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16. Abstract

This report is a compilation of research papers written by students participating in the 2004 Undergraduate Transportation Engineering Fellows Program. The ten-week summer program, now in its fourteenth year, provides undergraduate students in Civil Engineering the opportunity to learn about transportation engineering through participation in sponsored transportation research projects. The program design allows students to interact directly with a Texas A&M University faculty member or Texas Transportation Institute researcher in developing a research proposal, conducting valid research, and documenting the research results through oral presentations and research papers.

The papers in this compendium report on the following topics, respectively: 1) the impacts of night construction on crash likelihood; 2) the alleviation of congestion on the Katy Freeway through economic incentives; 3) the setting of detection zones for transit signal priority; 4) the improvement of planning-level speed estimation models; 5) the analysis of QuickRide users and nonusers; 6) the analysis of reading time and comprehension of simulated dynamic message sign messages; 7) the validation of video-based speed measurements; 8) the development of worksite criteria for "floating" speed zone research; 9) the comparison of erratic traffic behavior at congested daytime and nighttime work zones; 10) the investigation of issues regarding managed lane interoperability; 11) the evaluation of the effectiveness of dual portable changeable message signs in the display of a single message; 12) the evaluation of horizontal signing applications; and 13) the evaluation of red border speed limit signs.

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COMPENDIUM OF STUDENT PAPERS:

2004 UNDERGRADUATE TRANSPORTATION

ENGINEERING FELLOWS PROGRAM

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PREFACE

The Southwest Region University Transportation Center (SWUTC), through the Advanced Institute Program, the Texas Transportation Institute (TTI) and the Civil Engineering Department at Texas A&M University, established the Undergraduate Transportation Engineering Fellows Program in 1990. The program design allows students to interact directly with a Texas A&M University faculty member or TTI researcher in developing a research proposal, conducting valid research, and documenting the research results through oral presentations and research papers. The intent of the program is to introduce transportation engineering to students who have demonstrated outstanding academic performance, thus developing capable and qualified future transportation leaders.

In the summer of 2004, the following thirteen students and their faculty/staff mentors were:

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- Ms. Colleen Dau, who assisted with program administrative matters and in the preparation of the final compendium;
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DISCLAIMER

The contents of this report reflect the view of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

THE IMPACTS OF NIGHT CONSTRUCTION ON CRASH LIKELIHOOD

by

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SUMMARY

As the number of motorists increase throughout the State of Texas and the demand for better levels of service rise, it is necessary for engineers to find alternative methods to conduct roadway construction. One solution is the use of nighttime construction zones. Nighttime construction zones help to alleviate congestion associated with doing similar work during peak traffic hours. However, with nighttime construction zones there also comes dangers that until recently have gone uninvestigated. TxDOT has requested TTI researchers to help quantify increased risks associated with nighttime construction.

This project sought to investigate different types of work zones so as to provide a basis for determining the influence of each upon nighttime construction crash risk likelihood. Information was collected from project diaries and plans and cross-referenced with the Texas Department of Public Safety (DPS) crash database. Data were reduced and analyzed by time period of work activity (day or night), crash severity and collision type. Finally, researchers examined similarities and data trends between projects so as to get at the root of what hazards exist during nighttime construction.

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INTRODUCTION

As the number of motorists on Texas roadways increases and the demand for better levels of service on Texas roadways continues to grow, so will the need for reasonable construction work zone solutions. A solution that has existed since at least the 1960s is for construction work activities to be performed at night. However, with the implementation of night work practices come many issues that may not be beneficial to the safety of the motorist or construction worker.

It is an increasingly common occurrence for major urban freeways to experience congestion and operate at near capacity levels during several hours each day (*1*). The addition of construction zones only magnifies the deteriorating level of service on current roadways. Ultimately, roadway congestion causes economic loss, driver frustration, and many other problems within a community (*2*). In contrast, the improvement of roadways fuels the development of a community and preserves the quality of a community (*2*). Night time construction attempts to avoid creating additional congestion during daylight hours. However, the practice of nighttime construction at the same time is believed to create potential safety issues.

The implementation of nighttime construction brings with it many benefits to the motorist and to the construction worker. The use of nighttime work zones has been shown to minimize the impact to motorists, reduce the impact to the environment and allow easier access to work zones (*3*). Furthermore, the use of night construction also allows the workers to operate in much cooler temperatures than during the daytime (*3*). Meanwhile, many disadvantages surrounding nighttime work zones prompt many questions for motorists, construction workers and researchers. Driver and worker fatigue is cited as being a major problem involving safety in nighttime work zones (*4*). The need for increased traffic control and the added expense of night-premium pay for workers also drives up the cost of night construction projects (*4*).

In a report submitted by the Texas Transportation Institute in 1991, results concluded that severe accidents in construction zones increased by almost 38.8 percent while nighttime accidents in construction zones increased by 37.4 percent (*5*). The study collected data from five roadway construction projects in the State of Texas and clearly expresses the fact that construction zones can have a devastating effect on crash frequency and severity. Unfortunately, that study did not attempt to isolate the effects of nighttime construction work activity from the many other factors (loss of shoulders and entrance ramp acceleration lanes, narrowed lanes, lane shifts, etc.), which could increase crash risk, particularly at night when visibility is reduced.

Limited research has been conducted that considers the benefits and consequences regarding nighttime road construction. Therefore, it is necessary to go beyond the research that has already been conducted and target the source of what is causing nighttime work zone crashes. The uncertainty associated with the safety consequences of nighttime work zones leave researchers with the task of investigating these work zones and with the responsibility of formulating cost-effective solutions.

RESEARCH OBJECTIVES

This research focused on the following objectives:

- Determine the change in crash likelihood during periods of active night work, active day work (if applicable) and for times of inactivity in construction zones in Texas,
- Collect and analyze samples from road resurfacing projects (nighttime work only) and from hybrid (nighttime work and daytime work) construction projects in the State of Texas,
- Determine the level of consistency in crash likelihood for each category of work activity or inactivity, and

- To the extent possible, identify any increase in severity or rear-end collisions in a particular work zone.

PROCEDURE

The following procedure illustrates the steps and tasks that were conducted that led towards the completion of this project.

Identification of Potential Projects and Contacts

Potential projects included those that involve nighttime activities (resurfacing of the roadway) or projects that involved hybrid (nighttime and daytime) activities. Many locations throughout the State of Texas were assessed for their potential use in this study. Potential project locations were considered in Austin, Houston, Dallas, Fort Worth, San Antonio and Waco. These districts have conducted the largest amounts of nighttime construction throughout the State of Texas; therefore, these districts were given the greatest amount of attention for making contacts and locating potential projects. It was desirable to study projects involving divided highways and freeway systems. Based on these criteria the researcher selected four locations in the State of Texas. The summary of these locations is as follows:

Austin

This project took place on two separate roadways. The locations were on Loop 1 as well as on I-35 in the Austin district. This project involved bridge repair work, as well as overlay work. Only night work took place during the course of this project.

San Antonio

This project was on US-281 in the northern part of the San Antonio district. The project involved asphalt overlay of the roadway. Only night work took place during the course of this project.

Dallas

This project was a hybrid project located on I-35E running through the center of the Dallas district. The work involved bridge repair and also the construction of a High Occupancy Vehicle (HOV) lane.

Fort Worth

This project was a hybrid project running from the east side of Fort Worth to the Dallas County line. This project involved drainage work, the construction of an embankment and overlay work.

Data Collection

Data were gathered from project diaries from selected construction projects for the calendar years 1999-2001. The calendar years 1999-2001 were selected based on the fact that these are the three most recent years that the Texas Department of Public Safety (DPS) has crash records for. Data collection was completed by recording information from the project diaries into a table similar to the one shown in Table 1. A more detailed figure can be viewed in Appendix C. Although some of the information in the table was not necessary for the final statistical analysis of the project, it was valuable for the researcher to record this information so that a complete understanding of the construction work zone was possible. Additionally, the researcher also noted project numbers, the dates of construction, the location of the project and information pertaining to the contact person involved in the project. Lastly, crash data for the calendar years 1999-2001 corresponding to the project locations both before and during construction was obtained from the Texas Department of Public Safety crash database.

Table 1. Data Collection Sheet

Date	Time	Number of Lane Closures	Length of Lane Closure	Location of Lane Closure	Speed	Notes

Data Reduction and Analysis

Data were collected and sorted based on a pre-established criteria. Crash data from a specific project were separated into two groups. The first group represented the zone of interest, the region where the roadwork was actually taking place. The second group was a control group. The control group was a similar stretch of road in the proximity of the zone of interest. The control group allows the researcher to estimate how relative crash frequencies on that particular roadway changed over time (if at all). In this way, these normal fluctuations in crash frequencies can be factored out of the changes over time that was observed in the zone of interest. The changes that remain in crash frequency in that zone are believed to represent more closely the true influence of the work zone. The control group had the same divisions and classification system as the zone of interest; however the control group is a reference for the researcher to compare data trends.

The first divisions after separating data into the zone of interest and control zone breaks the project down to times before and during the construction process. This division is made so that a direct comparison of the increase in crashes can be made (as is discussed in more detail later in this report). Next, the data were broken down between nighttime and daytime work activity. Lastly, the data are broken down to compare whether or not the work zone was active or not active (inactive). Figure 1 illustrates the data categorization process.

After the categorization procedure, it was necessary to sort the data based on day and night activities, severity and type of collision. For the purposes of this study the researchers were only concerned with rear end collisions. Table 2 gives a sample from a raw crash data file with night activity classifications. The sample was taken from a location in a work zone during the construction period. Researchers then counted every instance involving factors of interest (i.e., the researcher counted how many property damage crashes, personal injury crashes, etc. there were in a given year).

Table Notes:

- A severity of "1, 2, 3, 4" denotes a crash that involves personal injury or fatality.
- A severity of "5"denotes a crash that involves only property damage.
- Rear-end collisions are denoted in the collision column as a "20".

After researchers counted the data, they then conducted compatibility tests between the control section and work zone location using a statistical hypothesis test (5). Next, an estimation of the expected number of crashes in the work zone during construction was calculated using a simple cross-product ratio. Estimation computations were made using the following equation:

(eq. 1)
$$E[Cons_{During}] = Cons_{Before}\left(\frac{Comp_{During}}{Comp_{Before}}\right) \quad (5)$$

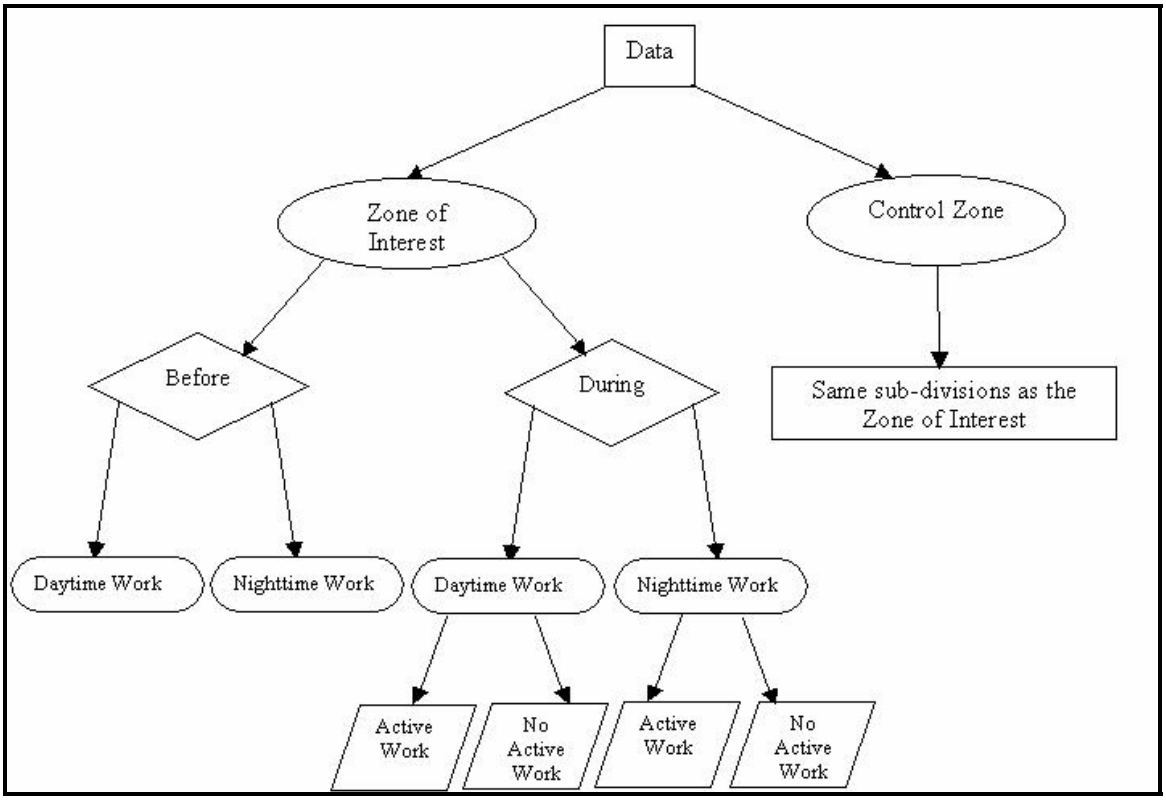

Figure 1. Categorization of Data Collection

Table 2. Sample Crash Data with Work Zone Activity Classifications

MILE 1	CONT SEC1	SEVERITY	COLLISION	MONTH	DATE	TIME	ACC YR	CRASH	WZ ACTIVITY
16.7	019603	3	22	2	15	8	2000	DAYTIME	DAY
16.3	019603	5	22	2	16	7	2000	DAYTIME	DAY-NO
17	019603	3	20	2	18	6	2000	DAYTIME	DAY
16.9	019603	3	22	2	19	18	2000	DAYTIME	NIGHT
15.1	044202	3	20	2	21	9	2000	DAYTIME	NIGHT
16.9	019603	3	20	2	21	7	2000	DAYTIME	NIGHT-NO

Where:

$E[\,]$ = Expected value

$Cons_{Before}$ = Number of crashes in the construction section in the before construction analysis period.

