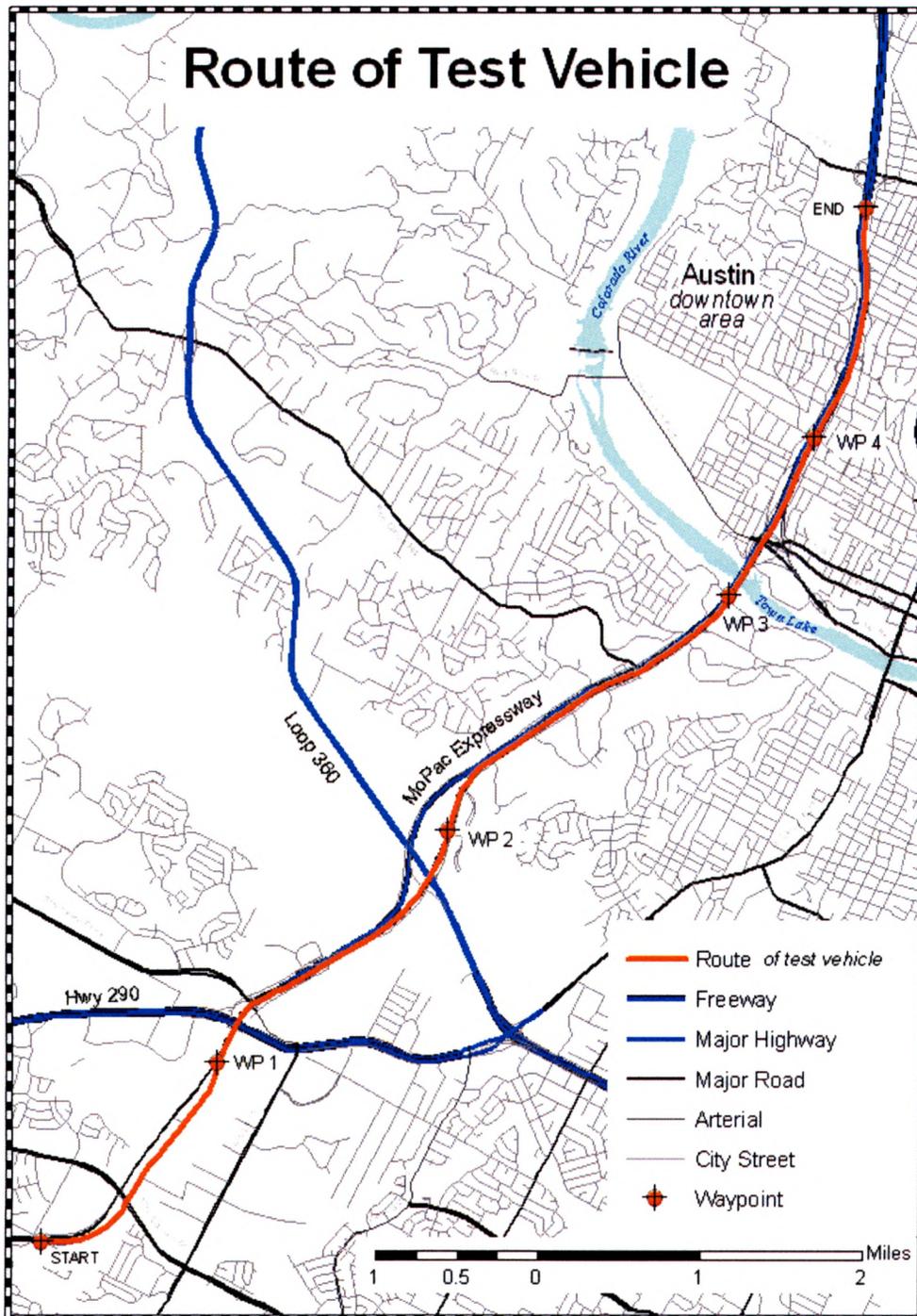
Reduction of the raw data to a usable format was accomplished with a combination of public domain programs and software designed and written especially for this project.

### **Route of Test Vehicle**

A section of highway in Austin, Texas was selected for this investigation because it provided a variety of road and congestion conditions that a typical commuter might experience on a daily basis. The stretch of road included an intersection with traffic control devices, a work zone, inflows from major feeder roads, a section of highway that consisted of several closely spaced series of interchanges with local streets, areas of reduced capacity resulting in physical bottlenecks as well as areas that experience free flow of traffic. In many areas that experience congestion, a typical commuter might experience one or more of these conditions as a part of the regular journey. In addition, traffic professionals and policy makers might need to communicate these kinds of traffic conditions to the community as part of a public information campaign.

The test route covered a section of the MoPac Expressway northbound from just south of the intersection at William Cannon Drive to the end at a point just south of 38<sup>th</sup> Street. See Figure 4. The test route began as a major feeder street with a traffic signal at William Cannon Drive and became a work zone. Then the route became a freeway that generally experiences free flow conditions. Feeder roads include William Cannon Drive, Highway 290, Loop 360 and to a lesser extent Southwest Parkway, Bee Caves Rd. and several downtown streets just north of Town Lake.

Depending on the amount of traffic, time of day and other factors, recurrent traffic congestion occurred at the work zone, the merge with Highway 290, the Town Lake Bridge and after the downtown streets just north of Town Lake. Runs 1 and 2 generally experienced traffic congestion at several points along their track, while runs 3 and 4 encountered more extreme congestion north of the Town Lake Bridge.



**Figure 4** Route of test vehicle

## **Data Reduction and Management**

Data reduction and management software to convert the raw data into visual aids and other outputs that provided a detailed trace of the vehicle trajectory for each data collection run was custom designed for the project. Representative sample runs typical of those used for research were selected to be analyzed visually so that the outputs are typical of similar traffic analysis research projects.

## **ANALYSIS OF SURVEY RESULTS**

A good visualization should convey the information accurately and quickly and leave the viewer with a high level of confidence that he understands the information presented. In addition, a good visualization should be pleasing to the eye and appeal the viewer aesthetically.

### **Summary of results**

For a period of a week starting on October 26, 2004, a short survey was conducted using a Web site to investigate the effectiveness of the trajectory graph as compared with the stacked bar graph for disseminating travel time information to the general public. Two graphic displays were presented to volunteer respondents and for each of the displays, users were asked to rate each of four trips in order of travel time. In addition, respondents were asked to rate the confidence level with which they understood

the presentation on a five-point Likert scale (1 = “Not at all”; 5 = “Completely”). In order to avoid biasing the results, approximately half of the surveys presented the trajectory vector first, followed by the stacked bar graph while the remainder presented the displays in the opposite order.

### **Demographics of Respondents**

Respondents were recruited from the general public by making requests for participation on general interest mailing lists (austin-chat@chiba.3jane.net). This list provides a forum for discussion of interest to people living in Austin and has not had any discussion of traffic issues in the recent past. Therefore, traffic issues are orthogonal to the discussions that occur on the list and it was assumed that respondents from this list would be representative of the general public. In addition, traffic professionals were recruited through an announcement on the official mailing list for the Transportation Research Board (TRB) Committee on Urban Transportation Data and Information Systems (ABJ30). The TRB is one of six major divisions of the National Research Council and attracts more than 5,000 engineers, scientists, transportation researchers and practitioners from public and private sectors as well as academia (TRB, 2005). The ABJ30 is one of thirteen standing committees related to transportation data, surveys and statistical and spatial technologies and concentrates on urban transportation issues (Committee on Urban Transportation Data and Information Systems, 2003). A total of 105 respondents completed the survey.

## Experience Level of Respondents

One of the demographic questions on the survey asked respondents to describe their level of experience with traffic. This question was used to differentiate between traffic professionals and members of the general public to determine whether this made a difference in preference or accuracy of response of one methodology over the other. The question appears below. Respondents were constrained to give answer only one by the use of a radio button selection on the survey form.

*Which statement best describes your level of experience with traffic?*

- Traffic Professional**
- I have studied traffic issues at school**
- I commute in heavy traffic regularly**
- I drive in heavy traffic occasionally**
- I rarely drive in heavy traffic**

Of the 105 respondents, 41 identified themselves as traffic professionals and for the purposes of this study; the remainder were classified as members of the general public. . Table 1 contains a breakdown on experience level as provided by survey respondents.

Table 1. Experience Level of Respondents

	Number of Respondents	Percent
Traffic Professional	41	38%
Traffic Studies in School	7	7%
Regular Commuter	23	22%
Occasional Commuter	30	29%
Rarely Commute	4	4%
Total	105	100%

#### Age and Education Level of Respondents

In order to determine how well the survey respondents represent the general population, two other demographic questions were asked. Mean age of survey respondents was 39 years as compared to population estimates from American FactFinder for 2003 of 36.0. The discrepancy in reported age is probably not significant.

*What is the highest level of education you completed?*

- Less than 9<sup>th</sup> grade completed**
- 9<sup>th</sup> to 12<sup>th</sup> grade completed – No Diploma**
- High School Graduate – Include Equivalency**
- Some College or Associate degree**
- Bachelor or Professional degree**
- Post-Graduate degree**

Below is a breakdown on education level as provided by survey respondents.

Table 2 Education Level of Respondents

Education Level	Overall		Professional		Non Professional	
Post Graduate	48	46%	28	68%	20	31%
Bachelor	35	33%	11	27%	24	38%
Some College	18	17%	2	5%	16	25%
High School	4	4%	0	0%	4	6%
No High School Diploma	0	0%	0	9%	0	0%
	105		41		64	

It would appear that education levels of respondents were significantly skewed toward those with higher levels of education than the general population. This is usually the case in self selection surveys. The discrepancy in reported educational levels may have been exacerbated as a result of the inclusion of traffic professionals in the survey. This group generally reported significantly higher level of education than did non-professionals. However, even among non-professionals as a group, educational levels were well above those of the general population.

## THE SURVEY

For a period of a week beginning on October 26, 2004, a survey was conducted to investigate the effectiveness of the stacked bar graph as opposed to the trajectory graph as a method of distributing travel time information. In order to comply with the requirements of Texas State University as required by the Institutional Review Board for Human Subjects Protection, this survey did not collect any identifying information about the respondents other than year of birth, gender, education level and experience level.

Respondents were solicited from a variety of sources, including mailing lists, personal contact and word of mouth. A total of 105 individuals completed the survey.

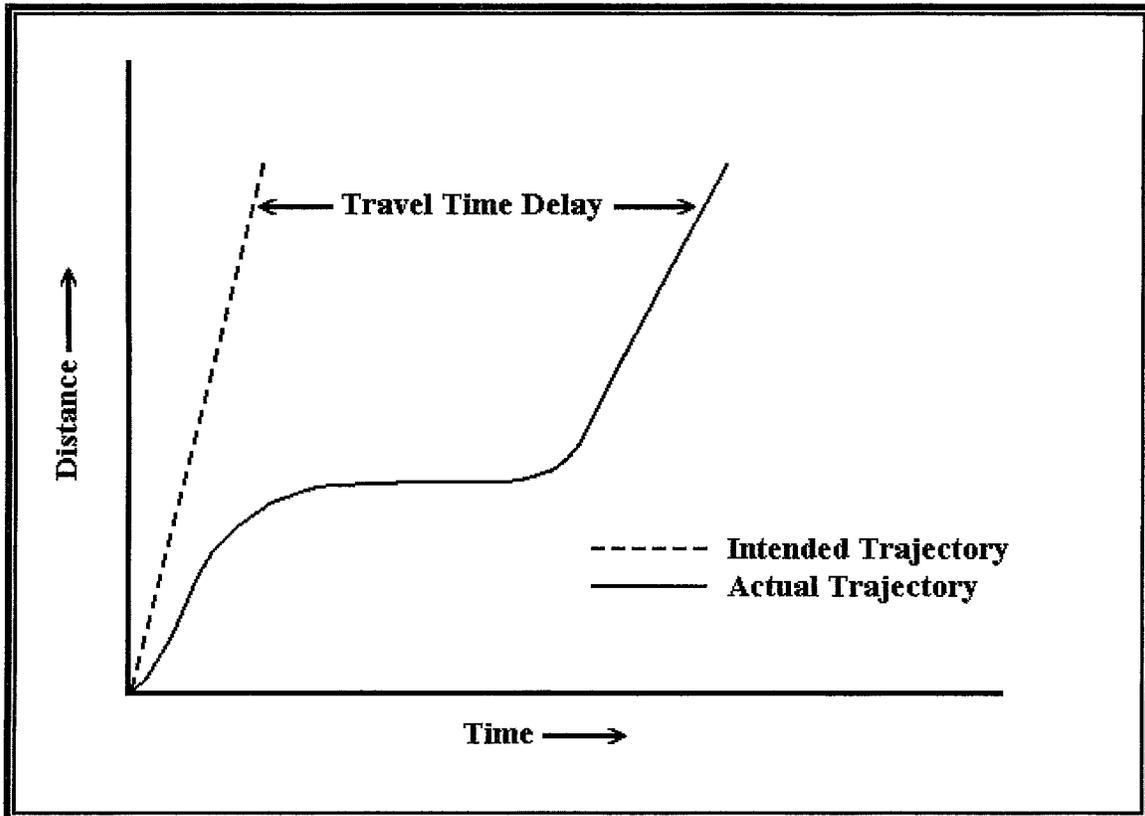
Using a Web server, two graphic displays were presented to volunteer respondents and for each graph, each user was asked to rate each of four trips in order of travel time. In addition, respondents were asked to rate the confidence level with which they understood the presentation on a five-point Likert scale (1 = “Not at all”; 5 = “Completely”). In order to avoid biasing the results, approximately half of the surveys presented the trajectory vector first, followed by the stacked bar graph while the remainder presented the displays in the opposite order.