$Cons_{During}$ = Number of crashes in the construction section in the during construction analysis period.

$Comp_{Before}$ = Number of crashes in the comparison section in the before construction analysis period.

$Comp_{During}$ = Number of crashes in the comparison section in the during construction analysis period.

Lastly, a computation was performed to evaluate the statistical significance of the difference between observed crashes in the work zone to that of the expected value. This last test indicated any deviation associated with the implementation of a construction zone (5). Equations used for this portion of the analysis can be seen in equations 2 and 3.

Variance:

(eq. 2) $$Var\left(\frac{Cons_{During}}{E[Cons_{During}]}\right) = \frac{1}{Comp_{Before}} + \frac{1}{Comp_{During}} + \frac{1}{Cons_{Before}} + \frac{1}{Cons_{During}}$$

A Z-Statistic was then used to compute significance.

Z-Statistic:

(eq. 3) $$Z = \frac{\ln\left(\frac{Cons_{During}}{E[Cons_{During}]}\right)}{\sqrt{Var\left(\frac{Cons_{During}}{E[Cons_{During}]}\right)}} = \frac{\ln\left(\frac{Cons_{During} \times Comp_{Before}}{Cons_{Before} \times Comp_{During}}\right)}{\sqrt{\frac{1}{Comp_{Before}} + \frac{1}{Comp_{During}} + \frac{1}{Cons_{Before}} + \frac{1}{Cons_{During}}}}$$

If the Z-Statistic exceeded a predetermined critical value, the data was considered statistically significant (5). For this analysis, significance was selected to be 1.96 with an alpha value of 0.05.

RESULTS

The analysis portion of this project involved two phases. The first phase involved a statistical compatibility test to determine if selected control sections were suitable for comparison with corresponding work zones. The second part of the analysis was aimed at determining deviation between an estimated number of crashes in the work zone and the actual number of crashes taking place in the work zone. This analysis compared differences and involved statistical evaluations to determine if the deviation was significant.

Compatibility

During the course of the statistical compatibility, all chosen control sections were shown to be compatible with corresponding work zones. This indicated that a linear correlation could be made between the two road sections and that the analysis could continue.

Day and Night Activities

The day and night analysis was aimed at determining the increase in crash likelihood depending on the type of work zone present (day active, day inactive, night active, night inactive). The results in Figures 2 and 3 show a trend of increased crashes in active work zones. The two pure night projects (Austin and San Antonio), show similar trends. Both projects have an increase in crash expectancy in active work

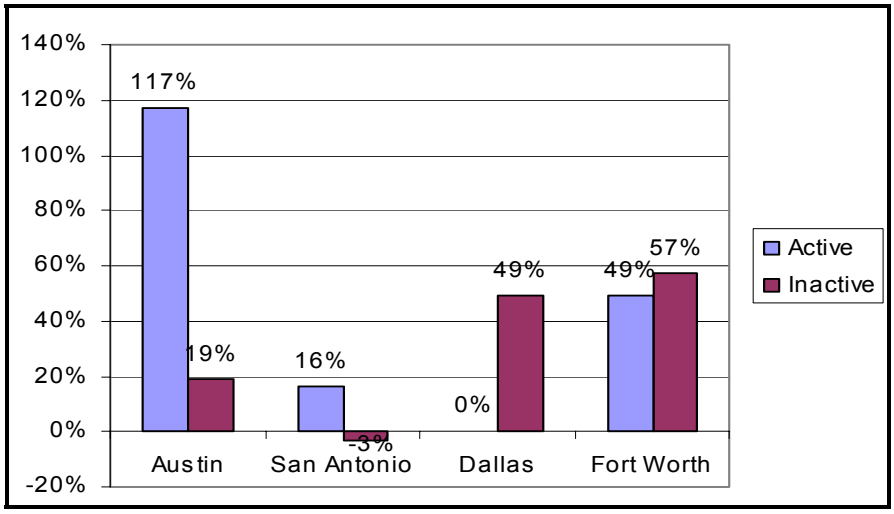

Figure 2. Night Percent Increase of Crashes in Work Zone during Construction

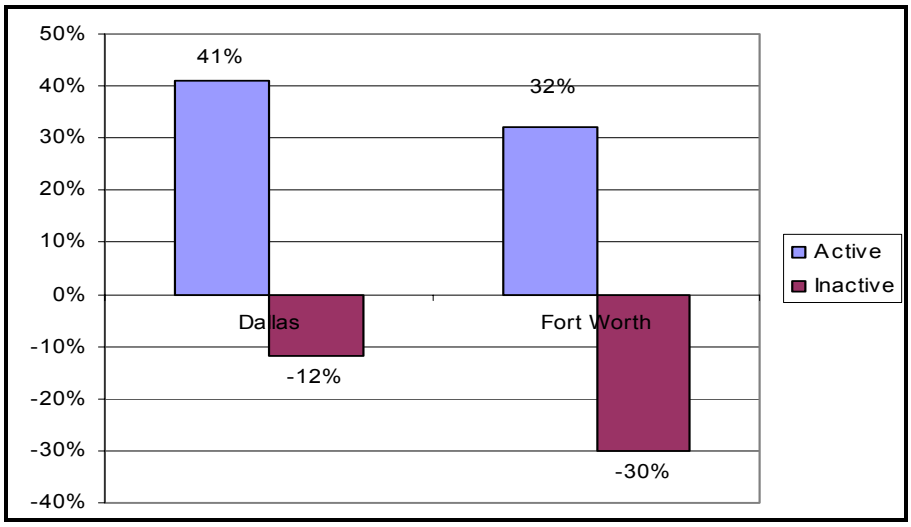

Figure 3. Day Percent Increase in Crashes in Work Zone during Construction

zones. The increase in crash expectancy for Austin is significantly larger than that for San Antonio. While none of these data showed to be statistically significant, similar trends for the effects of nighttime construction can be observed.

Again we are able to see a general trend for the effects of construction, this time for daytime work zones. The percent increase shown in Figure 3 proved to be statistically insignificant. It is important to notice that inactive work zones showed a decrease in daytime crashes from expected values. Perhaps this can be explained by motorists being made more aware of the construction zone and being given proper time to adjust and react to the presence of the work zone.

Severity

This study sought to find out how severity was affected by the presence of a work zone. Severe crashes are defined as those that cause personal injury or a fatality. As seen in Figures 4 and 5, accidents

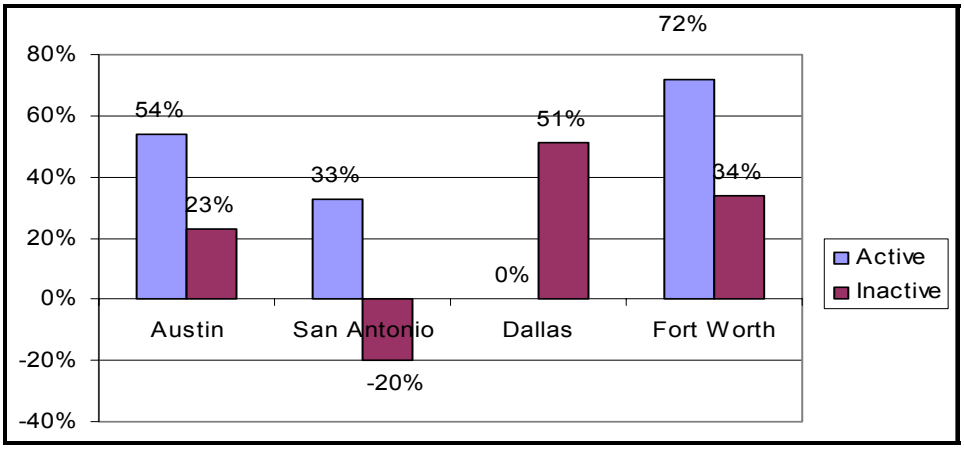

Figure 4. Night Percent Increase of Severe Crashes in Work Zones during Construction

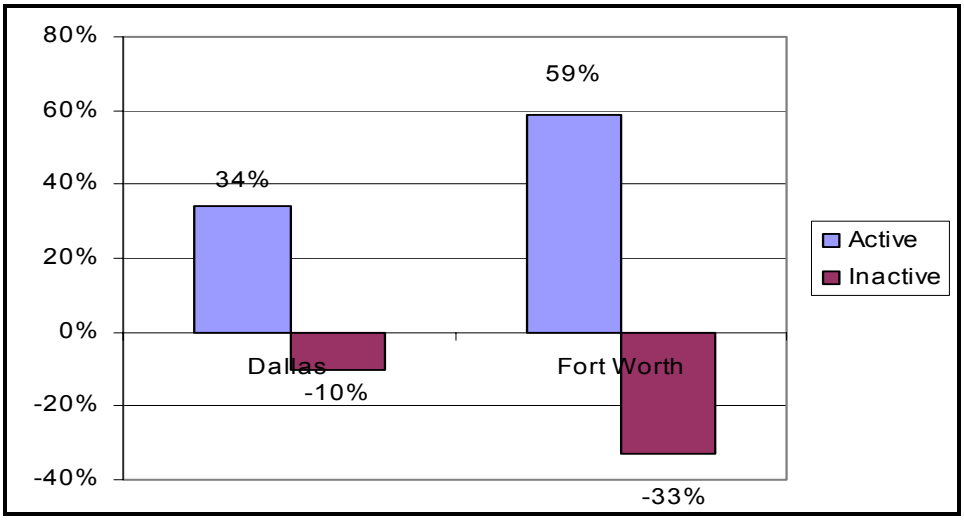

Figure 5. Day Percent Increase of Severe Crashes in Work Zones during Construction

generally tend to be more severe with the presence of a work zone. However, statistically, these results are not significant. Despite this, the researcher believes there is a direct correlation between the presence of a work zone and the general increase shown in the figures below.

Notice as in the day and night activities analysis there is a slight decrease concerning the inactive day severe crashes. This again can be attributed to the possibility that motorists were made more aware of the presence of the work zone.

Collision Type (Rear-end)

It was expected that the number of rear-end collisions would increase due to the presence of a construction work zone. While the San Antonio project did show a large increase in rear-end collisions for active night work zones, the results did not resemble what the researcher expected as shown in Figures and 6 and 7. Also, notice that many of the results show a zero percent increase. This is because there were too few occurrences of rear-end collisions for the researcher to produce results. Therefore, the researcher is unable to make solid conclusions regarding rear-end collisions.

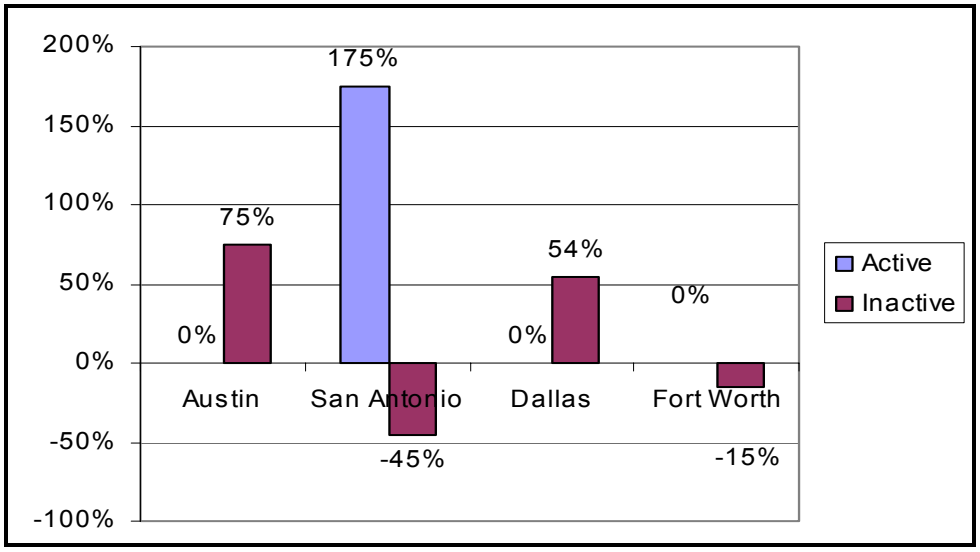

Figure 6. Night Rear-end Collision Crashes in Work Zone during Construction

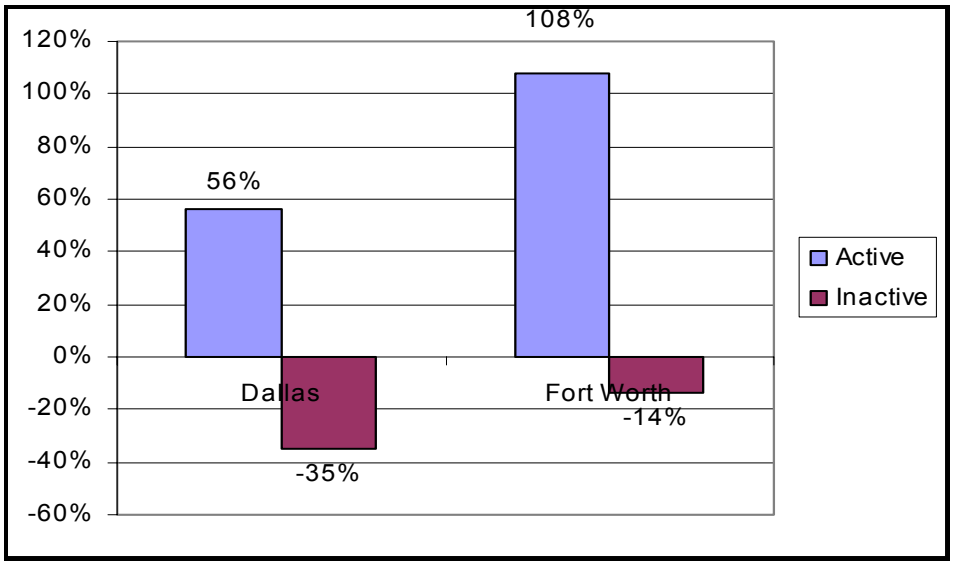

Figure 7. Day Rear-end Collision Crashes in Work Zone during Construction

CONCLUSION

There were many instances where sample sizes were relatively small. Therefore, in some cases, the researcher is not able to make definitive conclusions. However, the researcher is still able to suggest possible reasons as to why the data shows what it does.

An interesting trend can be seen when looking at the two hybrid projects (Dallas and Fort Worth). For day and night activity, severity, and rear-end collisions, the inactive day work zones showed a decrease in crash expectancy within each analysis. This continuity between each analysis leads the researcher to believe that perhaps motorists were better able to see the work zones. It is possible that the combination of increased visibility due to daylight conditions and the presence of construction zone indicators that slow down traffic could explain why crashes were lower than expected values.

The pure night projects both had short project durations of approximately 4 months time. The researcher does not believe this amount of time is sufficient for analysis using current statistical methods. The results for these two projects did not always show expected trends and could be caused by short project

duration. It is important to point out that for each analysis; San Antonio showed a decrease in expected crashes for nighttime inactive conditions. You would expect that there would be little or no change in crash expectancy in this situation. However, in the severity and rear-end collision analysis, there is measurable decrease from expected values. The only explanation that the researcher is able to offer is that motorists were made more aware of the work zone over time, therefore making them more adept to roadway conditions and activities.

In most cases, an increase in crashes can be observed. Generally, increases were not statistically significant; however, increases are still very much present in each analysis. Some of the projects show sharp increases in crashes. For example Austin shows a sharp increase in crashes expected for the day and night analysis, similarly, San Antonio shows a rather sharp increase in severity for active work zones. While these increases are expected, their large deviation from other expected increases could be the result of the small sample size for nighttime only projects. The researcher believes that the lack of large sample sizes for all work zone activities could contribute to some of the sharp deviations in the results. Ultimately, the data show a general increase in nighttime work zone crashes that seem to cause more physical injury to motorists.

RECOMMENDATIONS

Deviations encountered with the results of this project have led the researcher to make many recommendations for future research and study.

Throughout the initial stages of the data collection process, the researcher viewed many project diaries. At times these diaries were unclear as to the times, dates and conditions experienced on the roadways. Because of this, the researcher was left to interpret the information as best as possible. In the future it would be best for TxDOT to require the use of an electronic diary system. With the implementation of this system, the data would be more uniform and would leave out some of the interpretation involved in collecting work zone data.

Some of the deviation experienced with the pure night projects could have been because the work zones were often present for only a short duration. In this project the longer of the two pure night projects had a little more than four months of solid night activity. It is important that for future research that pure night projects are found that have larger project durations. The inclusion of pure night projects with a longer duration will contribute to a complete study and will show any complications associated with short duration projects.

In this project, the researcher was limited to the degree of detail involved in reducing the data by location and time. In the future it will be important to be able to break the time periods and locations down in order to obtain more specific results. This step will improve and evolve inherently with more detailed data collection techniques.

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APPENDIX A

Table A1. Project Locations, Project Numbers and CSJ

Location	Control Section Job	Project Number	Roadway
Austin	914-00-112	CSR 914-00-112	Loop 1 and I-35
San Antonio	0253-04-115	CPM 253-4-115	US - 281
Dallas	0196-03-178	BR99(332)	I-35E
Fort Worth	2374-05-053	IM-20-4(236)	I-20

APPENDIX B

Table B1. Night vs. Day Summary (Percent)

Location	Day		Night	
	Active	**Inactive**	**Active**	**Inactive**
Austin	18%	6%	117%	19%
San Antonio	N/A	25%	16%	-3%
Dallas	41%	-12%	N/A	49%
Fort Worth	32%	-30%	49%	57%

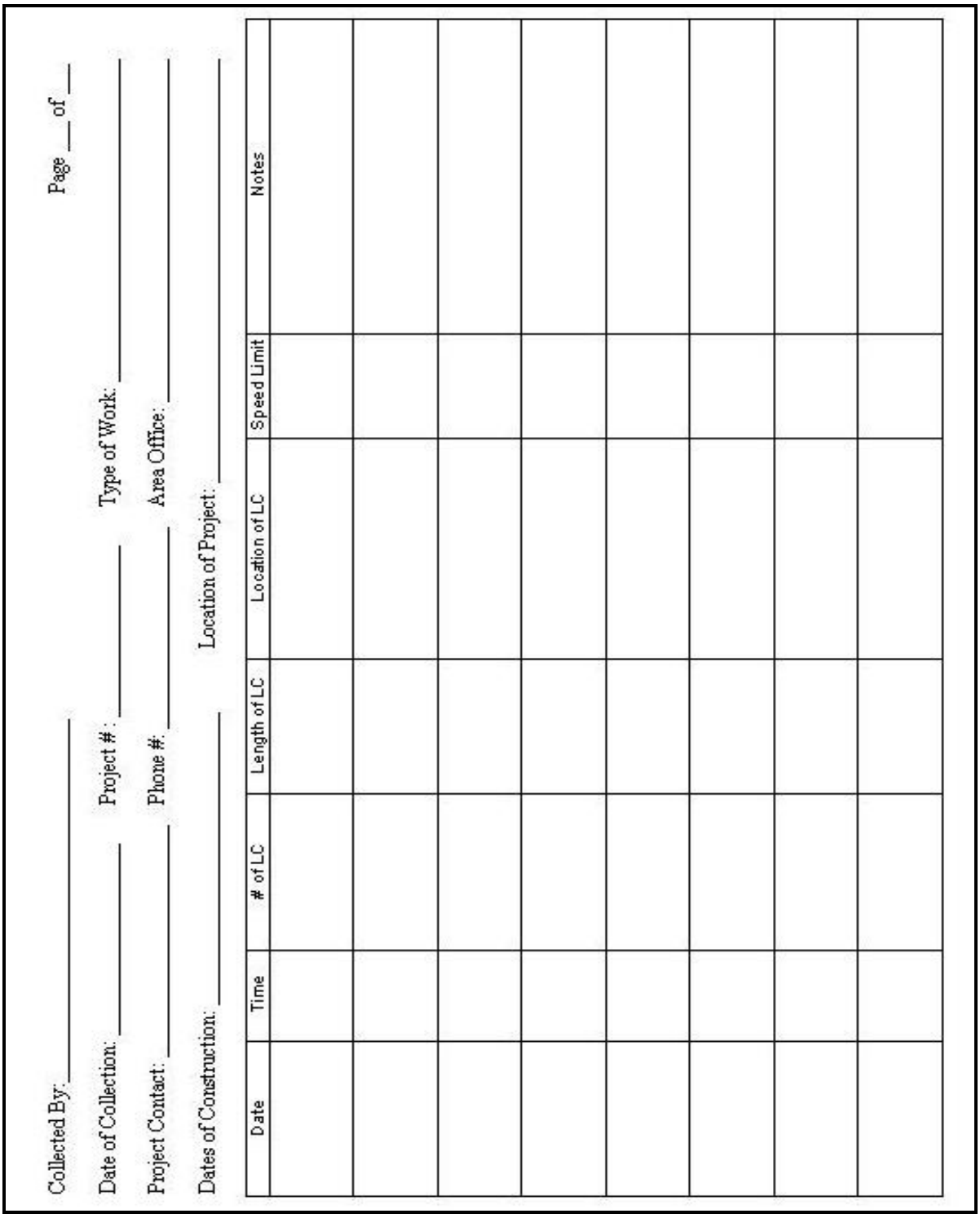
Table B2. Severity (1-4) Summary (Percent)

	Day		Night	
	Active	**Inactive**	**Active**	**Inactive**
Austin	-4%	0%	54%	23%
San Antonio	N/A	18%	33%	-20%
Dallas	34%	-10%	0%	51%
Fort Worth	59%	-33%	72%	34%

Table B3. Rear-end Collision Summary (Percent)

	Day		Night	
	Active	**Inactive**	**Active**	**Inactive**
Austin	0%	73%	N/A	75%
San Antonio	N/A	107%	175%	-45%
Dallas	56%	-35%	0%	54%
Fort Worth	108%	-14%	0%	-15%

APPENDIX C



Collected By: _____ Page ___ of ___

Date of Collection: _____ Project # : _____ Type of Work: _____

Project Contact: _____ Phone #: _____ Area Office: _____

Dates of Construction: _____ Location of Project: _____

Date	Time	# of LC	Length of LC	Location of LC	Speed Limit	Notes

Figure C1. Diary Data Collection Form

MARSHALL CHEEK

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Marshall is an active member in the Iowa State University Chapter of Chi Epsilon and Tau Beta Pi Engineering Honors Society. He was also awarded the Iowa State University Scholar and Leader Award in 2002 and 2003. His career interests include intelligent transportation systems, structural engineering and consulting.

ALLEVIATING CONGESTION VIA ECONOMIC INCENTIVE FOR I-10, THE KATY FREEWAY

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SUMMARY

This research explores the possibility of placing a variable toll on the Katy Freeway in Houston, Texas as a means of alleviating congestion, a condition caused by demand exceeding the roadway capacity.

Using the simulation software CORSIM to model the Katy Freeway, 30% of drivers were removed from the 6:00 a.m. to 9:00 a.m. peak period and relocated to other times of the morning, which resulted in vehicles speeds ranging from 50 mph to 60 mph throughout nearly the entire 5:00 a.m. to 11:00 a.m. simulation period. This is a significant increase over current speeds, which can fall below 20 mph during the most congested time of the morning. The toll required to accomplish the dissuasion of 30% of drivers from using the Katy Freeway during peak period was estimated to be $2.50. Drivers in the peak period can expect an average travel time savings of 13.8 minutes per morning commute trip.

The paper also compares the cost of implementing a tolling system to the cost of a supply-side remedy for congestion: freeway widening. At approximately 2% of the cost for the expansion and managed lanes project, a tolling system is a very cost-effective solution to the congestion problem.

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INTRODUCTION

Congestion

Traffic congestion is a condition plaguing transportation networks in metropolitan cities across the United States. It is a combined result of the growing wealth of American families, the availability of automobiles and the desire of humans to live in lower-density housing units (*1*). Congestion is an unpleasant reality in major cities, causing inefficient use of freeways, harming the environment and frustrating drivers, sometimes even leading to road rage.

Commonly Proposed Solutions

While peak-time congestion will likely never vanish from a metropolitan city, there have been many attempts to reduce the problem. The common solutions can be classified as either supply- or demand-side policies. Supply-side solutions involve increasing roadway capacity in some way or another. Widening the road has its benefits—more people per hour can travel and the most heavily congested period can potentially be shortened, yet it will not eliminate the breakdown of speed associated with congestion due to the principle of triple convergence (*1*). This principle basically states that if a freeway were to expand overnight, the next day vehicles could travel at free flow speeds without congestion. However, once word had spread that the road was no longer congested, drivers who had previously avoided the crowded freeway by altering their time, mode or route of travel would flock to the preferred travel time on the previously undesirable road. All of this will lead back to the original problem of travel delays due to freeway breakdown of speed.

Demand-side approaches to solve congestion involve influencing driver decisions so that the number of vehicles desiring to use the road stays below existing capacity of that road. The controlling factor influencing travel demand is the cost of travel, which has components including but not limited to travel time, fuel, vehicle maintenance, insurance, tolls, and parking costs. Studies have shown that the more directly the consumer must face the cost, the more likely the consumer is to alter his or her behavior in response to a price change (*2*). That is, the price elasticity is higher for direct costs, such as fuel and tolls and less sensitive for indirect costs, such as insurance payments or vehicle maintenance.