### **Survey Details**

In order to instruct users in the interpretation of each of the graphical displays, a page was presented at the beginning of the survey describing each of the methodologies.

#### **Trajectory Vector Diagram Explanation**

The following image and explanation were used to describe the trajectory vector diagram.



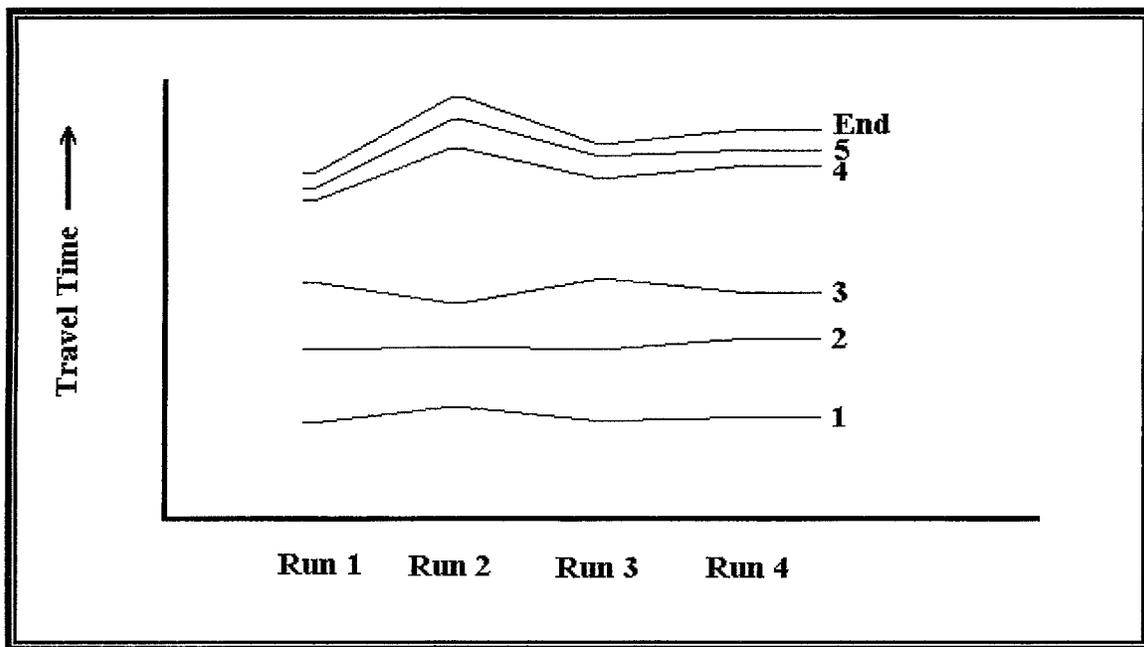
**Figure 5** Image used to describe the Trajectory Vector Graph

The graphic depicted above is a Trajectory Vector Diagram that is designed to show the progress of a vehicle along a track. Increasing distance is depicted as increasing values along the vertical axis and increasing time is depicted as increasing values along the horizontal axis. A horizontal line indicates that the vehicle is stopped and increasing slope means greater speed. The dashed straight line is the "intended trajectory" and the solid line is the actual trajectory of the vehicle. The intended trajectory is the trajectory that the vehicle would achieve if it were to complete the run along the specific length of roadway totally unimpeded. The horizontal distance between the intended trajectory and the actual trajectory is the travel time delay of the vehicle at any point during the trip.

The trajectory vector diagram is often used to depict multiple runs along a route. The dashed line is often left out of graphs depicting multiple runs.

### Travel Time Stacked Bar Graph Explanation

The following image and explanation were used to describe the travel time stacked bar graph.



**Figure 6 Image used to describe the Stacked Bar Graph**

The graphic depicted above is a Travel Time Stacked Bar Graph that is designed to show comparative travel times for multiple runs along a track. The height of the bar is proportional to the travel time and each stacked bar represents a different run. Horizontal lines connect points of equal distance. They may be named (ie "Interstate 20") or given another designation such as a number (ie "5" or "WP 5") or other designation. This allows the user to determine not only the overall travel time, but to also see where the delays are occurring.

## Survey Results

Respondents, both professional and non-professional, were much more likely to answer the travel time questions more accurately using the travel time stacked bar graph than using the trajectory graph. Traffic professionals had an average of 40% correct answers using the trajectory vector graph, but increased that average to 65% using the travel time stacked bar graph with the exact same data. Non professionals had similar results answering 36% of the questions correctly using the trajectory vector graph, and increasing that to 66% using time stacked bar graph.

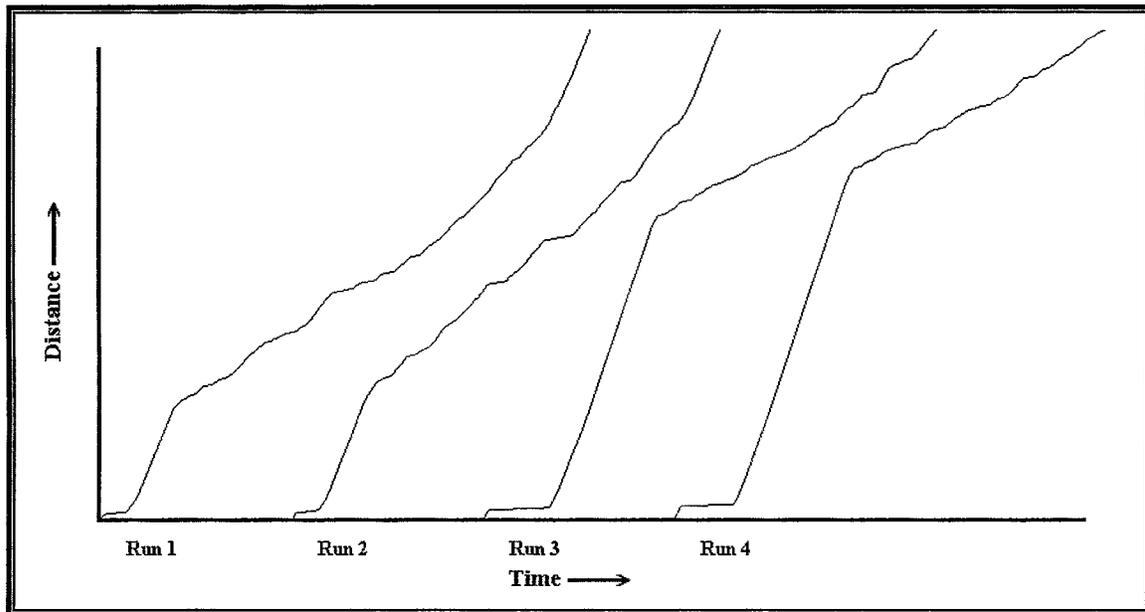
The confidence reported by participants as reported on the 5 point Likert scale were not significantly different. This points out a disparity between the actual understanding of the information presented in the graph and the perceived understanding.

## Response Accuracy

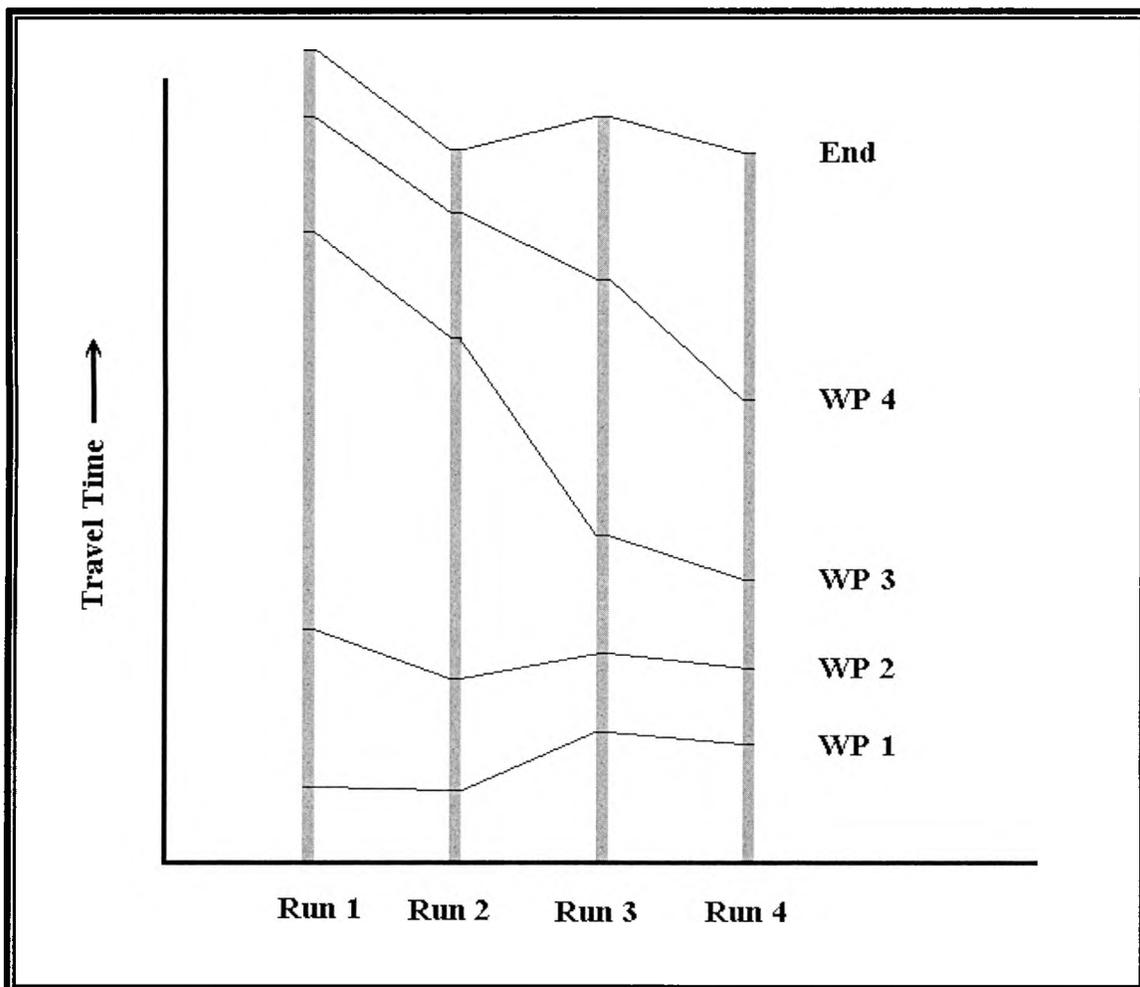
A central goal of any travel time visualization methodology should be to accurately convey travel time information to the user. In order to test accuracy of the two visualizations, it was decided to ask the user to rank trip in order of total elapsed time.

Each Web page that asked users to rank travel times for runs was headed by the appropriate graphic display for the visualization followed by these questions.

Respondents were asked to refer to the graph to answer the following questions.



**Figure 7** Image of Trajectory Vector Graph displaying data used in the survey



**Figure 8** Image of Stacked Bar Graph depicting data used in the survey

1. Which of the following runs took the least amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

2. Which of the following runs took the second least amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

3. Which of the following runs took the most amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

4. Which of the following runs took the second most amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

Table 3 Accuracy of Answers for all Respondents

	Travel Time Graph	Trajectory Graph
Question 1	38%	29%
Question 2	47%	22%
Question 3	88%	59%
Question 4	90%	41%
Overall	65%	38%

Table 4 Accuracy of Answers for Traffic Professionals vs. Non Professionals

	Travel Time Graph	Trajectory Graph
Traffic Professionals	65%	40%
Non Professionals	66%	36%
Overall	65%	38%

### Confidence of Response

A good visual display should leave the user with a feeling that he or she correctly understands the information presented. Since level of confidence is a personal perception of the user, this question made use of the standard 5-point Likert scale. The Likert scale measures the extent to which a person agrees or disagrees with the question.

*I am confident that I understand the information that the graphic is presenting.*

- Not at all**
- Slightly**
- Somewhat**
- Almost completely**
- Completely**

Table 5 Confidence Level of Respondents

	Travel Time	Trajectory Graph
Traffic Professionals	4.1	3.8
Non Professionals	3.3	3.4
Overall	3.6	3.5

### Comparative Results Page

A final questionnaire page asked the respondents to compare the two graphic methodologies. In each case the first graphic was displayed on the left side of the Web page while the second graphic was displayed on the right.