By implementing a tolling system during peak travel time, drivers are presented with several options. One option is to pay a toll, the price for a guaranteed faster trip during their preferred travel time. Those who do not want to pay the toll can change their departure time to before or after the peak period. Those drivers who do not have flexibility in their jobs and do not want to pay the toll will be the most inconvenienced group of drivers, as they will have to change their mode or travel route. This group may not receive the benefits of improved travel time, but they have chosen this over paying a toll for a quicker trip. Because adjacent routes may become overwhelmed with vehicles avoiding the peak period fee, the toll revenues should be in large spent on improving the conditions of the surrounding streets, maximizing the efficiency of its signal timing, road repairs, etc.

Speed-Flow Relationship

The relationship between vehicle speed and flow lays the framework for an understanding of how a peak period toll may help the Katy Freeway can accommodate similar, even larger volumes of traffic at faster speeds. Figure 1 shows a graph of the parabolic Speed-Flow relationship. The top portion of the curve represents the uncongested traffic condition, while the lower half represents the congested condition (*3*). The uncongested portion of the curve clearly illustrates that as more cars travel on the freeway (i.e., as flow increases) speed only decreases slightly until the flow approaches the freeway's capacity (point *C*). Around point *C*, the speed drops more dramatically and fewer cars can use the road as a result.

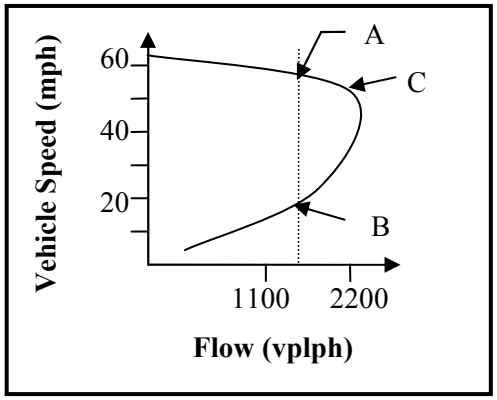

Figure 1. Speed-Flow Diagram

The parabolic nature of the speed-flow relationship above shows that traffic condition can allow for a particular flow rate at either a fast speed (condition *A*) or slow speed (condition *B*). Point *B* on Figure 1 is about where the Katy Freeway performs during the worst part of the morning on an average weekday. By using demand management, the flow rate can theoretically kept below *C*, the freeway capacity and thus never leading to condition *B*.

PROBLEM STATEMENT

The Katy Freeway in Houston is currently performing at a very poor level of service, with speeds below 20 miles per hour on an average weekday morning (*4*). In order to prevent freeway breakdown, the percentage of drivers required for removal from the peak period and the length of that period must be determined. Then a theoretical toll can be calculated to meet the vehicle removal requirement. Stochastic microsimulation software, CORSIM, was used to model a 16-mile stretch of the Katy Freeway between Barker-Cypress Road and Silber Road.

RESEARCH OBJECTIVES

The goals of the research project were as follows:

- Build a computer model that performs similarly to the actual Katy Freeway,
- Model the number of drivers necessary to remove from a peak period to prevent demand from exceeding capacity,
- Model the start and stop time of the peak period,
- Model congestion changes due to trip time redistribution,
- Calculate the toll necessary to persuade the previously determined number of drivers to leave the peak period considering price elasticity for highway travel, average toll rates, driver travel costs, and the value of time,
- Calculate travel time savings for Katy Freeway drivers, and
- Evaluate the costs of implementing a tolling system and compare it to the $2 billion expansion and managed lanes project currently underway.

METHODOLOGY

Simulation Software as an Analytical Tool

Computer simulation is a useful analytical tool because it allows traffic engineers to experiment in a way that is much more practical than a field experiment. Results can be obtained much more quickly and economically and real traffic operations are not disrupted.

Due to the stochastic nature of CORSIM, it was necessary to run CORSIM multiple times varying the random number seeds to gain an accurate reflection of the performance of the test case. The CORSIM Driver Tool, TSIS, has a built-in multiple-run capability. This multiple-run capability runs a test case multiple times changing the random number seeds for each run. The results of several runs of a single input file were then averaged for comparison to real Katy Freeway speed data.

CORSIM was chosen for this research project because a working model of the Katy Freeway was already developed. The existing Katy Freeway model consisted of the east bound main lanes and all access ramps between cross streets Barker-Cypress Road and Silber Road. It was set up for one time period, containing a constant traffic flow between 7 a.m. and 8 a.m. The model had already been calibrated to include many commercial truck types and contained driver behavior information such as gap acceptance and aggressiveness.

Model Updates and Data Collection

Simulation Model Updates

The research project aim was to clear up congestion throughout the entire morning. Thus, the structure of the model was changed to cover 5:00 a.m. to 11:00 a.m. in order to encompass the worst congestion period on the Katy Freeway. The model was expanded to 18 time periods of 20 minutes duration each.

Data Origin and Condition

Traffic volume from non-holiday weekdays in 2003 was obtained from loop detector data. A Texas Transportation Institute (TTI) researcher had previously cleaned the data, removing entries that had come from malfunctioning detectors in the field. Loop detectors along the Katy Freeway are typically located at cross-streets, some of which correspond to nodes in the model.

Volume Calculations

The loop detector data came in the form of 5-minute average volumes throughout the day. Each group of four consecutive volumes was added to obtain 20-minute volumes. Columns of the 20-minute volumes were assembled in an excel spreadsheet from left to right as the cross streets appear on the Katy Freeway from West to East. Next, blank columns for each entrance and exit ramp were inserted and volume data was filled based on percentages of main lane traffic using the access ramp percentage data from a TTI 2001 urban study.

Data Transformation

The columnar format was convenient for calculations of entering and exiting traffic on the freeway, but the model input file (FRESIM) format required a bit of data manipulation. After the volume calculations were completed, the Excel file was separated into two groups, one for turning movement volumes (known as record type 25) and the other for entry link volumes (known as record type 50). The two data types were stored as ASCII text files.

Each file was then transformed into the FRESIM format using a text editing program (Appendix B) coded by Texas A&M Computer Science student Chad Wellington using the programming language PERL. The programs inserted the proper space separations between data entries and other information contained in the record type such as the upstream and downstream node numbers. The output of the PERL programs was copied and pasted directly into the FRESIM file in large blocks, saving a great deal of time.

Running the Model, Experimentation, and Tolls

After completion of the data transformation, the FRESIM input file was run in CORSIM several times. The performance of the model in terms of traffic speed is shown in the Model Validation under Preliminary Results below.

Only after validation of the model could the experimentation begin. Once a reasonably accurate model had been developed, many runs were executed with removal of portions of traffic during the period with the highest flows and relocating them to other time periods. This step determined the necessary reduction in demand from the most congested period.

After the necessary reduction in demand to travel during the peak period was known, an approximate toll to accomplish the reduction was calculated based on the price elasticity of demand.

PRELIMINARY RESULTS

Model Verification

Model verification is the process of inspecting traffic behavior on the model to ensure that it behaves like the real freeway system under investigation. For example, all vehicles should progress from entry to exit in a logical sequence. A vehicle tracker was used to make sure that a vehicle entering the model made it all the way to either an exit ramp or the end of the model. In addition, the model output report was examined to make sure the number of vehicles entering each link was similar to the number of vehicles leaving. There was one mildly alarming issue with the model animation utility TRAFVU. While watching the system run its course, vehicles frequently switched lanes without waiting for enough space to open up. Vehicles overlapped each other without CORSIM recognizing an incident. A response on a 'frequently asked questions' help page run by the makers of CORSIM suggested that this was a glitch in the animation, and not an actual defect in the model.

Model Validation

Validation is the process of ensuring the model adequately replicates existing freeway speed conditions. This process is necessary before experimentation with traffic removal can begin. Below are speed comparisons between the CORSIM output and 2002/2003 peak average speed on the Katy Freeway, divided up into four segments.

Problems and CORSIM Limitations

The speeds did not perfectly match the yearly peak average speeds as illustrated in Figures 2 through 5. Because the model had already been calibrated for driver behavior, the percentages of vehicles using the freeway access ramps had to be altered in order to achieve semi-realistic freeway speed performance. Figures 2 through 5 are the result of many simulation runs containing the altered volume percentages.

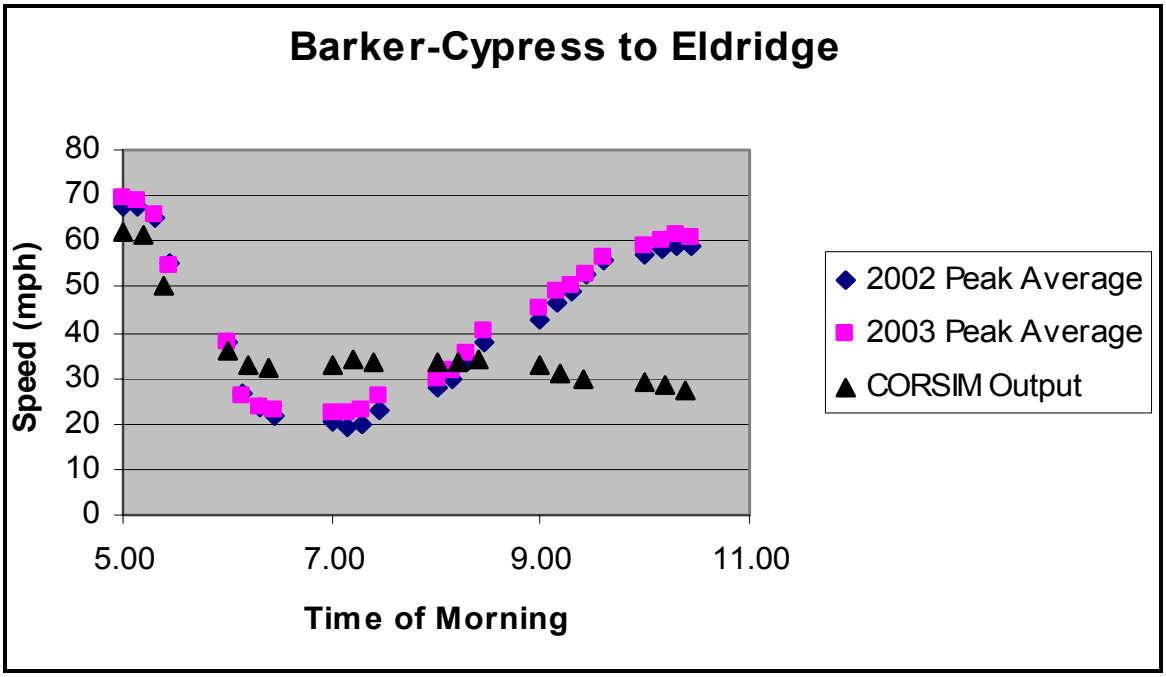

Figure 2. Barker-Cypress to Eldridge

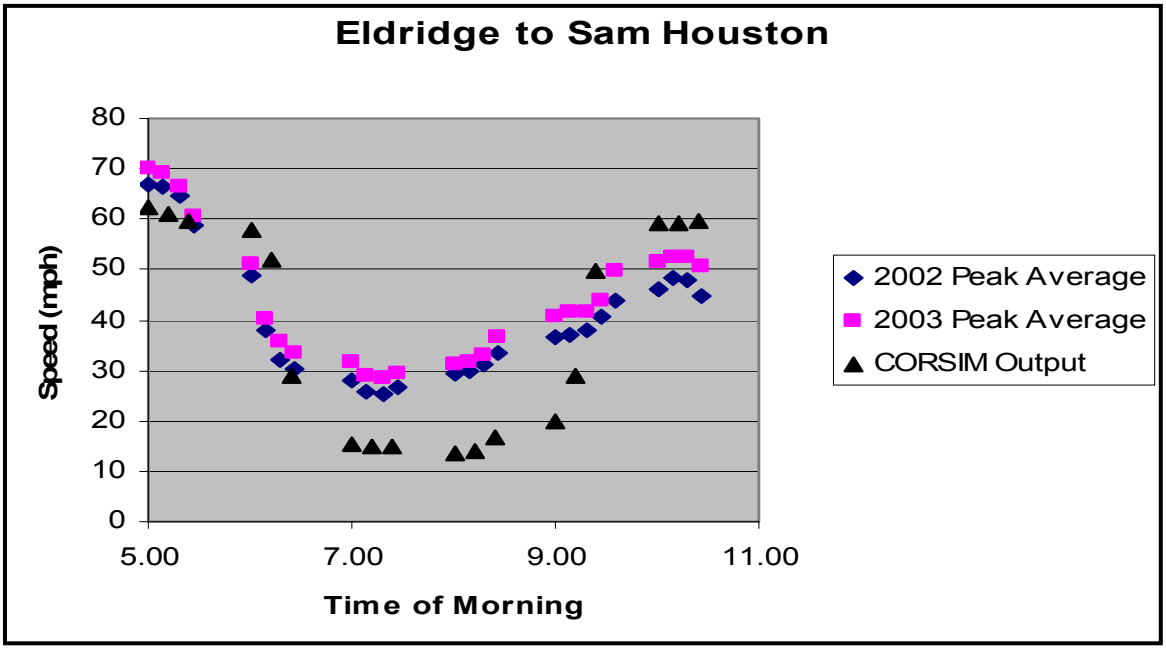

Figure 3. Eldridge to Sam Houston

The Blalock to 610 segment would not break down, even when sharp volume increases were applied over the morning. The first three segments can be considered average or worse-than average-day on the Katy Freeway.

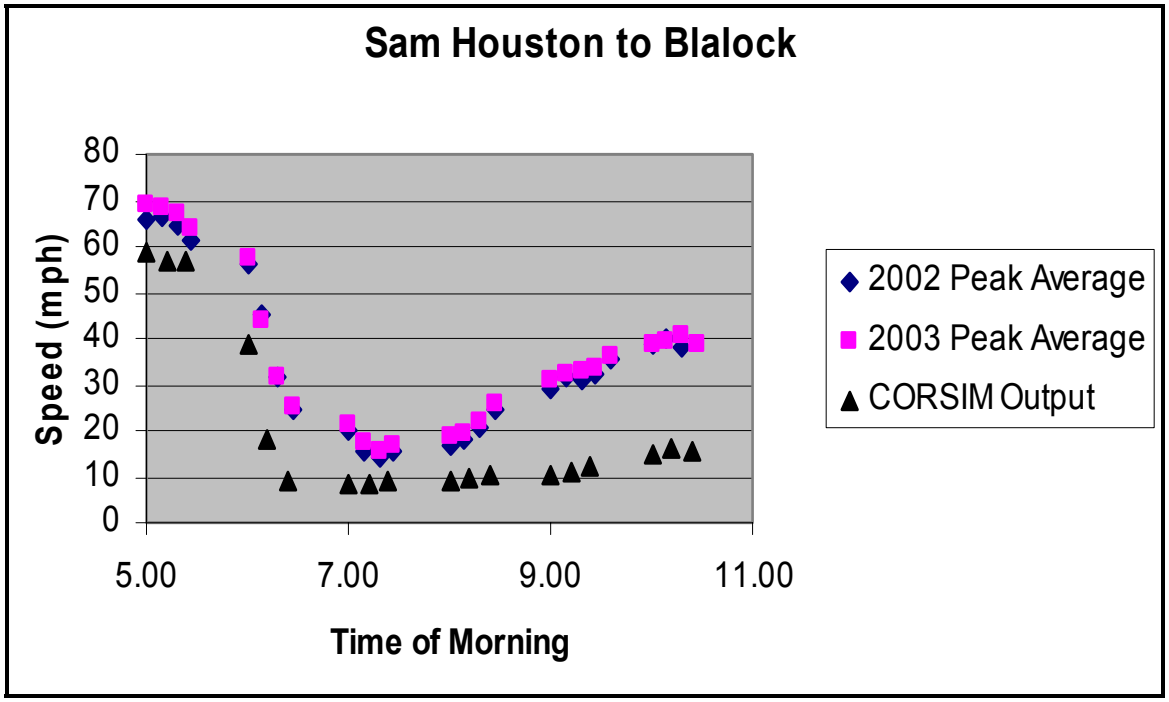

Figure 4. Sam Houston Tollway to Blalock

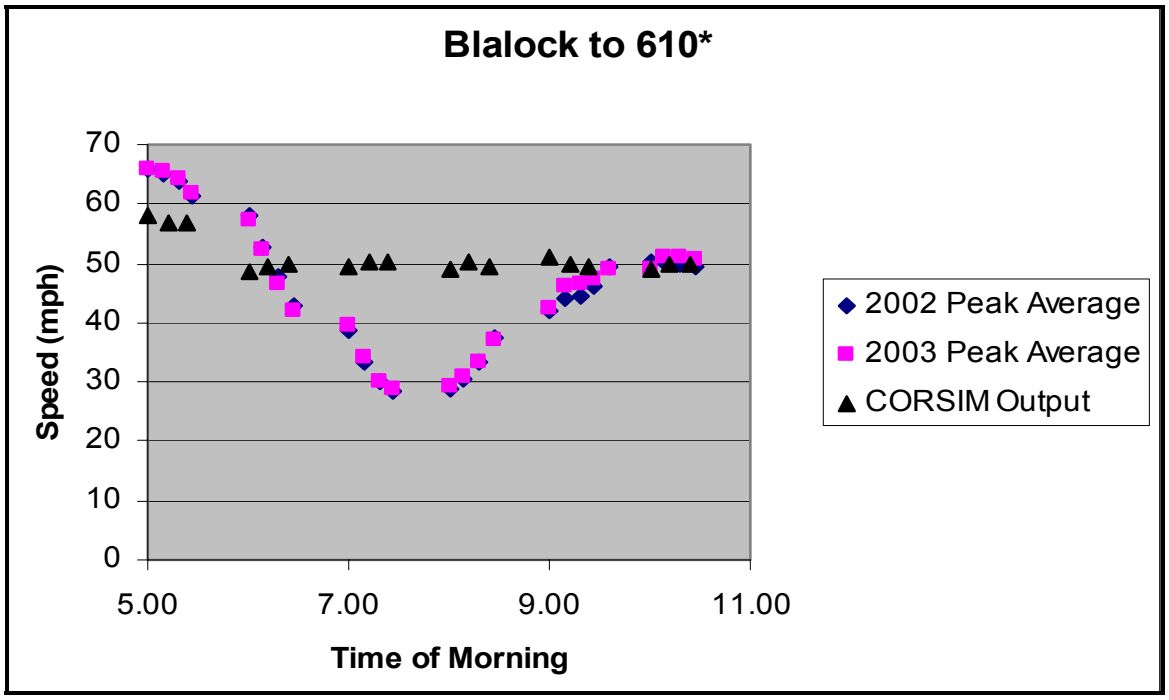

Figure 5. Blalock to 610

CORSIM does not seem to be well-suited for use with multiple time periods. For example, driver behaviors which are supposed to serve as calibration parameters are only allowed in the first time period, and not in consecutive ones. This makes the accuracy of a model spanning long periods of time difficult to obtain without altering the input volumes.

Perhaps the largest limitation with using CORSIM is that the output report is not very useful. It reports speeds for each link, but CORSIM bases all of its calculations on cumulative statistics since the beginning of the simulation. In order to get the true speed for each of 18 time periods, the data had to be pulled from the output file, saved as its own text file, exported to Excel and then finally have the previous time period's data subtracted from it, and the speed recalculated based on current information for that time period only.

RESULTS

Traffic Volume Relocation

After running many scenarios of different percentages of traffic volume removal and relocation, simulations with removing and relocating portions of peak-time traffic volume, the required displaced volume of vehicles was a constant 30% over the time period 6:00 a.m. to 9:00 a.m. Figures 6 through 9 show the effects of relocating said amount of traffic.

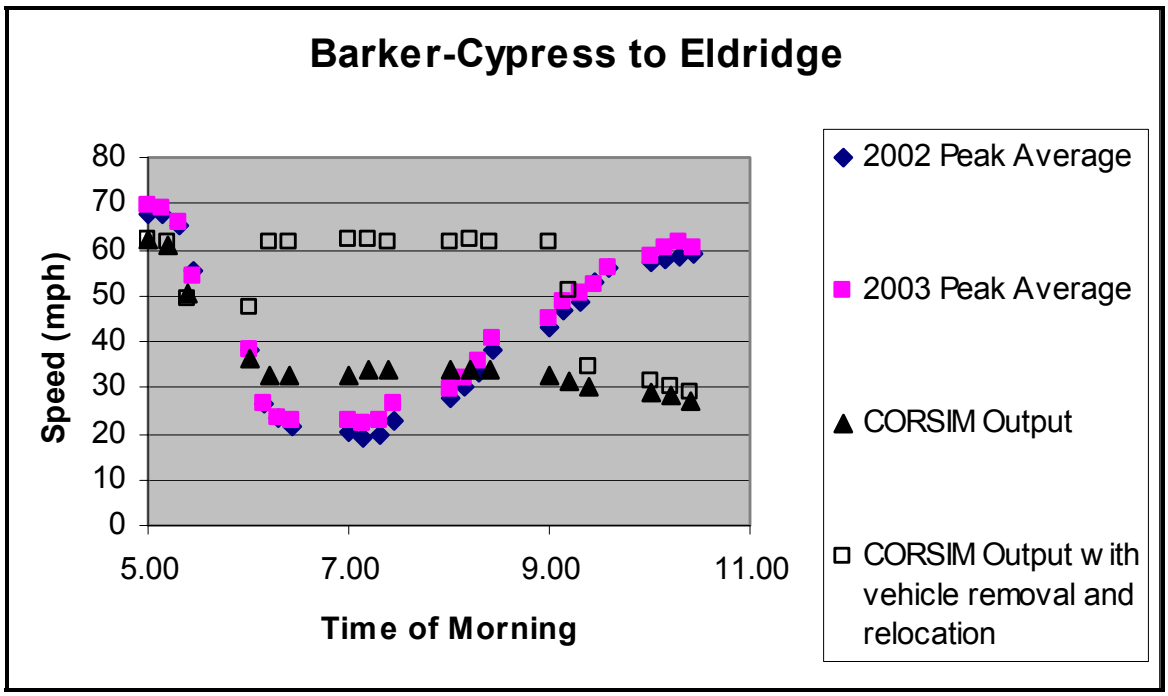

Figure 6. Barker-Cypress to Eldridge

After the removal of vehicles from the 6:00 to 9:00 a.m. peak period and their relocation to other time periods, the average vehicle speed stayed between 50 and 60 miles per hour throughout the entire morning. The only exception to this is the first segment, Eldridge to Sam Houston (Fig. 6). This can be explained by the fact that the model for this segment was too congested during the later morning periods to receive any additional traffic relocated from the peak period. In reality, Eldridge to Sam Houston does clear up by late morning (see 2002 and 2003 peak averages in Fig. 2).

Calculation of Toll Amount

The toll price demand elasticity for highway travel is approximately -0.3 (*5*). This means that if the toll were to double, 30% of the drivers would avoid paying that cost and thus would not use the freeway