### User Preference

A good visual display should appeal to the user. Similar to the “confidence” question, this is a value judgment and will be scored in a similar fashion using a standard 3-point Likert scale.

### 1. Display Preference

*Please rate the graphs on the ease of extracting information*

- I prefer the display on the left
- I prefer the display on the right
- I do not have a preference

Table 6 Comparative Preference

	Travel Time	Trajectory Graph	No Preference
Traffic Professional	51%	41%	7%
Non Professional	52%	39%	9%
Overall	51%	40%	9%

### Comparative Confidence

Comparative confidence differs from the simple confidence levels reported above in that the respondent is comparing which of the two displays provided the greater relative confidence level between the two display methodologies. Simple confidence level was reported without reference to the other display.

### 2. Display Confidence

*Please rate the graphs on your confidence level that the answers you gave are correct*

- I had greater confidence in the display on the left
- I had greater confidence in the display on the right
- I had equal confidence in my ability to understand both displays

Table 7 Comparative confidence level of answers given

	Travel Time	Trajectory Graph	No Preference
Traffic Professional	55%	33%	13%
Non Professional	49%	29%	22%
Overall	51%	30%	18%

Both traffic professionals and non professionals reported significantly higher confidence levels in the travel time stacked bar graph than the trajectory vector graph.

### Speed of Comprehension

A good visual display should convey the information to the user quickly. While it would be nice to actually time the response, using a Web based interface creates technical barriers that make timing of the response to individual questions impractical. Therefore, the speed of comprehension became a judgment call on the part of the user and be scored using the standard 3-point Likert scale.

### *3. Display Speed*

*Please rate the graphs based on the amount of time it took you to understand the information presented*

- I was able to understand the display on the left more quickly than the one on the right**
- I was able to understand the display on the right more quickly than the one on the left**
- I was able to understand both displays equally quickly**

Table 8 Comparative speed with which the graph was understood

	Travel Time	Trajectory Graph	No Preference
Traffic Professional	30%	50%	20%
Non Professional	49%	35%	15%
Overall	42%	41%	17%

### Comment

The final question allowed the respondent to make any freeform comments that he felt was appropriate.

*4. Please enter any comments or suggestions in the box below*

### Discussion of Issues

Respondents to the survey were recruited via e-mail, word of mouth and convenience sampling. Therefore some amount of bias from respondent self-selection may be present in the data, as well as sampling error. Additionally, invitation online sampling and other forms of bias associated with web surveys is also present in the poll results.

## Web survey advantages and disadvantages

Web based surveys have several advantages including the fact that they are convenient for users and therefore will generate a relatively large number of respondents in a relatively short period of time. Traditional measurement errors associated with transcription and recording of data are eliminated in Web based surveys through electronic real-time entry of the data. Transcription, interpretation and processing errors are likewise eliminated due to automated data processing. Since there are no interviewers or transcribers, human error from these sources is eliminated. The order of presentation of graphic displays can be randomized to eliminate order bias as was done in this survey. Studies have shown that on-line surveys generate similar results as standard paper-and-pencil or telephone surveys.

Perhaps the greatest source of error for this survey was due to the fact that invitation online sampling and word of mouth were the major methods of recruitment of survey respondents. Invitation on-line sampling leads to a form of sampling error called self-selection error that introduces socioeconomic and demographic biases into the sample frame. One issue with self-selection is that people who respond to surveys tend to be better educated, have higher incomes, and feel more strongly about the matters dealt with in the questionnaire than the general population. While this survey did not sample income levels of respondents, education levels were sampled and found to be considerably higher than the general population indicating that this survey does suffer from self-selection bias.

Other issues with Web based surveys may include differences in format and display caused by the numerous combinations of hardware and software available. Issues such as the type, resolution and size of monitor, the browser brand and version, and operating system will affect the display of graphic images and the appearance of browser features such as drop-down boxes, checkboxes and radio buttons. Font characteristics, bolding and italicizing, horizontal and vertical spacing may appear different on certain combinations of hardware and software. Since this survey relied on a graphical component, any or all of these items may have influenced the survey results.

### **Withdrawal error**

This survey also suffered from withdrawal error. For some reason, respondents on Path B of the survey dropped out at a far greater rate than those on Path A. When the survey and Web page were designed, this issue was not expected. If it had been anticipated, incremental logging of progress during the survey could have been included in the survey design. Incremental logging would allow analysis of which page of the survey that respondents withdrew from the study. However, because of the lack of incremental logging in the design of the survey, it is difficult to speculate where respondents withdrew and therefore why they might have done so.

Incremental logging would not be difficult to implement and is a feature that should be included in similar surveys of this type.

## CONCLUSIONS

This thesis has adapted a stacked bar graph methodology as an alternative to traditional methods of displaying travel time for traffic analysis. The study used data collected from a vehicle equipped with a passive GPS receiver that made several traverses of a selected roadway in Austin, TX. Raw data from the GPS was converted into a detailed record of the test vehicle's progress using custom designed software. These data were then converted into graphical displays that were included in a Web based survey. Both the software to create the charts and the software to conduct and analyze the survey were designed especially for this research.

The survey was designed to avoid prejudicing the results by presenting approximately half of the survey respondents were presented the stacked bar graph first while the other half were presented the trajectory vector graph. Survey respondents included both traffic professionals and non professionals. Results show that both groups answered travel time questions much more accurately using the stacked bar graph than the traditional method. Overall, respondents answered travel time questions with a 65% accuracy using the stacked bar graph as compared to 38% using the trajectory vector diagram. In addition, users preferred the stacked bar graph and were more confident in their answers when using this display.

## **Limitations**

The survey suffered from several limitations due to the fact that it was a Web based survey using invitation on-line sampling for recruitment of respondents. Self selection bias is evident in the results as evidenced by the fact that education level of the respondents was considerably higher than that of the general population.

## **Summary of Contributions**

This research demonstrated that simple graphical displays can be effective in increasing the comprehension level of travel time information for both traffic professionals and non professionals. This may help to provide a wide variety of users the common level of understanding of traffic problems that fosters thoughtful discussion of traffic issues. With better dialogue there may be a greater ability to leverage available resources to provide better and more robust solutions to the problems plaguing the traveling public, taxpayers and other stakeholders in our transportation network.

## **Statement of Future Research**

Future research involving display of travel time and travel time reliability information should focus on presenting the information to end users in a way that appropriately provides information to a wide range of end users. For example, a display or methodology that communicates performance in a manner that is meaningful to the

freight community may not make much sense to a daily commuter who is trying to find the most efficient route to take to work in the morning. The most efficient displays of system performance would be intuitive and speak equally well to both groups.

The passive GPS tracking system used for the data collected for this thesis is relatively inexpensive and easy to use. Due to the economical nature of the system, similar units can be widely deployed to collect regional data. GPS tracking units were installed in hundreds of vehicles in three cities in Sweden and observed for up to two years (Wolf et al, 2004). Information from such studies can provide detailed historical data about the movement of individual vehicles, thus providing a regional database of transportation indicators.

One example of the use of these data would be to form the basis for the establishment of a more holistic, regionally derived model of the transportation network and its performance factors rather than relying entirely on the analysis of data from established data collection points along main corridors where speeds are measured by more traditional methods.

Data from vehicles equipped with passive GPS units offer a unique measure of performance since these vehicles could be privately owned and therefore representative of the normal driving behavior, whereas most current AVL and traffic probe data is made up of information from transit vehicles, delivery trucks or other fleet vehicles.

Information from vehicles equipped with passive GPS units would allow researchers to analyze the progress of individual vehicles through a road network and use these data to create a database of past travel times and to make predictions of expected future travel times. This database of historical information will allow researchers to compute travel time estimates that provide actual point-to-point travel times based on real world historical data. These historical data can be compared with real time data to provide knowledge regarding how specific facilities are performing.

## **APPENDIX I**

### **SURVEY SOURCE CODE**

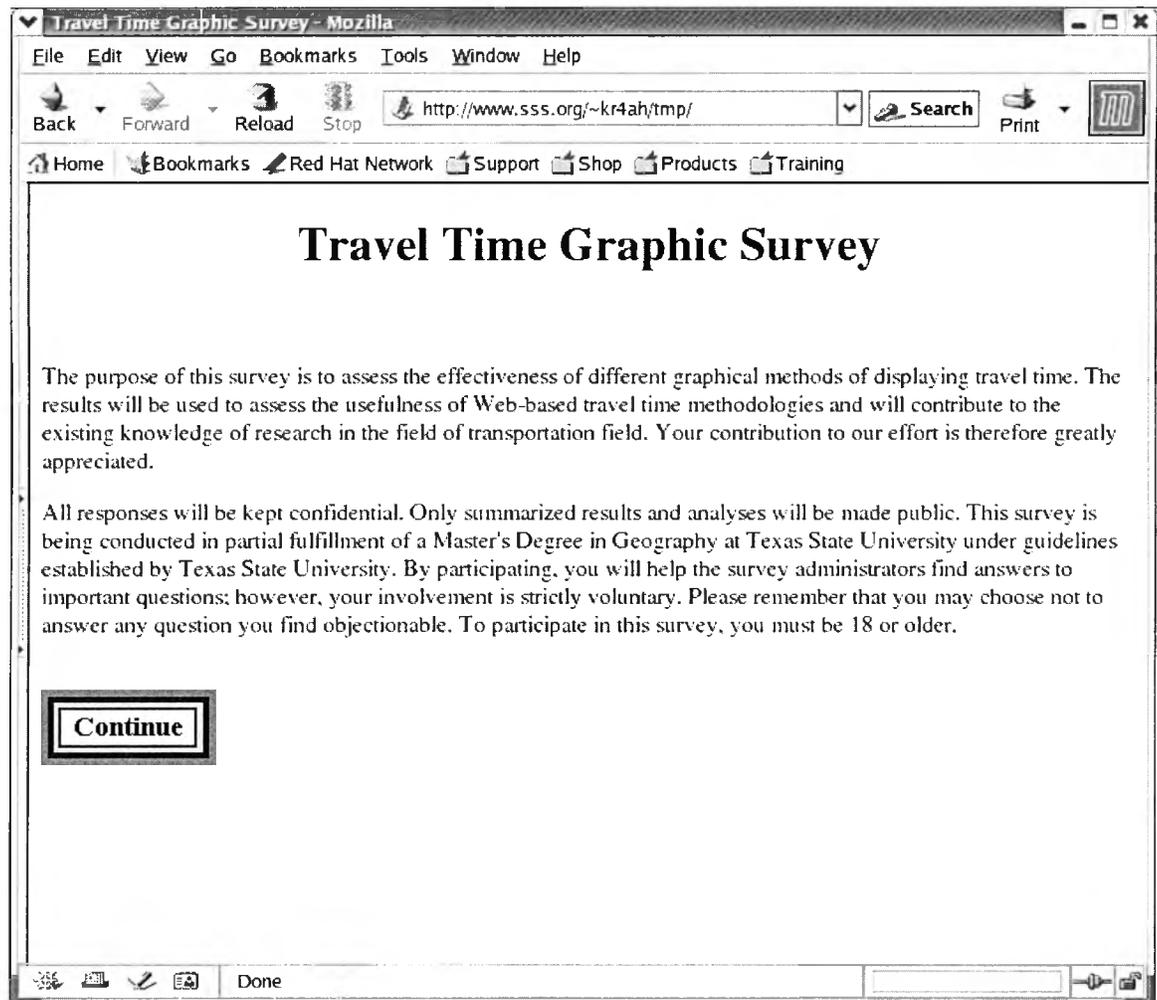
The following sections contain a short description of the contents of each survey page, a screen capture of the page as it appeared on the Web and source code. The source code is written in PHP, a language designed to allow the author flexibility in presentation of Web pages. This language provides for tracking of users as they proceed through a series of Web pages and logging of responses, thus providing an ideal environment for creating a survey form. The code ran under PHP version 4, the current version available on the Web server at the time of the survey and should be compatible with future releases. This source code is available as Open Source <<http://www.opensource.org/>> software and may be modified for use in other projects under the Open Source Software License current at the time of use.

#### **SURVEY PAGE 1**

Page 1 introduces the Travel Time Graphic Survey, explains the purpose of the survey and creates the environment for the remainder of the survey. There is a statement in compliance with the requirements of Texas State University Institutional Review Board for Human Subjects Protection (TXState IRB) that this survey would not collect

any identifying information about the respondents other than year of birth, gender, education level and experience level and that only summarized results and analyses would be made public.

This page also creates the environment for the survey and decides whether the survey will follow PathA or PathB. PathA introduces the Trajectory Vector Graph before the Travel Time Stacked Bar Graph while PathB reverses the order of appearance of the two graphs. A randomly generated SurveyID is created and used for housekeeping purposes and the start time is recorded. A screen capture of page 1 of the survey appears below.