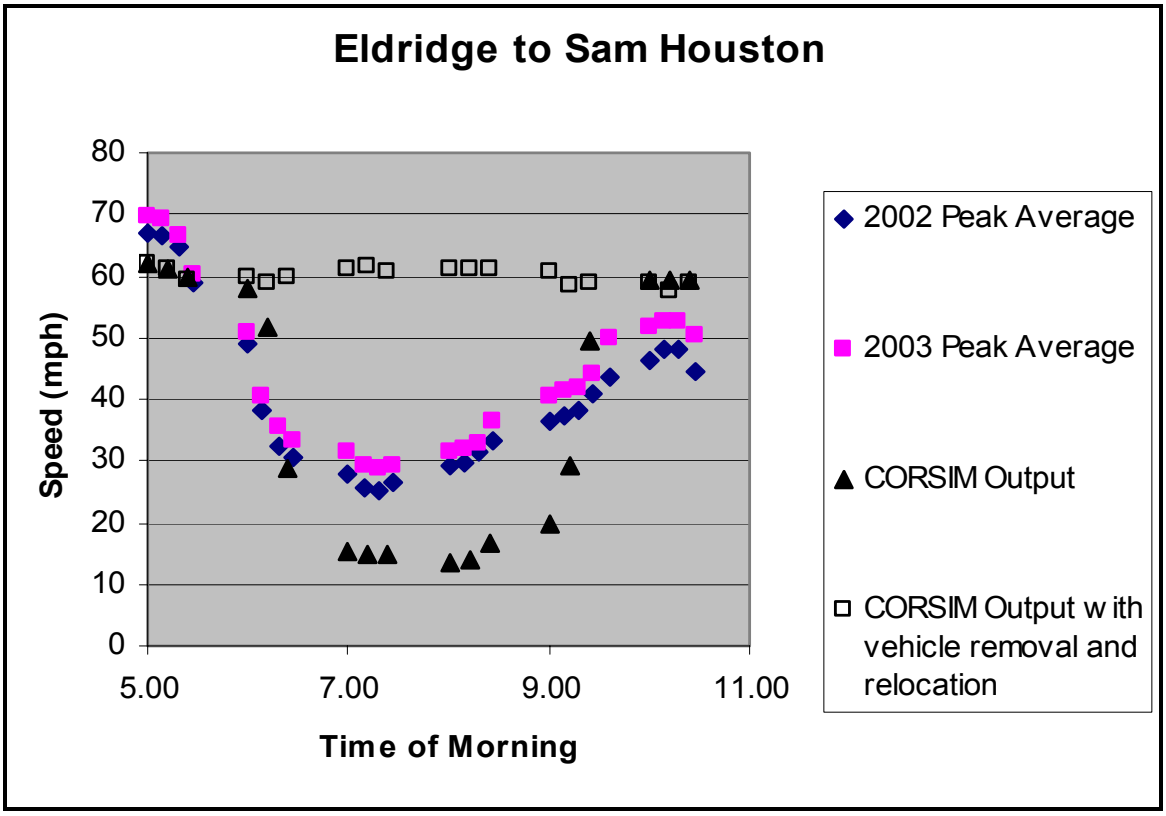

Figure 7. Eldridge to Sam Houston Tollway

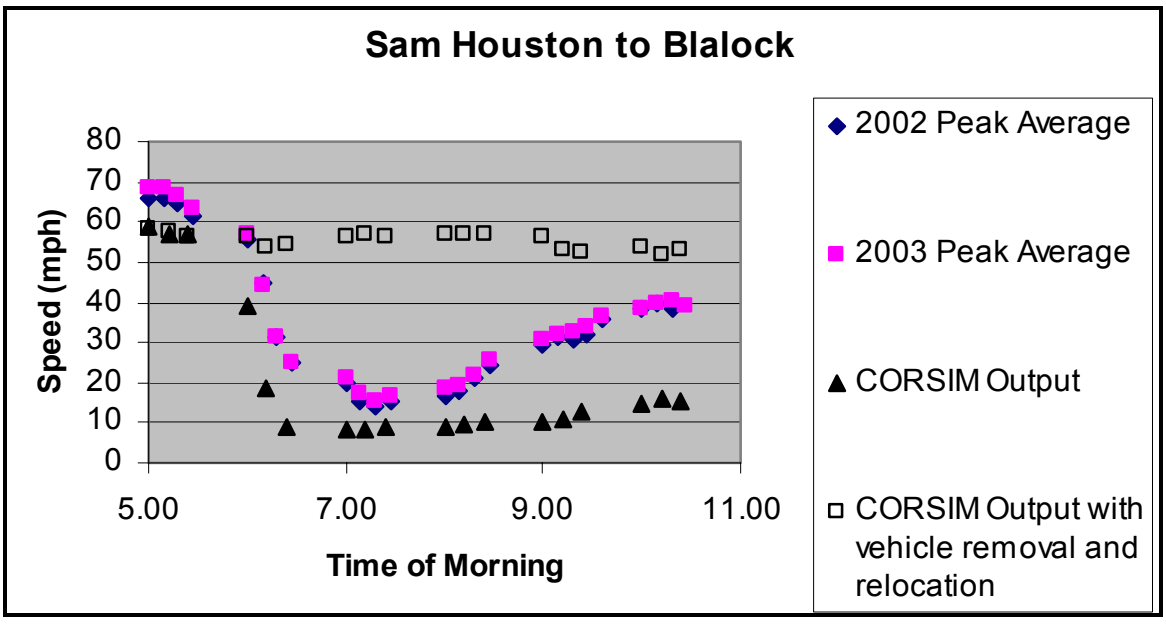

Figure 8. Sam Houston Tollway to Blalock

during the peak period. Tolls are generally priced \$0.10 to \$0.15 per mile (*6*), and with the 16-mile stretch of Katy Freeway under study, a typical toll would be approximately \$2.50. If a toll road with a \$2.50 toll increased the fee to \$5.00, the road would lose 30% of the volume during the toll period.

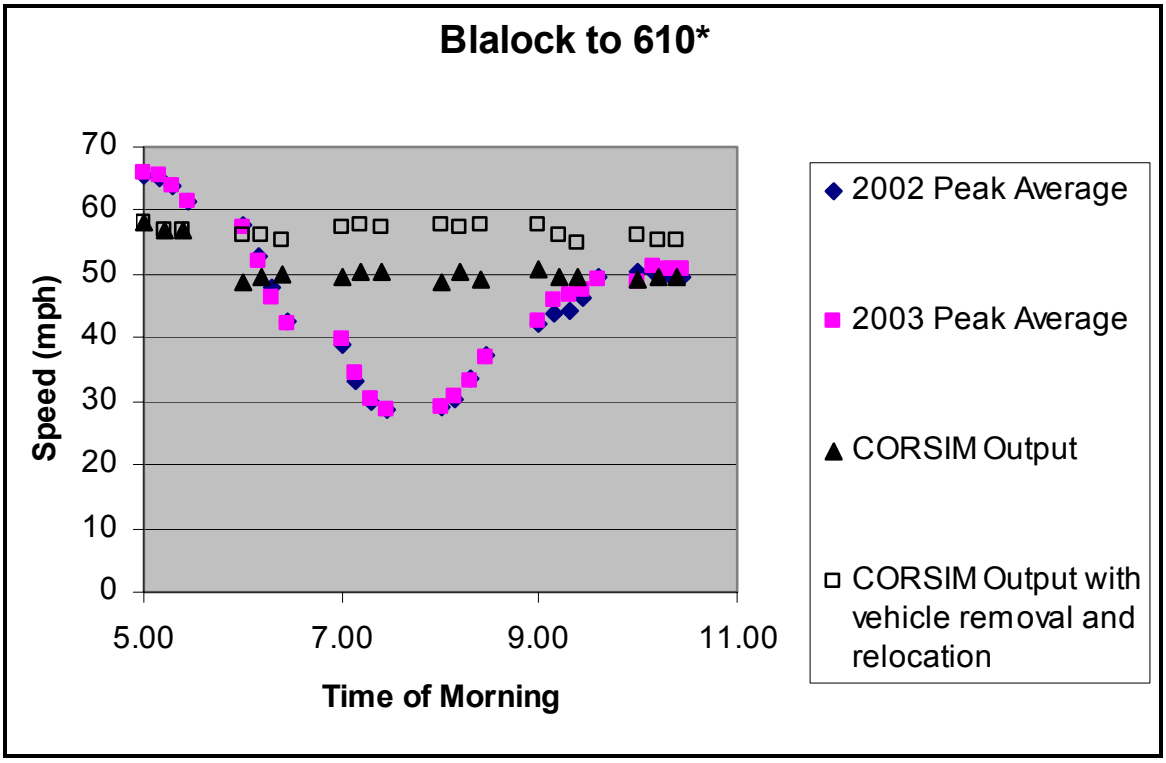

Figure 9. Blalock to 610

Similarly the non-tolled roadway increased to $2.50 should have a similar effect. In reality, the true toll required may be greater than $2.50 due to the lack of free travel alternatives. The ultimate goal is to optimize the freeway by keeping demand just below the freeway capacity. However, if a toll is suddenly imposed on drivers, the initial goal needs to be to guarantee travel time savings. For that reason, the $2.50 is simply an average value, with the toll varying based on travel demand. Thus, the toll amount required to accomplish the persuasion of 30% of drivers against using the 6:00 AM to 9:00 AM peak period averages $2.50.

Travel Time Savings

The average travel time for all vehicles traveling from their origin to destination for the base model (Figures 2 through 5) was 28.5 minutes. After the removal of vehicles from the peak period and their relocation to other time periods (Figures 6 through 9), the average vehicle travel time became 14.7 minutes. This results in a total travel time savings of 6,900 hours per day for the 30,000 vehicles in the 5:00 AM to 11:00 AM morning period.

COST COMPARISON OF PROJECTS

The simulation shows that it is possible to significantly improve the flow of traffic using a variable toll to regulate demand. Alternatively, traffic flow could be significantly improved by increasing the available roadway (increasing supply). Texas Department of Transportation (TxDOT), in cooperation with the Federal Highway Administration (FHWA), Harris County Toll Road Authority (HCTRA) and Houston METRO, has begun the effort to widen the Katy Freeway and provide the supply-side remedy to this congestion problem. The freeway will be widened to have three frontage roads, four general purpose lanes and two managed lanes in each direction from State Highway 6 to IH 610 (see Figure 10).

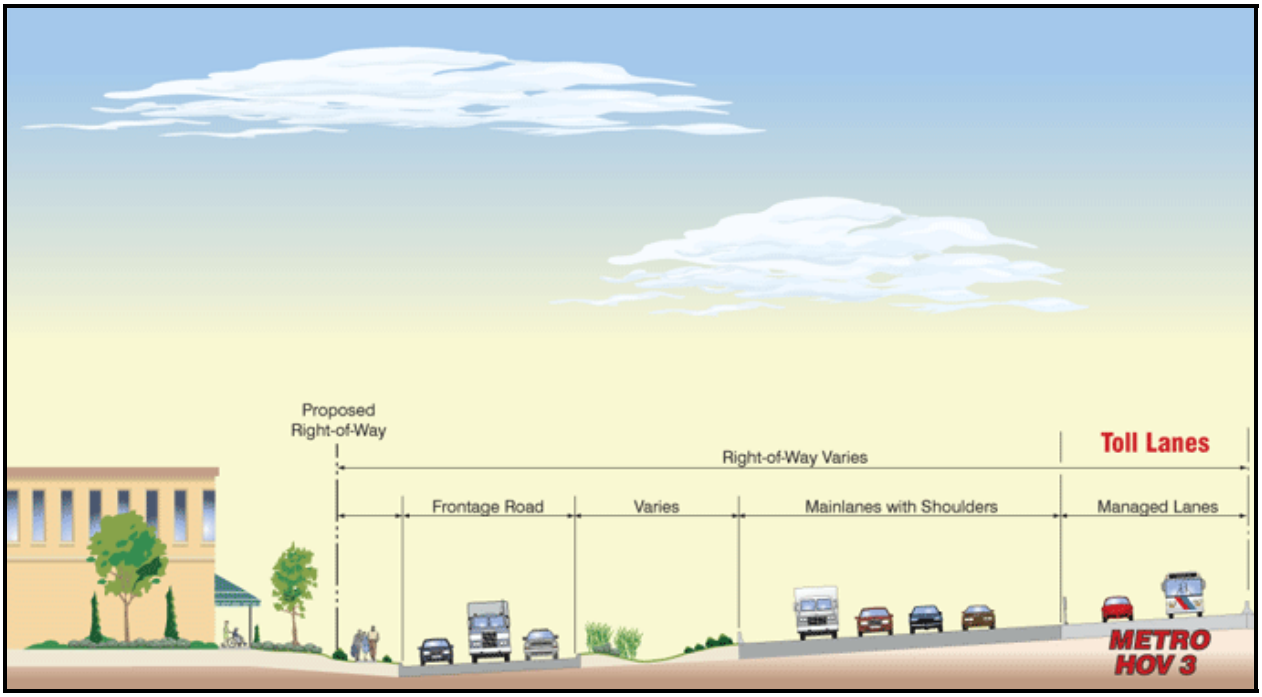

Figure 10: Katy Freeway Expansion Project Plans

This project is scheduled to require six years to complete and cost over $2 billion. It will greatly enhance mobility for travelers to the west of downtown Houston and provide significant economic benefits for the region. The demand management (toll) solution examined here would not provide the additional capacity to allow additional travel. Instead, it would force drivers to carefully consider their travel behavior and, in some cases, alter their time of travel to off-peak periods. Although this does not provide the same benefits as the newly constructed lanes, it is an economically efficient solution to the congestion problem.

The costs to add tolls to the Katy Freeway would be significantly lower than the freeway expansion project. To begin, all tolls would be collected electronically at all on-ramps and at one main lane toll plaza at the west end of the congested portion of the freeway. This eliminates both the cost of constructing large toll plazas and the delay to vehicles associated with manual toll collection.

Using typical costs for electronic toll (ETC) equipment, rough cost estimates were developed as shown in Table 1 (7).

CONCLUSIONS

The total estimated cost of $36.7 million is less than 2% of the costs of the reconstruction project. Thus, the proposed solution is a more cost-efficient method of congestion reduction. However, as noted previously, tolls do not offer the benefits associated with the increased mobility of additional lanes. Perhaps a city that does not have a large transportation budget should consider tolls as a demand management remedy to congested freeways.

Table 1. Typical Costs for Electronic Toll Collection Equipment

Equipment	Cost	Unit
Toll Equipment (Includes Automatic Vehicle Identification (AVI), Automatic Vehicle Classification System (AVC), Video Enforcement System (VES), and all associated computer equipment)	$60,000	Per lane
Gantries	$50,000	On ramp
	$200,000	Mainline
Computers	$250,000	On-ramp & mainline
	$1,000,000	Main host
Installation	$10,000	Per lane
Transponders	$25	Per user (estimate 1,000,000 users)
Service Center	$1,000,000	Start-up
	+ $1,000,000	Per year
Operation & Maintenance	$16,000	Per lane
Total Cost	$36,696,000	