### Source Code for Page 1

```
<?php
### The following print statement opens the Web page
print "<HTML>\n\n<HEAD>\n\n";

### Random numbers are used to assign the survey to either
### path A or Path B and create a Survey ID for tracking
### purposes.

### Create a "seed" for the random number generator.
mt_srand ((float) microtime() * 1000000);

### Create several random numbers
$random1 = mt_rand(0,1);    ### Will be either 0 or 1
```

```

$random2 = mt_rand(0,2);    ### 0, 1, or 2
$random3 = mt_rand(0,10);  ### 0 - 9
$random4 = mt_rand(0,9);   ### 0 - 8
$random5 = mt_rand(0,9);   ### 0 - 8

### Create title for the Web page

$title = "Travel Time Graphic Survey";

### The following print statements finish the head, open
### the body and create the page title centered in the browser

print "<title>$title</title>";
print "</HEAD>\n\n<BODY bgcolor=\"#ffffff\"> <center>";
print "<H1> $title </H1> </center>";
print "<br><P>\n\n";

### The following print statements are the body of text as
### displayed in the browser

print "The purpose of this survey is to assess the effectiveness\n";
print "of different graphical methods of displaying travel \n";
print "time. The results will be used to assess the usefulness \n";
print "of Web-based travel time methodologies and will \n";
print "contribute to the existing knowledge of research in \n";
print "the field of transportation field. Your contribution to \n";
print "our effort is therefore greatly appreciated.\n";

### A second paragraph of text.

print "<P>\n";
print "All responses will be kept confidential. Only summarized \n";
print "results and analyses will be made public. \n";
print "This survey is being conducted in partial fulfillment of \n";
print "a Master's Degree in Geography at Texas State University \n";
print "under guidelines established by Texas State University. \n";
print "By participating, you will help the survey administrators \n";
print "find answers to important questions; however, your \n";
print "involvement is strictly voluntary. Please remember that \n";
print "you may choose not to answer any question you find \n";
print "objectionable. To participate in this survey, you must be \n";
print "18 or older.<BR>\n<BR>\n";

### The uses FORMS to get feedback from the respondent.
### The following print statement sets up the form.

print "<FORM METHOD=POST";
print "ACTION=\"http://24.242.128.21/maps/survey/page2.php\"</n";

### Select PathA or PathB

if ($random1 == 1)
{
    $survey_path = "PathA";
}
else
{
    $survey_path = "PathB";
}

### Housekeeping variables to be passed on to the
### following pages.

### Starting time of the survey so we can see how long it
### took to complete.

$start_time = time();

```

```

### Survey ID for housekeeping purposes
$survey_ID = $random2 . $random3 . $random4 . $random5;
$survey_ID = $survey_ID . $survey_path $random1;

### These values get passed to the next page

print "<INPUT type=\"hidden\" NAME=type VALUE=\"A\">\n";
print "<INPUT type=\"hidden\" NAME=start_time VALUE=$start_time>\n";
print "<INPUT type=\"hidden\" NAME=begin VALUE=$start_time>\n";
print "<INPUT type=\"hidden\" NAME=SurveyPath VALUE=$survey_path>\n";

### This is the button to take the respondent to the next page.

print "<INPUT TYPE=IMAGE SRC=\"survey/images/continue.gif\" "
print " NAME=\"submitted\">\n";

### Close out the FORM

print "</FORM>\n";

### Close out the Web page

print "</body>\n\n";
print "</html>\n\n";
?>

```

## SURVEY PAGE 2

Page 2 of the survey collects demographic data from the respondent. Due to TXState IRB requirements, data was limited to year of birth, gender, level of education and level of experience with traffic issues. A screen capture of Page 2 appears below.

Travel Time Graphic Survey Mozilla

File Edit View Go Bookmarks Tools Window Help

Back Forward Reload Stop <http://www.sss.org/~kr4ah/tmp/survey/page2.pl> Search Print

Home Bookmarks Red Hat Network Support Shop Products Training

## Travel Time Graphic Survey

Please answer the following questions before continuing. Please complete all the questions in sequence and respond to each statement or question. You are invited to add comments at the end of the questionnaire.

1. What year were you born?
2. What is your gender?
  - Male
  - Female
3. What is the highest level of education you completed?
  - Less than 9th grade completed
  - 9th to 12th grade completed - No Diploma
  - High School graduate - Include Equivalency
  - Some College or Associate degree
  - Bachelor or Professional degree
  - Post-Graduate degree
4. Which statement best describes your level of experience with traffic

Done

### Source Code for Page 2

```
<?php
### The following print statement opens the Web page
print "<HTML>\n\n<HEAD>\n\n";

### Create title for the Web page
$title = "Travel Time Graphic Survey";

### The following print statements finish the head, open
### the body and create the page title centered in the browser

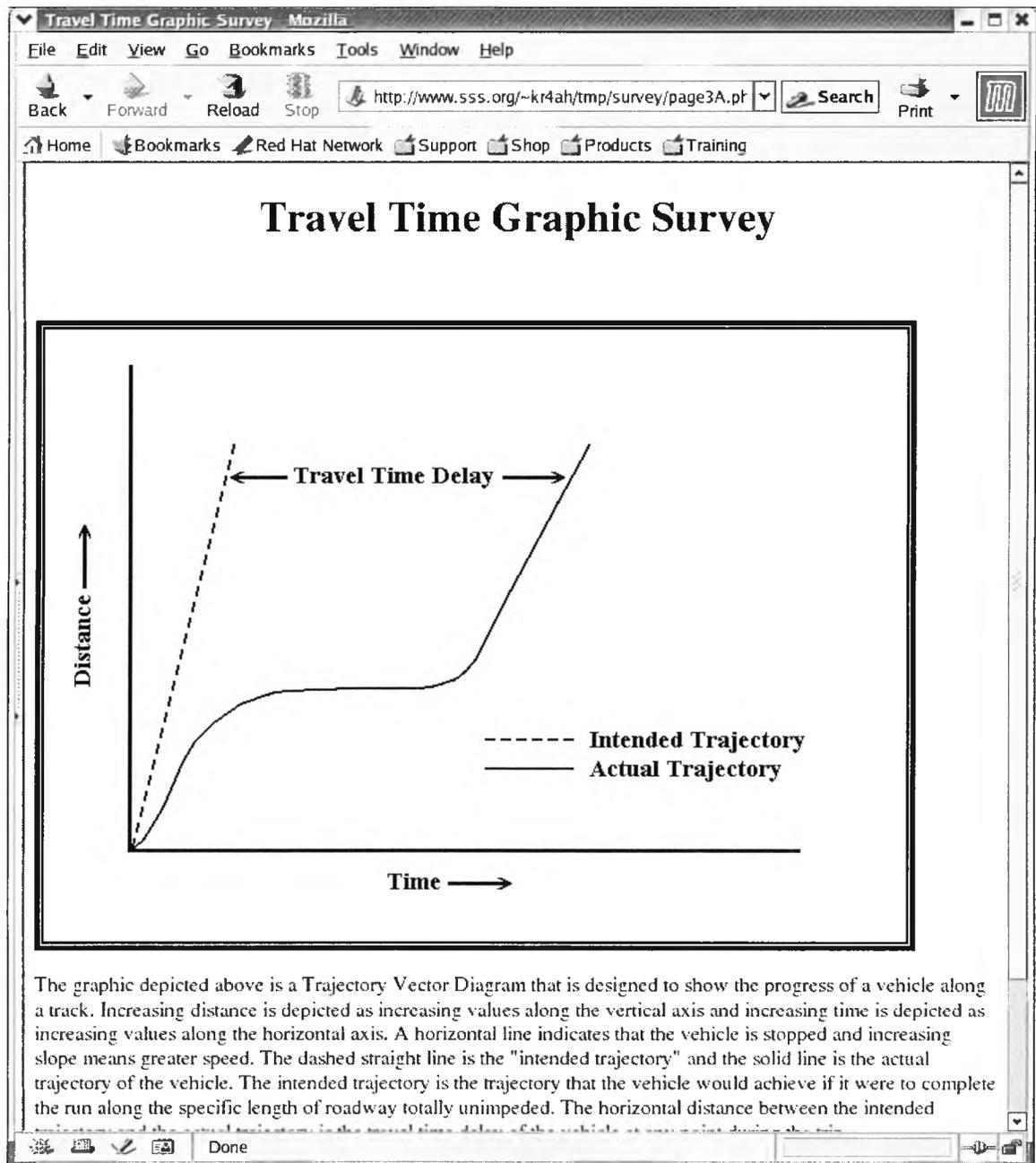
print "<title>$title</title>";
print "</HEAD>\n\n<BODY bgcolor=\n\n\"#ffffff\"> <center>";
print " <H1> $title </H1> </center>";
print "<br><P>\n\n";
```





### SURVEY PAGE 3

Page 3 of the survey is the first page where the paths diverge. Along PathA, the Trajectory Vector Graph is introduced and a short explanation is given. For PathB the Travel Time Graph is introduced. A screen capture of page 3A appears below.



### Source Code for Page 3

```
<?php
    ### The following print statement opens the Web page
```

```

print "<HTML>\n\n<HEAD>\n\n";

### Create title, header and body opening for the Web page

$title = "Travel Time Graphic Survey";
print "<title>$title</title>";
print "</HEAD>\n\n<BODY bgcolor=\`#\`ffffff\`"> <center> ";
print "<H1> $title </H1> </center>";
print "<br><P>\n\n";

### Place the figure of the Trajectory Vector Diagram on
### on the Web page.

print "<IMG SRC=\`images/figure_1.gif\`";
print " ALT=\`Trajectory Vector Diagram\`";
print " ALIGN=\`CENTER\`">\n\n";

### Be sure that the text does not try to wrap around the figure

print "<BR CLEAR=\`ALL\`">\n\n";

### Provide a short synopsis of the Trajectory Vector Diagram

print "<P>The graphic depicted above is a Trajectory Vector Diagram \n";
print "that is designed to show the progress of a vehicle along \n";
print "a track. Increasing distance is depicted as increasing values \n";
print "along the vertical axis and increasing time is depicted as \n";
print "increasing values along the horizontal axis. A horizontal line \n";
print "indicates that the vehicle is stopped and increasing slope \n";
print "means greater speed. The dashed straight line is the \n";
print "&quot;intended trajectory&quot; and the solid line is the actual \n";
print "trajectory of the vehicle. The intended trajectory is the \n";
print "trajectory that the vehicle would achieve if it were to \n";
print "complete the run along the specific length of roadway \n";
print "totally unimpeded.\n";
print "\n";

print "The horizontal distance between the intended trajectory and the \n";
print "actual trajectory is the travel time delay of the vehicle at \n";
print "any point during the trip. \n";

print "<P>The trajectory vector diagram is often used to depict \n";
print "multiple runs along a route. \n";
print "The dashed line is often left out of graphs \n";
print "depicting multiple runs.\n";
print "<P>";
print "\n";

### This code sets up the FORM

print "<FORM METHOD=POST ";
print "ACTION=\`http://24.242.128.21/maps/survey/page4A php\`"\n\n";

### These values are housekeeping passed on to the following
### page as hidden values that are not seen by the respondent

print "<INPUT type=\`hidden\` NAME=type VALUE=\`A\`">\n";
print "<INPUT TYPE=\`hidden\` NAME=start_time VALUE=$start_time>\n";
print "<INPUT TYPE=\`hidden\` NAME=year_born VALUE=$year_born>\n";
print "<INPUT TYPE=\`hidden\` NAME=gender VALUE=$gender>\n";
print "<INPUT TYPE=\`hidden\` NAME=grade VALUE=$grade>\n";
print "<INPUT TYPE=\`hidden\` NAME=experience VALUE=$experience>\n";

### This is the button to take the respondent to the next page.

print "<INPUT TYPE=SUBMIT VALUE=\`Continue to Page 4\`">\n\n";

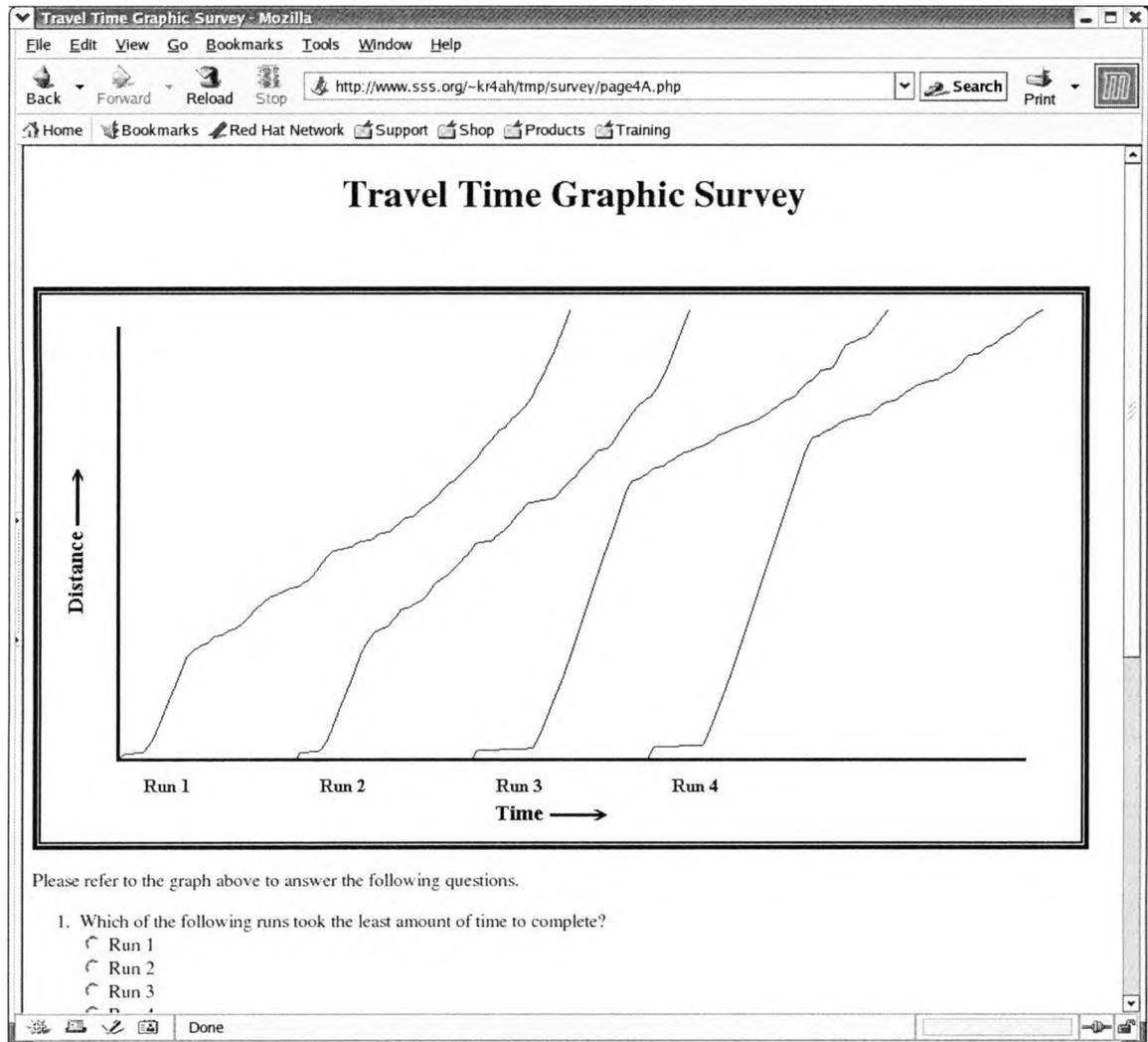
### Close out the FORM

```

```
print "</FORM>\n";  
  
### Close out the Web pag  
  
print "</body>\n\n";  
print "</html>\n\n";  
?>
```

## SURVEY PAGE 4

Page 4 gathers user responses regarding the selected graphic display. Four questions ask the user to rate the various runs in order of travel time and a fifth question asks the user his confidence level with regard to his answers. A screen capture of Page 4A appears below.



### Source Code for Page 4

```
<?php
    ### The following print statement opens the Web page
    print "<HTML>\n\n<HEAD>\n\n";

    ### Create title, header and body opening for the Web page

    $title = "Travel Time Graphic Survey";
    print "<title>$title</title>";
    print "</HEAD>\n\n<BODY bgcolor=\"#ffffff\"> <center> ";
    print "<H1> $title </H1> </center>";
    print "<br><P>\n\n";

    ### Place the figure of the Trajectory Vector Diagram
```

```

### with the real data on the Web page.

print "<IMG SRC=\"images/Figure_3.gif\"";
print " ALT=\"Trajectory Vector Diagram\"";
print " ALIGN=\"CENTER\">\n";

### Be sure that the text does not try to wrap around the figure

print "<BR CLEAR=\"ALL\">\n";

### Text of the instructions

print "<P>Please refer to the graph above to answer the ";
print "following questions.\n";

print "<FORM METHOD=POST ";
print "ACTION=\"http://24.242.128.21/maps/survey/page5A.php\">\n";

### The questions are in ORDERED LIST format. The
### following print statements are questions and answers

print "<OL>\n";
print "<LI>\n";
print "Which of the following runs took the least amount \n";
print "of time to complete?<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMin1 VALUE=\"Run1\">\n";
print "Run 1<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMin1 VALUE=\"Run2\">\n";
print "Run 2<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMin1 VALUE=\"Run3\">\n";
print "Run 3<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMin1 VALUE=\"Run4\">\n";
print "Run 4<BR>\n";
print "<LI>\n";
print "Which of the following runs took the second least amount \n";
print "of time to complete?<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMin2 VALUE=\"Run1\">\n";
print "Run 1<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMin2 VALUE=\"Run2\">\n";
print "Run 2<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMin2 VALUE=\"Run3\">\n";
print "Run 3<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMin2 VALUE=\"Run4\">\n";
print "Run 4<BR>\n";
print "<LI>\n";
print "Which of the following runs took the most amount \n";
print "of time to complete?<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMax1 VALUE=\"Run1\">\n";
print "Run 1<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMax1 VALUE=\"Run2\">\n";
print "Run 2<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMax1 VALUE=\"Run3\">\n";
print "Run 3<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMax1 VALUE=\"Run4\">\n";
print "Run 4<BR>\n";
print "<LI>\n";
print "Which of the following runs took the second most amount \n";
print "of time to complete?<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMax2 VALUE=\"Run1\">\n";
print "Run 1<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMax2 VALUE=\"Run2\">\n";
print "Run 2<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMax2 VALUE=\"Run3\">\n";
print "Run 3<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajMax2 VALUE=\"Run4\">\n";
print "Run 4<BR>\n";
print "<LI>\n";
print "I am confident that I understand the information that\n";

```

```

print "the graphic is presenting.<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajConfidence VALUE=1>\n";
print "Not at all<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajConfidence VALUE=2>\n";
print "Slightly<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajConfidence VALUE=3>\n";
print "Somewhat<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajConfidence VALUE=4>\n";
print "Almost completely<BR>\n";
print "<INPUT TYPE=RADIO NAME=TrajConfidence VALUE=5>\n";
print "Completely<BR>\n";
print "</OL>\n";

### These values are housekeeping passed on to the following
### page as hidden values that are not seen by the respondent

print "<INPUT type=\"hidden\" NAME=type VALUE=\"A\">\n";
print "<INPUT TYPE=\"hidden\" NAME=start_time VALUE=$start_time>\n";
print "<INPUT TYPE=\"hidden\" NAME=year_born VALUE=$year_born>\n";
print "<INPUT TYPE=\"hidden\" NAME=gender VALUE=$gender>\n";
print "<INPUT TYPE=\"hidden\" NAME=grade VALUE=$grade>\n";
print "<INPUT TYPE=\"hidden\" NAME=experience VALUE=$experience>\n";

### This is the button to take the respondent to the next page.

print "<INPUT TYPE=SUBMIT VALUE=\"Continue to Page 5\">\n";

### Close out the FORM

print "</FORM>\n";

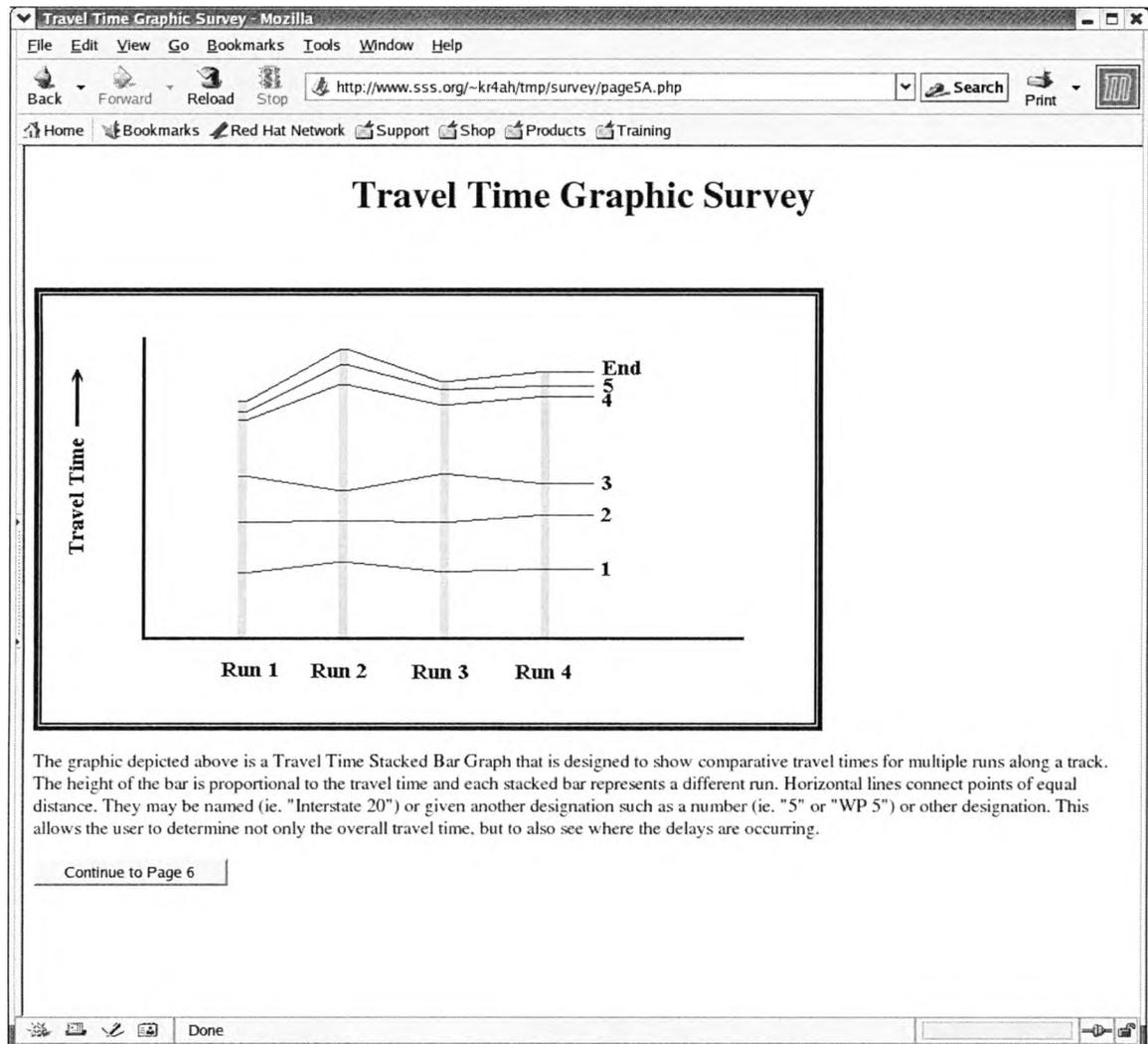
### Close out the Web page

print "</body>\n\n";
print "</html>\n\n";
?>

```

## SURVEY PAGE 5

Page 5 of the survey on PathA is identical to Page 3 of the survey on Path B. The Travel Time Graph is introduced. A screen capture of page 5A appears below.