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APPENDIX A

FRESIM Input File of Katy Freeway Model

```
FRESIM MODEL OF I-10 EB of Houston                                              00
18 time periods, 20 minutes duration per period                                 00
                                                                                00
Allison DenBleyker                    07  01  04  TTI TransLink                01
       1   0      60     7981       21             80500        7781    7581  02
120012001200120012001200120012001200120012001200120012001200120012001200      03
                                                                                04
                                                 1   0I10AAC                    05
8011  11 711     0 3                          1                                19
8112 112  12     1 1                          1                                19
8114 114  14     1 1                          1                                19
8116 116  16     1 1                          1                                19
8118 118  18     1 1                          1                                19
8120 120  20     1 1                          1                                19
8123 123  23     1 1                          1                                19
8125 125  25     1 1                          1                                19
8126 126  26     1 1                          1                                19
8128 128  28     1 1                          1                                19
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8131 131  31     1 1                          1                                19
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8136 136  36     1 1                          1                                19
8138 138  38     1 1                          1                                19
  11 711  12  6350 3                          1                                19
 711  12  13 33840 3                          1                                19
  12  13  14100890 3 91  810 92  154          1 9                              19
  13  14 714 25720 3                          1                                19
  14 714  15 48110 3 91  525                  1                                19
 714  15  16 11600 3 92  181                  1 9                              19
  15  16  17 22510 3                          1                                19
  16  17  18 15320 3 93 1532                  1 9                              19
  17  18  19 22510 3                          1                                19
  18  19  20 27660 3 93 2766                  1 9                              19
  19  20  21 22510 3                          1                                19
  20  21  22 20440 3 93 2044                  1 9                              19
  21  22  23 41040 3 92   80                  1 9                              19
  22  23 723  7090 3                          1                                19
  23 723  24  2000 3 91  200                  1                                19
 723  24  25  3150 3 92   80                  1 9                              19
  24  25  26  9250 3                          1                                19
  25  26  27 36020 3 91  174                  1 9                              19
  26  27  28 16470 3 91  150 92  174          1 9                              19
  27  28  29 15450 3                          1                                19
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  37  38 738 28870 4                          1                                19
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8118 118 957   3                                                  100              50
8120 120 522   3                                                  100              50
8123 123 723   3                                                  100              50
8125 125 327   3                                                  100              50
8126 1261458   3                                                  100              50
8128 128 951   3                                                  100              50
8129 1291800   3                                                  100              50
8131 131 342   3                                                  100              50
8134 134 795   3                                                  100              50
8136 1362310   3                                                  100              50
8138 138   0   3                                                  100              50
                                                                                  170
   0   8                                                                          210
  12  13  144488 113  33                                                           25
 714  15  164434 1151653                                                           25
  16  17  184989 117 555                                                           25
  18  19  205376 119 597                                                           25
  20  21  224317 1211596                                                           25
  21  22  233798 122 519                                                           25
 723  24  253444 1241113                                                           25
  26  27  284167 1271041                                                           25
 729  30  316924 130   0                                                           25
  31  32  335091 1322184                                                           25
  32  33  344083 1331008                                                           25
  34  35  363675 1351224                                                           25
  36  37  385760 137 303                                                           25
8011  113348   3                                                   33 33 34        50
8112 1121173   3                                                  100              50
8114 1141599   3                                                  100              50
8116 1161110   3                                                  100              50
8118 118 984   3                                                  100              50
8120 120 537   3                                                  100              50
8123 123 759   3                                                  100              50
8125 125 345   3                                                  100              50
8126 1261419   3                                                  100              50
8128 128 957   3                                                  100              50
8129 1291800   3                                                  100              50
8131 131 351   3                                                  100              50
8134 134 816   3                                                  100              50
8136 1362388   3                                                  100              50
8138 138   0   3                                                  100              50
                                                                                  170
   0   8                                                                          210
  12  13  144410 113  48                                                           25
 714  15  164350 1151662                                                           25
  16  17  184896 117 543                                                           25
  18  19  205292 119 588                                                           25
  20  21  224332 1211497                                                           25
  21  22  233813 122 519                                                           25
 723  24  253462 1241113                                                           25
  26  27  284125 1271032                                                           25
 729  30  317104 130   0                                                           25
  31  32  335217 1322238                                                           25
  32  33  344197 1331020                                                           25
  34  35  363777 1351260                                                           25
```

```
  36  37  385973 137 315                                                  25
8011  113303   3                                          33 33 34        50
8112 1121155   3                                         100              50
8114 1141602   3                                         100              50
8116 1161089   3                                         100              50
8118 118 984   3                                         100              50
8120 120 537   3                                         100              50
8123 123 762   3                                         100              50
8125 125 345   3                                         100              50
8126 1261350   3                                         100              50
8128 1281179   3                                         100              50
8129 1291800   3                                         100              50
8131 131 351   3                                         100              50
8134 134 840   3                                         100              50
8136 1362511   3                                         100              50
8138 138   0   3                                         100              50
                                                                        170
   0   8                                                                210
  12  13  144302 113  33                                                 25
 714  15  164245 1151800                                                 25
  16  17  184776 117 531                                                 25
  18  19  205163 119 573                                                 25
  20  21  224293 1211395                                                 25
  21  22  233777 122 516                                                 25
 723  24  253441 1241092                                                 25
  26  27  284041 1271011                                                 25
 729  30  317071 130   0                                                 25
  31  32  335190 1322223                                                 25
  32  33  344182 1331008                                                 25
  34  35  363765 1351254                                                 25
  36  37  386390 137 336                                                 25
8011  113210   3                                          33 33 34        50
8112 1121125   3                                         100              50
8114 1141743   3                                         100              50
8116 1161062   3                                         100              50
8118 118 960   3                                         100              50
8120 120 525   3                                         100              50
8123 123 756   3                                         100              50
8125 125 345   3                                         100              50
8126 1261266   3                                         100              50
8128 1281230   3                                         100              50
8129 1291800   3                                         100              50
8131 131 342   3                                         100              50
8134 134 837   3                                         100              50
8136 1362961   3                                         100              50
8138 138   0   3                                         100              50
                                                                        170
   0   8                                                                210
  12  13  144182 113 165                                                 25
 714  15  164368 1151947                                                 25
  16  17  184914 117 546                                                 25
  18  19  205298 119 588                                                 25
  20  21  224356 1211476                                                 25
  21  22  233834 122 522                                                 25
 723  24  253492 1241110                                                 25
  26  27  284122 1271032                                                 25
 729  30  317194 130   0                                                 25
  31  32  335280 1322262                                                 25
  32  33  344266 1331014                                                 25
  34  35  363837 1351281                                                 25
  36  37  386396 137 336                                                 25
8011  113219   3                                          33 33 34        50
8112 1121128   3                                         100              50
8114 1142133   3                                         100              50
8116 1161092   3                                         100              50
8118 118 972   3                                         100              50
8120 120 534   3                                         100              50
8123 123 768   3                                         100              50
8125 125 348   3                                         100              50
8126 1261314   3                                         100              50
8128 1281272   3                                         100              50
8129 1291800   3                                         100              50
8131 131 348   3                                         100              50
8134 134 852   3                                         100              50
8136 1362895   3                                         100              50
8138 138   0   3                                         100              50
                                                                        170
   0   8                                                                210
  12  13  144017 113 321                                                 25
 714  15  164290 1151926                                                 25
  16  17  184827 117 537                                                 25
  18  19  205211 119 579                                                 25
  20  21  224365 1211380                                                 25
  21  22  233840 122 525                                                 25
```

```
 723  24  253489 1241119                                                  25
  26  27  284149 1271038                                                  25
 729  30  317245 130   0                                                  25
  31  32  335316 1322277                                                 25
  32  33  344299 1331017                                                 25
  34  35  363870 1351290                                                 25
  36  37  386468 137 342                                                 25
8011  113213   3                                    33 33 34             50
8112 1121125   3                                   100                   50
8114 1142199   3                                   100                   50
8116 1161074   3                                   100                   50
8118 118 963   3                                   100                   50
8120 120 534   3                                   100                   50
8123 123 768   3                                   100                   50
8125 125 348   3                                   100                   50
8126 1261350   3                                   100                   50
8128 1281296   3                                   100                   50
8129 1291800   3                                   100                   50
8131 131 348   3                                   100                   50
8134 134 861   3                                   100                   50
8136 1362940   3                                   100                   50
8138 138   0   3                                   100                   50
                                                                        170
   1   0                                                                210
```

APPENDIX B

Below are the two PERL programs used to transform the data to the FRESIM input file format.

rt25_adb3.pl used for turning movement data

```
# rt25_ADB3.pl
# date: 4 August 2004
# author: Chad Wellington
# copyright 2004, all rights reserved

sub count;

# <cheap kludgery>
$first_nums[0]="  12  13  14";
$first_nums[1]=" 714  15  16";
$first_nums[2]="  16  17  18";
$first_nums[3]="  18  19  20";
$first_nums[4]="  20  21  22";
$first_nums[5]="  21  22  23";
$first_nums[6]=" 723  24  25";
$first_nums[7]="  26  27  28";
$first_nums[8]=" 729  30  31";
$first_nums[9]="  31  32  33";
$first_nums[10]="  32  33  34";
$first_nums[11]="  34  35  36";
$first_nums[12]="  36  37  38";

$second_nums[0]=" 113";
$second_nums[1]=" 115";
$second_nums[2]=" 117";
$second_nums[3]=" 119";
$second_nums[4]=" 121";
$second_nums[5]=" 122";
$second_nums[6]=" 124";
$second_nums[7]=" 127";
$second_nums[8]=" 130";
$second_nums[9]=" 132";
$second_nums[10]=" 133";
$second_nums[11]=" 135";
$second_nums[12]=" 137";
# </cheap kludgery>

print "volume filename: ";
chomp ($filename=<STDIN>);
print "output filename: ";
chomp ($output=<STDIN>);

open IN, "<$filename"
        or die;
$n = 0;
while(chomp($given_list[$n]=<IN>)) {
        ++$n;
}
close IN or die;

# take out duplicate values
for($i=0; $i<$n; $i+=2){
        $given_list2[$i/2]=$given_list[$i];
}
$n /= 2;

# extract numerical values
for($i=0; $i<$n; $i++){
        $_ = $given_list2[$i];
        #@given_list3[$i] = split(/\W/,$_);
        my @temp_array = split(/\W/,$_);
        $k=0;
        foreach $element (@temp_array) {
                $given_list3[$i][$k]=$element;
                $k++;
        }
}

for($k=0; $k<$n; $k++){
        for($i=0;$i<26;$i+=2){
                $odd_list[$k][$i/2] = $given_list3[$k][$i];
                $even_list[$k][$i/2] = $given_list3[$k][$i+1];
        }
}

open OUT, ">$output"
```

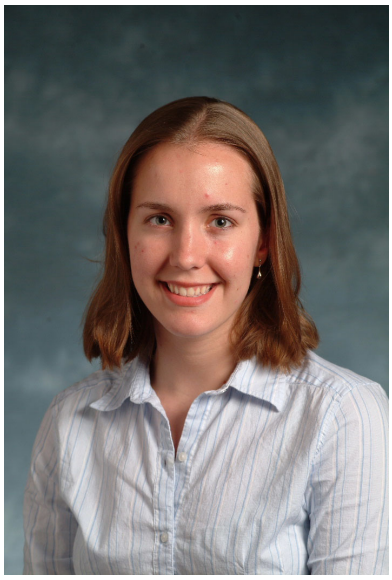
```
        or die "output death : $!";

for($k=0; $k<$n; $k++){
        for($i=0; $i<13; $i++){

                print OUT $first_nums[$i];
                $spaces = &count($odd_list[$k][$i]);
                for($j=0; $j<$spaces; $j++){
                        print OUT " ";
                }
                print OUT $odd_list[$k][$i] - 0;

                print OUT $second_nums[$i];
                $spaces = &count($even_list[$k][$i]);
                for($j=0; $j<$spaces; $j++){
                        print OUT " ";
                }
                print OUT $even_list[$k][$i] - 0;

                for($l=0; $l<54; $l++){
                        print OUT " ";
                }
                print OUT "25\n";
        }
        print OUT "\n";
}

close OUT
        or die "output death : $!";

sub count {
        my $temp = 4 - length($_[0]);
        if($_[0] == 0){
                $temp = 3;
        }
        $temp;
}
```

rt50_adb4.pl used for entry link data

```
# ADB4.pl
# date: 9 July 2004
# author: Chad Wellington
# copyright 2004, all rights reserved

sub count;

# <cheap kludgery>
$first_nums[0]="8011  11";
$first_nums[1]="8112 112";
$first_nums[2]="8114 114";
$first_nums[3]="8116 116";
$first_nums[4]="8118 118";
$first_nums[5]="8120 120";
$first_nums[6]="8123 123";
$first_nums[7]="8125 125";
$first_nums[8]="8126 126";
$first_nums[9]="8128 128";
$first_nums[10]="8129 129";
$first_nums[11]="8131 131";
$first_nums[12]="8134 134";
$first_nums[13]="8136 136";
$first_nums[14]="8138 138";

$second_nums[0]="   3                                                  33 33 34         50";
for($i=1; $i<15; $i++){
        $second_nums[$i]="   3                                                 100               50";
}
# </cheap kludgery>

print "volume filename: ";
chomp ($filename=<STDIN>);
print "output filename: ";
chomp ($output=<STDIN>);

open IN, "<$filename"
        or die;
$n = 0;
while(chomp($given_list[$n]=<IN>)) {
        ++$n;
}
close IN or die;

# take out duplicate values
```

```
for($i=0; $i<$n; $i+=2){
        $given_list2[$i/2]=$given_list[$i];
}
$n /= 2;

# extract numerical values
for($i=0; $i<$n; $i++){
        $_ = $given_list2[$i];
        #@given_list3[$i] = split(/\W/,$_);
        my @temp_array = split(/\W/,$_);
        $k=0;
        foreach $element (@temp_array) {
                $given_list3[$i][$k]=$element;
                $k++;
        }
}

open OUT, ">$output"
        or die "output death : $!";

for($k=0; $k<$n; $k++){
        for($i=0; $i<15; $i++){

                print OUT $first_nums[$i];
                $spaces = &count($given_list3[$k][$i]);
                for($j=0; $j<$spaces; $j++){
                        print OUT " ";
                }
                print OUT $given_list3[$k][$i] - 0;

                print OUT $second_nums[$i]."\n";

        }
        print OUT "\n";
}

close OUT
        or die "output death : $!";

sub count {
        my $temp = 4 - length($_[0]);
        if($_[0] == 0){
                $temp = 3;
        }
        $temp;
}
```

ALLISON DENBLEYKER



Allison DenBleyker is a student at Texas A&M University pursuing a Bachelor of Science in Civil Engineering. During the course of her studies, she has interned twice with CenterPoint Energy in Houston and was on a student team which helped a Texas A&M mathematics professor update vector calculus commands for Maple 8 to be used in Engineering Calculus III classes. Allison is also active in her dorm, serving as a Peer Advisor and Hall Council executive officer. She is a participant in the Engineering Scholars Program and a member of the American Society of Civil Engineers. Allison plans to graduate in December 2005 and attend graduate school the following spring.