### Source Code for Page 5

```
<?php
    ### The following print statement opens the Web page
    print "<HTML>\n\n<HEAD>\n\n";

    ### Create title for the Web page
    $title = "Travel Time Graphic Survey";

    ### The following print statements finish the head, open
    ### the body and create the page title centered in the browser
    print "<title>$title</title>";
```

```

print "</HEAD>\n\n<BODY bgcolor=\\"#ffffff\"> <center> <H1> $title </H1>
</center>";
print "<br><P>\n\n";

### Place the figure of the Travel Time Graph
### on the Web page.

print "<IMG SRC=\\"images/Figure_2.gif\"";
print " ALT=\\"Travel Time Graph\"";
print " ALIGN=\\"CENTER\">\n";

### Be sure that the text does not try to wrap around the figure

print "<BR CLEAR=\\"ALL\">\n";

### Provide a short synopsis of the Travel Time Graph

print "<P>The graphic depicted above is a Travel Time Stacked Bar \n";
print "Graph that is designed to show comparative travel times for \n";
print "multiple runs along a track. The height of the bar is \n";
print "proportional to the travel time and each stacked bar represents \n";
print "a different run. Horizontal lines connect points of equal \n";
print "distance. They may be named (ie. &quot;Interstate 20&quot;) \n";
print "or given another designation such as a number (ie. &quot;5&quot; \n";
print "or &quot;WP 5&quot;) or other designation. This allows the user \n";
print "to determine not only the overall travel time, but to also see \n";
print "where the delays are occurring. \n";
print "\n";
print "<P>";
print "\n";

### This code sets up the FORM

print "<FORM METHOD=POST
ACTION=\\"http://24.242.128.21/maps/survey/page6A.php\"";

### These values are housekeeping passed on to the following
### page as hidden values that are not seen by the respondent

print "<INPUT type=\\"hidden\" NAME=type VALUE=\\"A\">\n";
print "<INPUT TYPE=\\"hidden\" NAME=start_time VALUE=$start_time>\n";
print "<INPUT TYPE=\\"hidden\" NAME=year_born VALUE=$year_born>\n";
print "<INPUT TYPE=\\"hidden\" NAME=gender VALUE=$gender>\n";
print "<INPUT TYPE=\\"hidden\" NAME=grade VALUE=$grade>\n";
print "<INPUT TYPE=\\"hidden\" NAME=experience VALUE=$experience>\n";
print "<INPUT TYPE=\\"hidden\" NAME=TrajMin1 VALUE=$TrajMin1>\n";
print "<INPUT TYPE=\\"hidden\" NAME=TrajMin2 VALUE=$TrajMin2>\n";
print "<INPUT TYPE=\\"hidden\" NAME=TrajMax1 VALUE=$TrajMax1>\n";
print "<INPUT TYPE=\\"hidden\" NAME=TrajMax2 VALUE=$TrajMax2>\n";
print "<INPUT TYPE=\\"hidden\" NAME=TrajConfidence VALUE=$TrajConfidence>\n";

### This is the button to take the respondent to the next page.

print "<INPUT TYPE=SUBMIT VALUE=\\"Continue to Page 6\">\n";

### Close out the FORM

print "</FORM>\n";

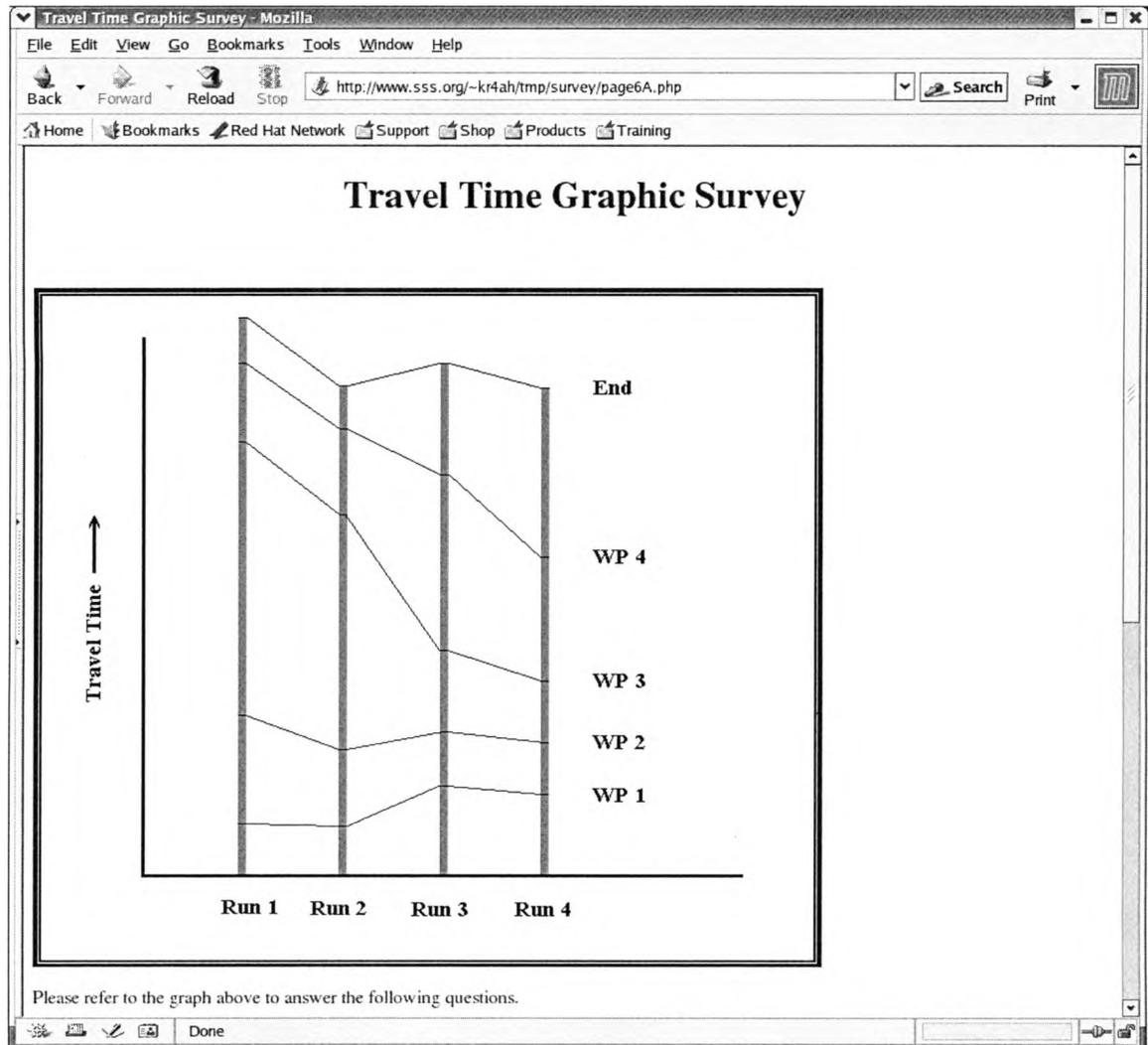
### Close out the Web page

print "</body>\n\n";
print "</html>\n\n";
?>

```

## SURVEY PAGE 6

Page 6 gathers user responses regarding the selected graphic display. Four questions ask the user to rate the various runs in order of travel time and a fifth question asks the user his confidence level with regard to his answers. A screen capture of Page 6A appears below.



### Source Code for Page 6

```
<?php
    ### The following print statement opens the Web page
    print "<HTML>\n\n<HEAD>\n\n";

    ### Create title, header and body opening for the Web page
    $title = "Travel Time Graphic Survey";
    print "<title>$title</title>";
    print "</HEAD>\n\n<BODY bgcolor=\"#ffffff\"> <center> ";
    print "<H1> $title </H1> </center>";
    print "<br><P>\n\n";

    ### Place the figure of the Travel Time Graph
```

```

### with the real data on the Web page

print "<IMG SRC=\"images/Figure_4.gif\"";
print " ALT=\"Travel Time Graph\"";
print " ALIGN=\"CENTER\">\n";

### Be sure that the text does not try to wrap around the figure

print "<BR CLEAR=\"ALL\">\n";

### Text of the instructions

print "<P>Please refer to the graph above to answer the ";
print "following questions.\n";

### Set up the FORM

print "<FORM METHOD=POST ";
print "ACTION=\"http://24.242.128.21/maps/survey/page7A.php\">\n";

### The questions are in ORDERED LIST format. The
### following print statements are questions and answers

print "<OL>\n";
print "<LI>\n";
print "Which of the following runs took the least amount \n";
print "of time to complete?<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMin1 VALUE=\"Run1\">\n";
print "Run 1<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMin1 VALUE=\"Run2\">\n";
print "Run 2<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMin1 VALUE=\"Run3\">\n";
print "Run 3<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMin1 VALUE=\"Run4\">\n";
print "Run 4<BR>\n";
print "<LI>\n";
print "Which of the following runs took the second least amount \n";
print "of time to complete?<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMin2 VALUE=\"Run1\">\n";
print "Run 1<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMin2 VALUE=\"Run2\">\n";
print "Run 2<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMin2 VALUE=\"Run3\">\n";
print "Run 3<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMin2 VALUE=\"Run4\">\n";
print "Run 4<BR>\n";
print "<LI>\n";
print "Which of the following runs took the most amount \n";
print "of time to complete?<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMax1 VALUE=\"Run1\">\n";
print "Run 1<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMax1 VALUE=\"Run2\">\n";
print "Run 2<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMax1 VALUE=\"Run3\">\n";
print "Run 3<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMax1 VALUE=\"Run4\">\n";
print "Run 4<BR>\n";
print "<LI>\n";
print "Which of the following runs took the second most amount \n";
print "of time to complete?<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMax2 VALUE=\"Run1\">\n";
print "Run 1<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMax2 VALUE=\"Run2\">\n";
print "Run 2<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMax2 VALUE=\"Run3\">\n";
print "Run 3<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTMax2 VALUE=\"Run4\">\n";
print "Run 4<BR>\n";

```

```

print "<LI>\n";
print "I am confident that I understand the information that\n";
print "the graphic is presenting.<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTConfidence VALUE=1>\n";
print "Not at all<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTConfidence VALUE=2>\n";
print "Slightly<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTConfidence VALUE=3>\n";
print "Somewhat<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTConfidence VALUE=4>\n";
print "Almost completely<BR>\n";
print "<INPUT TYPE=RADIO NAME=TTConfidence VALUE=5>\n";
print "Completely<BR>\n";
print "</OL>\n";

### These values are housekeeping passed on to the following
### page as hidden values that are not seen by the respondent

print "<INPUT type=\"hidden\" NAME=type VALUE=\"A\">\n";
print "<INPUT TYPE=\"hidden\" NAME=start_time VALUE=$start_time>\n";
print "<INPUT TYPE=\"hidden\" NAME=year_born VALUE=$year_born>\n";
print "<INPUT TYPE=\"hidden\" NAME=gender VALUE=$gender>\n";
print "<INPUT TYPE=\"hidden\" NAME=grade VALUE=$grade>\n";
print "<INPUT TYPE=\"hidden\" NAME=experience VALUE=$experience>\n";
print "<INPUT TYPE=\"hidden\" NAME=TrajMin1 VALUE=$TrajMin1>\n";
print "<INPUT TYPE=\"hidden\" NAME=TrajMin2 VALUE=$TrajMin2>\n";
print "<INPUT TYPE=\"hidden\" NAME=TrajMax1 VALUE=$TrajMax1>\n";
print "<INPUT TYPE=\"hidden\" NAME=TrajMax2 VALUE=$TrajMax2>\n";
print "<INPUT TYPE=\"hidden\" NAME=TrajConfidence ";
print "VALUE=$TrajConfidence>\n";

### This is the button to take the respondent to the next page.

print "<INPUT TYPE=SUBMIT VALUE=\"Continue to Page 7\">\n";

### Close out the FORM

print "</FORM>\n";

### Close out the Web page

print "</body>\n\n";
print "</html>\n\n";
?>

```

## SURVEY PAGE 7

This page asks the user to compare the effectiveness of the two display methodologies in terms of preference, confidence and speed of comprehension. There is

also an area that allows the user to insert any freeform comments or suggestions. Below is a screen capture of Page 7.

Travel Time Graphic Survey - Mozilla

File Edit View Go Bookmarks Tools Window Help

Back Forward Reload Stop <http://www.sss.org/~k> Search Print

Home Bookmarks Red Hat Network Support Shop Products Training

## Travel Time Graphic Survey

Please compare the effectiveness of the two methods of representing travel time

- 1. Display Preference**  
 Please rate the graphs on the ease of extracting information
  - I prefer the display on the left
  - I prefer the display on the right
  - I do not have a preference
- 2. Display Confidence**  
 Please rate the graphs on your confidence level that the answers you gave are correct
  - I had greater confidence in the display on the left
  - I had greater confidence in the display on the right
  - I had equal confidence in my ability to understand both displays
- 3. Display Speed**  
 Please rate the graphs based on the amount of time it took you to understand the information presented
  - I was able to understand the display on the left more quickly than the one on

Done

## Source Code for Page 7

```

<?php
    ### The following print statement opens the Web page

    print "<HTML>\n\n<HEAD>\n\n";

    ### Create title, header and body opening for the Web page

    $title = "Travel Time Graphic Survey";
    print "<title>$title</title>";
    print "</HEAD>\n\n<BODY bgcolor=#ffffff> <center> <H1> ";
    print "$title </H1> </center>";
    print "<br><P>\n\n";

    ### Instructions for comparing the two methodologies

    print "<P>Please compare the effectiveness of the two methods of ";
    print "representing travel time";
    print "<BR><BR>";
    print "\n";

    ### Place the two figures on the Web page.

    print "<IMG SRC=\"images/Figure_1.gif\" ALT=\"Method A\" ";

    ### This forces the diagram into an area of 250 X 150 pixels

    print "ALIGN=\"LEFT\" WIDTH=250 HEIGHT=150 BORDER=2>\n";
    print "<IMG SRC=\"images/Figure_2.gif\" ALT=\"Method B\" ";
    print "ALIGN=\"RIGHT\" WIDTH=250 HEIGHT=150 BORDER=2>\n";
    print "<BR CLEAR=ALL><BR><BR><BR>\n";

    ### Set up the FORM

    print "<FORM METHOD=POST ";
    print "ACTION=\"http://24.242.128.21/maps/survey/page8.php\">\n";

    ### The questions are in ORDERED LIST format. The
    ### following print statements are questions and answers

    print "<OL>\n";
    print "<LI>\n";
    print "Display Preference <BR>\n";
    print "Please rate the graphs on the ease of extracting ";
    print "information <BR>\n";
    print "&nbsp;&nbsp;&nbsp;";
    print "<INPUT TYPE=\"radio\" NAME=\"DisplayPreference\" ";
    print "VALUE=\"Trajectory\">";
    print "&nbsp;&nbsp;&nbsp;I prefer the display on the left<BR>\n";
    print "&nbsp;&nbsp;&nbsp;";
    print "<INPUT TYPE=\"radio\" NAME=\"DisplayPreference\" ";
    print "VALUE=\"TravelTime\">";
    print "&nbsp;&nbsp;&nbsp;I prefer the display on the right<BR>\n";
    print "&nbsp;&nbsp;&nbsp;";
    print "<INPUT TYPE=\"radio\" NAME=\"DisplayPreference\" ";
    print "VALUE=\"None\">";
    print "&nbsp;&nbsp;&nbsp;I do not have a preference<BR>\n";
    print "<BR><BR>\n";
    print "<LI>\n";
    print "Display Confidence <BR>\n";
    print "Please rate the graphs on your confidence level that the \n";
    print "answers you gave are correct <BR>\n";

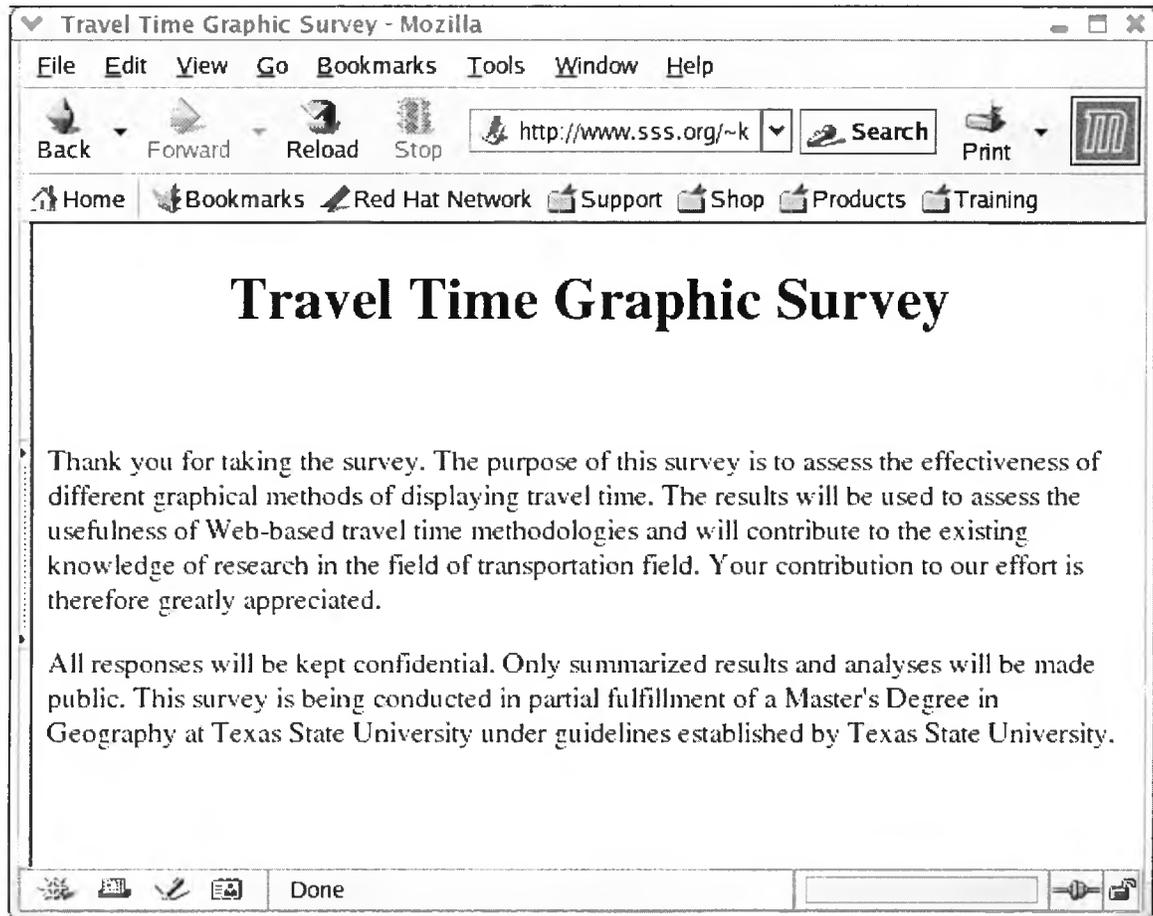
```



```
print "<INPUT TYPE=SUBMIT VALUE=\"Continue to final page\">\n";  
### Close out the FORM  
print "</FORM>\n";  
### Close out the Web page  
print "</body>\n\n";  
print "</html>\n\n";  
>
```

## SURVEY PAGE 8

Page 8 is the final page of the survey. It thanks the respondent for his participation, reiterates that the information will be kept confidential and that only summarized results and analyses will be published. Page 8 also handles the logging of all the data collected. A screen capture of Page 8 appears below.



### Source Code for Page 8

```
<?php
    ### The following print statement opens the Web page
    print "<HTML>\n\n<HEAD>\n\n";

    ### This is a PHP function that gets the IP address of the
    ### respondent

function getIP()
{
    $tmparr = array();
    $tmparr[] = $_SERVER['REMOTE_ADDR'];
    if (isset($_SERVER['HTTP_X_FORWARDED_FOR']))
    {
        $tmparr += explode(',', $_SERVER['HTTP_X_FORWARDED_FOR']);
    }
    return $tmparr;
}
```

```

### This function call gets the IP address of the
### respondent so that duplicate respondents can
### be identified

$ip = getenv("REMOTE_ADDR");

### Create title

$title = "Travel Time Graphic Survey";

### Get the time that the survey ends

$end_time = time();

### The logfile name will be the in the form of
### Final_NNNNNNNNN.txt in the data directory
### Each file will contain information about
### one survey

### The following line creates the file name

$filename = "data/Final_" . "$end_time" . ".txt";

### The following lines create an array of data to be
### sent to the file

$data_out = "Start Time = $start_time<BR>\n";
$data_out = $data_out . "End Time = $end_time<BR>\n";
$data_out = $data_out . "Ip Address = $ip<BR>\n";
$data_out = $data_out . "Path = $Path<BR>\n";
$data_out = $data_out . "Year of Birth = $year_born<BR>\n";
$data_out = $data_out . "Gender = $gender<BR>\n";
$data_out = $data_out . "Education = $grade<BR>\n";
$data_out = $data_out . "Experience Level = $experience<BR>\n";
$data_out = $data_out . "Trajectory Min = $TrajMin1<BR>\n";
$data_out = $data_out . "Trajectory second Min = $TrajMin2<BR>\n";
$data_out = $data_out . "Trajectory Max = $TrajMax1<BR>\n";
$data_out = $data_out . "Trajectory second Max = $TrajMax2<BR>\n";
$data_out = $data_out . "Trajectory Confidence = $TrajConfidence<BR>\n";
$data_out = $data_out . "Travel Time Min = $TTMin1<BR>\n";
$data_out = $data_out . "Travel Time second Min = $TTMin2<BR>\n";
$data_out = $data_out . "Travel Time Max = $TTMax1<BR>\n";
$data_out = $data_out . "Travel Time second Max = $TTMax2<BR>\n";
$data_out = $data_out . "Travel Time Confidence = $TTConfidence<BR>\n";
$data_out = $data_out . "Display Preference = $DisplayPreference<BR>\n";
$data_out = $data_out . "Display Confidence = $DisplayConfidence<BR>\n";
$data_out = $data_out . "Display Speed = $DisplaySpeed<BR>\n";
$data_out = $data_out . "Comment = $Comment<BR>\n";

### This opens the log file for writing

$handle = fopen("$filename", "w");

### This actually writes the file or if there is a
### problem, sends a warning.

if (fwrite($handle, $data_out) == FALSE)
{
    echo "Cannot write to file ($handle)";
    exit;
}

### This closes the log file

fclose($handle);

### The following print statements create the final Web page

```

```
print "<title>$title</title>";
print "</HEAD>\n\n<BODY bgcolor=\"#ffffff\"> <center> ";
print "<H1> $title </H1> </center>";
print "<br><P>\n\n";
print "<P>Thank you for taking the survey. \n";
print "The purpose of this survey is to assess the effectiveness\n";
print "of different graphical methods of displaying travel \n";
print "time. The results will be used to assess the usefulness \n";
print "of Web-based travel time methodologies and will \n";
print "contribute to the existing knowledge of research in \n";
print "the field of transportation field. Your contribution to \n";
print "our effort is therefore greatly appreciated.\n";
print "<P>\n";
print "All responses will be kept confidential. Only summarized \n";
print "results and analyses will be made public. \n";
print "This survey is being conducted in partial fulfillment of \n";
print "a Master's Degree in Geography at Texas State University \n";
print "under guidelines established by Texas State University. \n";
print "<BR>\n<BR>\n";
print "\n";

### Close out the Web page

print "</body>\n\n";
print "</html>\n\n";
?>
```

## **APPENDIX II**

### **PRINTED SURVEY**

The following pages are the Travel Time Graphic Survey in printed format. This version of the survey follows PathA and introduces the Trajectory Vector Graph before the Travel Time Stacked Bar Graph. Please note that there is a difference in “look and feel” between a Web presentation and the printed format.

## **Travel Time Graphic Survey**

The purpose of this survey is to assess the effectiveness of different graphical methods of displaying travel time. The results will be used to assess the usefulness of Web-based travel time methodologies and will contribute to the existing knowledge of research in the field of transportation field. Your contribution to our effort is therefore greatly appreciated.

All responses will be kept confidential. Only summarized results and analyses will be made public. This survey is being conducted in partial fulfillment of a Master's Degree in Geography at Texas State University under guidelines established by Texas State University. By participating, you will help the survey administrators find answers to important questions; however, your involvement is strictly voluntary. Please remember that you may choose not to answer any question you find objectionable. To participate in this survey, you must be 18 or older.



## Travel Time Graphic Survey

Please answer the following questions before continuing. Please complete all the questions in sequence and respond to each statement or question. You are invited to add comments at the end of the questionnaire.

What year were you born?

What is your gender?

- Male
- Female

What is the highest level of education you completed?

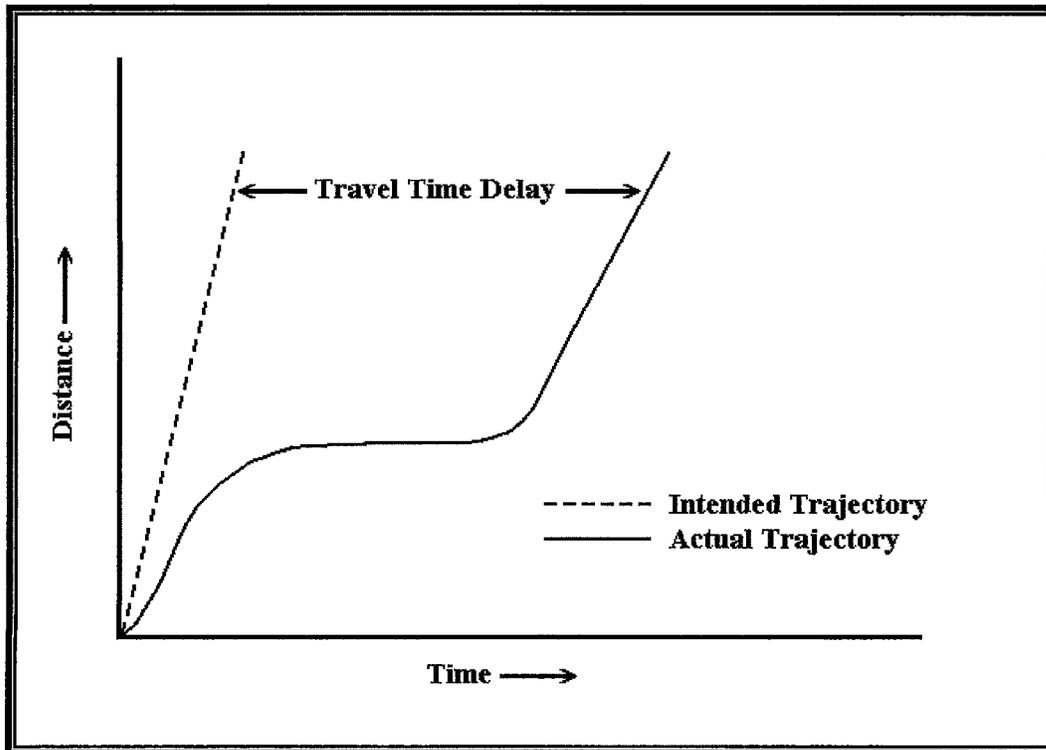
- Less than 9th grade completed
- 9th to 12th grade completed - No Diploma
- High School graduate - Include Equivalency
- Some College or Associate degree
- Bachelor or Professional degree
- Post-Graduate degree

Which statement best describes your level of experience with traffic

- Traffic Professional
- I have studied traffic issues at school
- I commute in heavy traffic regularly
- I drive in heavy traffic occasionally
- I rarely drive in heavy traffic

Continue to Page 3

## Travel Time Graphic Survey

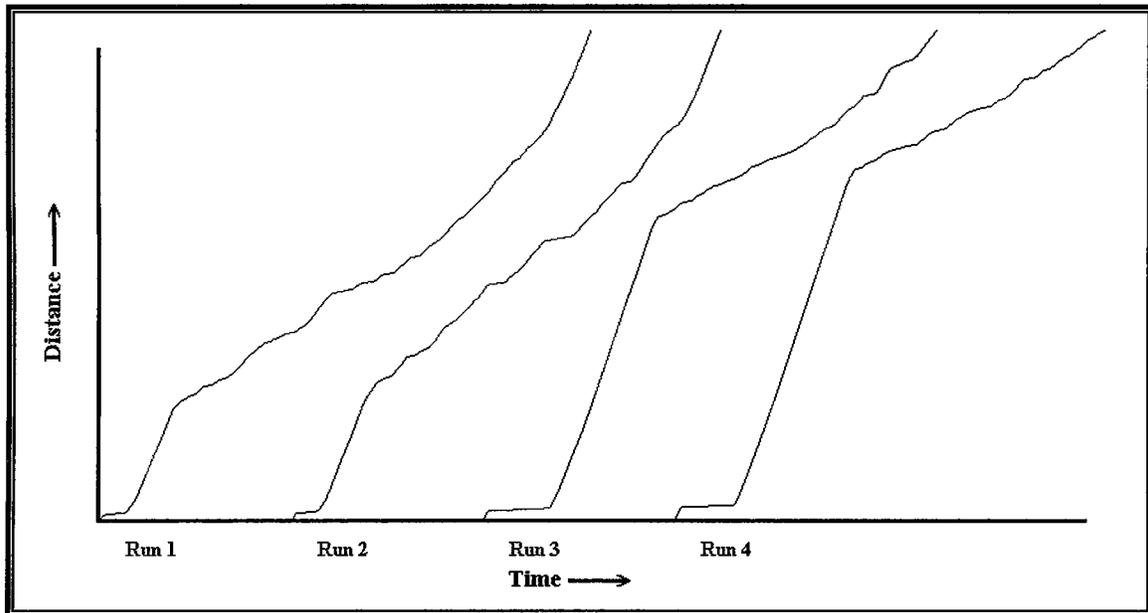


The graphic depicted above is a Trajectory Vector Diagram that is designed to show the progress of a vehicle along a track. Increasing distance is depicted as increasing values along the vertical axis and increasing time is depicted as increasing values along the horizontal axis. A horizontal line indicates that the vehicle is stopped and increasing slope means greater speed. The dashed straight line is the "intended trajectory" and the solid line is the actual trajectory of the vehicle. The intended trajectory is the trajectory that the vehicle would achieve if it were to complete the run along the specific length of roadway totally unimpeded. The horizontal distance between the intended trajectory and the actual trajectory is the travel time delay of the vehicle at any point during the trip.

The trajectory vector diagram is often used to depict multiple runs along a route. The dashed line is often left out of graphs depicting multiple runs.

Continue to Page 4

## Travel Time Graphic Survey



Please refer to the graph above to answer the following questions.

Which of the following runs took the least amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

Which of the following runs took the second least amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

Which of the following runs took the most amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

Which of the following runs took the second most amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

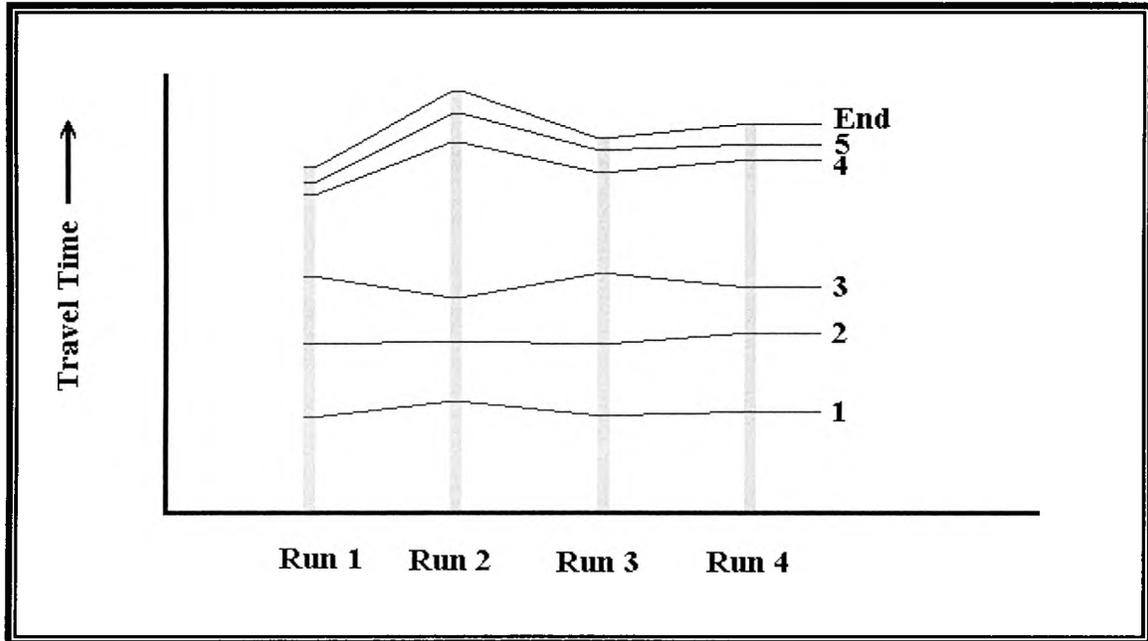
I am confident that I understand the information that the graphic is presenting.

- Not at all
- Slightly
- Somewhat
- Almost completely
- Completely

---

Continue to Page 5

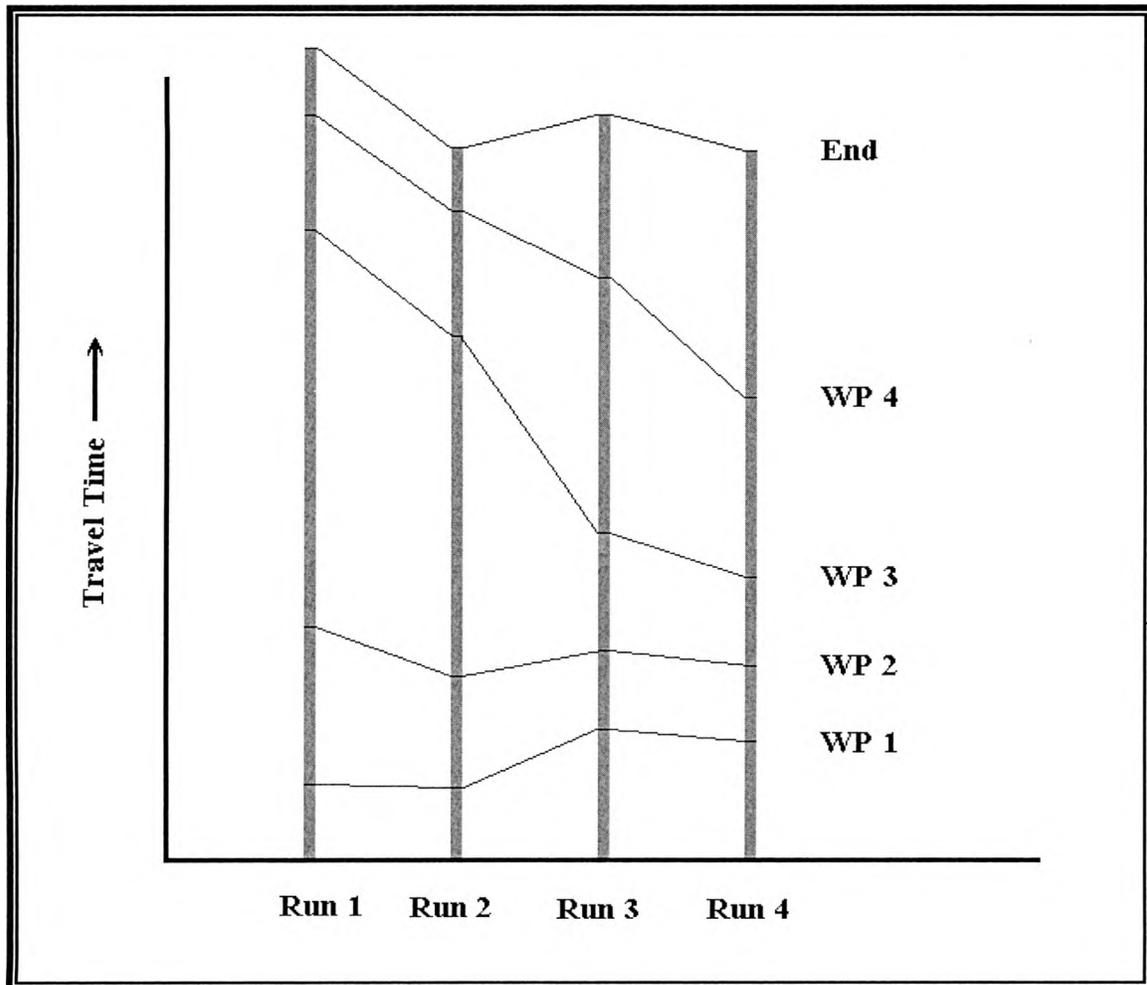
## Travel Time Graphic Survey



The graphic depicted above is a Travel Time Stacked Bar Graph that is designed to show comparative travel times for multiple runs along a track. The height of the bar is proportional to the travel time and each stacked bar represents a different run. Horizontal lines connect points of equal distance. They may be named (ie. "Interstate 20") or given another designation such as a number (ie. "5" or "WP 5") or other designation. This allows the user to determine not only the overall travel time, but to also see where the delays are occurring.

Continue to Page 6

## Travel Time Graphic Survey



Please refer to the graph above to answer the following questions.

Which of the following runs took the least amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

Which of the following runs took the second least amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

Which of the following runs took the most amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

Which of the following runs took the second most amount of time to complete?

- Run 1
- Run 2
- Run 3
- Run 4

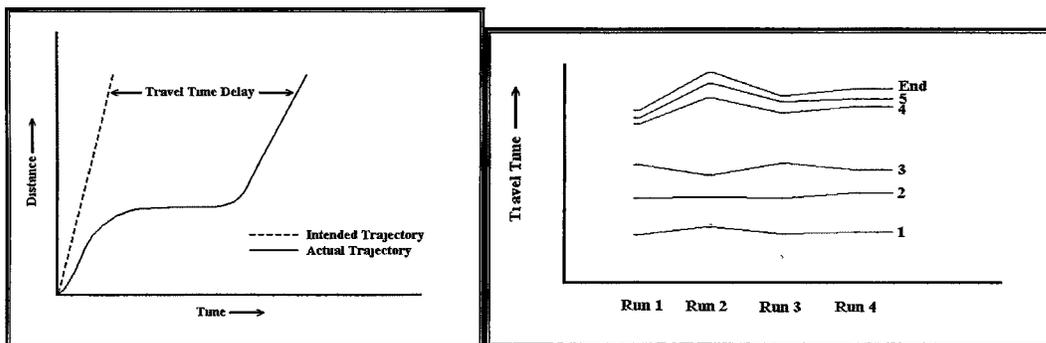
I am confident that I understand the information that the graphic is presenting.

- Not at all
- Slightly
- Somewhat
- Almost completely
- Completely

Continue to Page 7

## Travel Time Graphic Survey

Please compare the effectiveness of the two methods of representing travel time



### Display Preference

Please rate the graphs on the ease of extracting information

- I prefer the display on the left
- I prefer the display on the right
- I do not have a preference

### Display Confidence

Please rate the graphs on your confidence level that the answers you gave are correct

- I had greater confidence in the display on the left
- I had greater confidence in the display on the right
- I had equal confidence in my ability to understand both displays

**Display Speed**

Please rate the graphs based on the amount of time it took you to understand the information presented

- I was able to understand the display on the left more quickly than the one on the right
- I was able to understand the display on the right more quickly than the one on the left
- I was able to understand both displays equally quickly

Please enter any comments or suggestions in the box below

**Continue to Page 8**

## **Travel Time Graphic Survey**

Thank you for taking the survey. The purpose of this survey is to assess the effectiveness of different graphical methods of displaying travel time. The results will be used to assess the usefulness of Web-based travel time methodologies and will contribute to the existing knowledge of research in the field of transportation field. Your contribution to our effort is therefore greatly appreciated.

All responses will be kept confidential. Only summarized results and analyses will be made public. This survey is being conducted in partial fulfillment of a Master's Degree in Geography at Texas State University under guidelines established by Texas State University.

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## VITA

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