SETTING DETECTION ZONES FOR TRANSIT SIGNAL PRIORITY

by

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August 6, 2004

SUMMARY

Transit signal priority (TSP) systems are an area of traffic engineering that has gained popularity in the United States over the last decade. These systems utilize intelligent transportation systems (ITS) technology in order to grant priority to transit vehicles at traffic signals. TSP systems have been successful at creating more reliable transit systems that are more attractive to commuters.

TSP systems, however, are not functioning as well as they potentially could. The placements of many bus stops have caused problems with the effectiveness of the TSP systems. The presence of many nearside bus stops has created confusion on where detection zones for these approaches should be placed. A methodology for setting detection zones had been created but had not yet been tested and verified. The following report details the testing process for this methodology and offers recommendations on how to optimize the performance of TSP systems that set detection zones using this approach.

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INTRODUCTION

In recent years the technology in the field of transportation engineering has matured dramatically, allowing engineers to turn dreams into commonplace practices. Perhaps the most significant technological development has been the creation of Intelligent Transportation Systems (ITS). ITS technology has provided transportation engineers with the tools that they need to implement increasingly complex systems. One concept that has been developed due to the recent advances in ITS technology is transit priority.

The idea of transit priority has been around for quite some time. The first experiments involving a system that grants priority to buses were occurring as long ago as 1962 (*1*). While people continued to run experiments involving bus priority, it was not until the development of ITS technology that these ideas were able to be practically realized. A wide variety of ITS technology is now available that can be used for bus priority systems (*2*). This variety has given engineers the ability to choose unique systems for each intersection or corridor in which a priority system is to be implemented.

The area of Transit Signal Priority (TSP) is one that has recently gained popularity in the United States (*3*,*4*). In the last decade, many cities have established test corridors to observe the effects of implementing TSP systems. As a result of successful trials, many of these sites have already installed TSP systems on a city wide scale. A typical TSP system involves a transmitter, present on every bus, which sends a request for priority to a device in the traffic signal. This device reports that the request has been made and adjusts the signal cycle accordingly. The manner in which the cycle is adjusted is dependant on which type of system is being used.

Houston is an example of an area that is in the process of implementing a TSP system over a large part of the city. Houston's bus system (METRO) contains 1,577 vehicles that service an area of over 1,200 sq miles (*5*). The size of the METRO system along with the constantly heavy traffic in Houston makes an effective TSP system almost a necessity in order to provide a reliable bus service.

PROBLEM STATEMENT

The city of Houston has run into a problem with the operation of their TSP systems due to the placement of many of the area bus stops. Currently, many of Houston's bus stops are what are known as nearside stops. This simply means that the bus stop occurs before the intersection. This causes a problem because it raises the question of where the detection zone should be set. The detection zone is the range at which the device in the traffic signal will begin to receive the priority transmission from the bus.

In the case of nearside stops, a signal whose detection zone causes it to receive a transmission from the bus before it makes its stop must account for the length of time that the bus will be at the stop (dwell time) in it's adjustment of the cycle. While programming extra time to account for the dwell time is not difficult, it can be very difficult to predict how long a bus will typically dwell at a certain stop. For this reason, finding the optimal detection zone for an intersection can be a very difficult task.

A system has been developed to aid in choosing appropriate detection zones but until recently, it remained untested. This system sets detection zones based primarily on the predicted dwell times. In addition to the predicted dwell times, this methodology also uses anticipated travel times to set detection zones. These travel times are calculated using the average travel speed expected as well as the acceleration and deceleration characteristics of the buses. It was necessary to perform the research detailed in this paper involving this detection zone methodology in order to maximize the effectiveness of the TSP system. The main focus of the research was on determining what dwell time used with this methodology, average or 95th percentile, was the most effective in reducing delay by allowing more buses through the intersection without stopping.

RESEARCH OBJECTIVES

The research conducted on methods for setting detection zones had the following objectives:

- Create and run a simulation model based on the Bellaire Blvd corridor in Houston, TX. Use this model to study the effects of dwell time on the setting of detection zones.
- Use results of simulation tests to try and verify current detection zone methodology.
- Use simulation results to offer recommendations on which dwell time lends the most effective TSP system.

PROCEDURE

Literature Review

In order to conduct this research, it was necessary to obtain a general understanding of TSP systems. For example, to understand how different detection zones affect the quality of a TSP system, it is necessary to be familiar with how a TSP system works and also with the other variables that affect how well the system operates. The literature review contained material covering the following topics:

- Functions of TSP systems,
- Applications of TSP systems,
- Case studies involving TSP, and
- New detection zone methodology.

Data Collection

The primary source of data collection for this research came from observation of the test corridor. Data were collected for the intersection of Bellaire Boulevard and Hillcroft Avenue in Houston, Texas. This intersection was chosen for a number of factors. The most important criteria met by this intersection was the presence of nearside bus stops. In addition to having the desired bus stop locations, this intersection was a bus transfer site making it a good location to study the effects of varying dwell times. The data collected included the following:

- The total number of vehicles that participated in each movement through the intersection over the time period of an hour,
- The dimensions of the intersection,
- The number of passengers getting on and off the bus at the Bellaire eastbound bus stop,
- The dwell time of each bus at that stop, and
- The number of buses that experienced delay due to the traffic signal.

After the data was collected, it was consolidated for use in building the simulation model. Table 1 shows an example of the data that was collected from the test corridor.

Simulation Model

Creating the simulation model was the most important and time consuming task involved with this research. Using the data collected from the test site, a model was created to simulate the traffic conditions and bus behaviors present at this location. The simulation model for this research was built using VISSIM 3.70. This model was intended to be run as a hardware-in-the-loop model; however due to problems with the external controller, this option was no longer viable. To replace the controller, the

Table 1: Tabular Summary of Vehicle Counts- Eastbound Bellaire

Time Period	Right Turning Vehicles	Through Vehicles	Left Turning Vehicles	Total Vehicles
11:00 AM - 11:15 AM	38	189	39	266
11:15 AM - 11:30 AM	37	173	42	252
11:30 AM - 11:45 AM	25	173	30	228
11:45 AM - 12:00 PM	31	178	46	255
1 Hour Totals	131	713	157	1001

NEMA signal timing function in VISSIM was used to run the traffic signals. The Bus Basic TSP system that is built into the NEMA function was used in order to grant priority phases within the simulations. This system grants priority using an early return strategy. An early return strategy involves shortening a non-priority phase in order to return earlier than normal to the priority phase. When the phase begins early, it adds extra time and will run for the total length of this added time together with the normal length of the phase.

Nine total simulations were run for this research encompassing three different sets of parameters. A set of parameters contained three characteristics unique to it; a random seed number, a bus start time, and a distance between buses. The random seed number determined the order in which vehicles entered the system as well as determining their behavior once inside the system. The bus start time established the time at which the first bus would enter the system. Likewise, the distance between buses set the time separation between buses entering the system. For this research, buses typically started somewhere between 100 and 150 seconds into the simulations and they had a time separation of between 900 and 915 seconds. For each set of parameters, three different types of simulations were conducted. The first type of simulation was one that did not employ any type of priority; this was the control group. The second type of simulation was one where the detection used for the priority system was set based on an average dwell time. The last type of simulation was one where the detection zone was set using a 95th percentile dwell time. Each simulation lasted three hours and included twelve buses. An example of a simulation output file is shown below in Figure 1.

Data Collection (Raw Data)

Data Collection Point 1: Link 7 Lane 1 at 2.530 m, Length 0.000 m.
Data Collection Point 2: Link 11 Lane 1 at 7.074 m, Length 0.000 m.

Data C.P.	t(enter)	t(leave)	VehNo	Type	Line	v[m/s]	a[m/s²]	Occ	Pers	tQueue	Temp	VehLength[m]
1	94.02	-1.00	72	100	0	19.2	-0.27	0.18	1	0.0	0.0	4.61
1	-1.00	94.26	72	100	0	19.2	-0.27	0.06	1	0.0	0.0	4.61
2	98.84	-1.00	72	100	0	18.5	0.27	0.16	1	0.0	0.0	4.61
2	-1.00	99.08	72	100	0	18.6	0.27	0.08	1	0.0	0.0	4.61
1	122.38	-1.00	84	300	1	5.4	-0.92	0.02	0	0.0	20.0	10.92
1	-1.00	125.04	84	300	1	2.8	-1.02	0.04	0	0.0	20.0	10.92
1	131.79	-1.00	95	100	0	3.4	-2.92	0.01	1	0.0	0.0	4.40
1	-1.00	139.69	95	100	0	2.9	1.15	0.09	1	0.0	0.0	4.40
1	141.84	-1.00	104	100	0	2.4	-1.44	0.16	1	0.0	0.0	4.40
2	151.11	-1.00	91	100	0	16.2	1.68	0.09	1	12.4	0.0	4.48
2	-1.00	151.38	91	100	0	16.6	1.48	0.18	1	12.4	0.0	4.48

Figure 1. Sample Data Output File

Analyzing Data

The analysis stage was intended to create useful statistics based on the simulations that were run with the VISSIM model. This step focused primarily on determining the number of times that buses had to stop at

the Bellaire and Hillcroft intersection. A secondary focus was to determine the delay caused to each bus under each of the three priority types.

RESULTS

One of the main focuses of this research was to decide which type of priority system allowed the highest number of buses to get through the intersection without stopping. Figure 2 shows the simulation results for the number of buses that had to stop using different seed numbers and different types of priority.

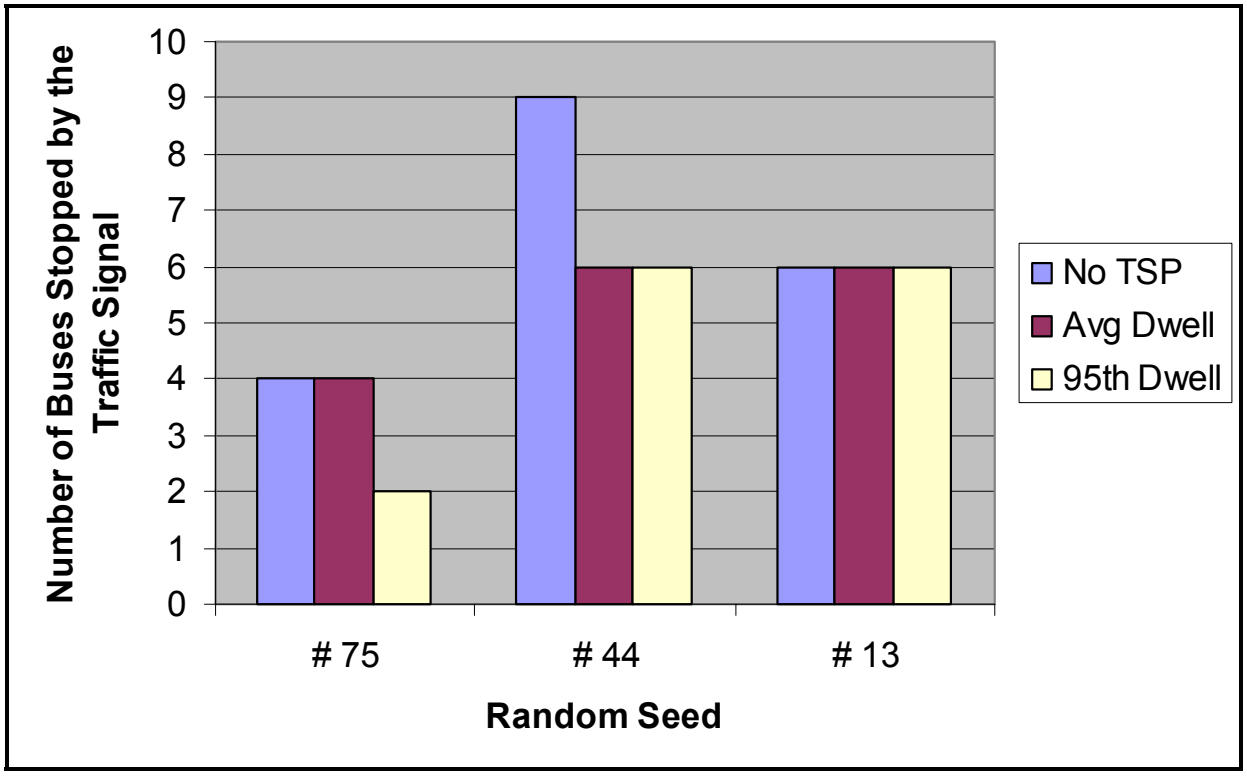

Figure 2. Number of Buses Stopped by the Traffic Signal

As the graph above shows, the number of buses that had to stop at the traffic signal varied greatly between the different random seeds. The only simulation group that showed a discrepancy between the number of buses allowed through the intersection using average and 95th percentile dwell was the first random seed group, #75.

Through running the simulation model, it became evident that simply looking at how many buses got through the intersection without stopping did not provide a comprehensive picture of how well the different systems were functioning. In order to get a more accurate measure of the performances of the different systems, it became necessary to analyze the travel time through the intersection of each of the buses under the three different conditions. Figure 3 shows the travel times for all 36 buses under each of the three priority conditions. The first twelve buses correspond to random seed #75, the second twelve to random seed #44 and the final twelve to random seed #13.

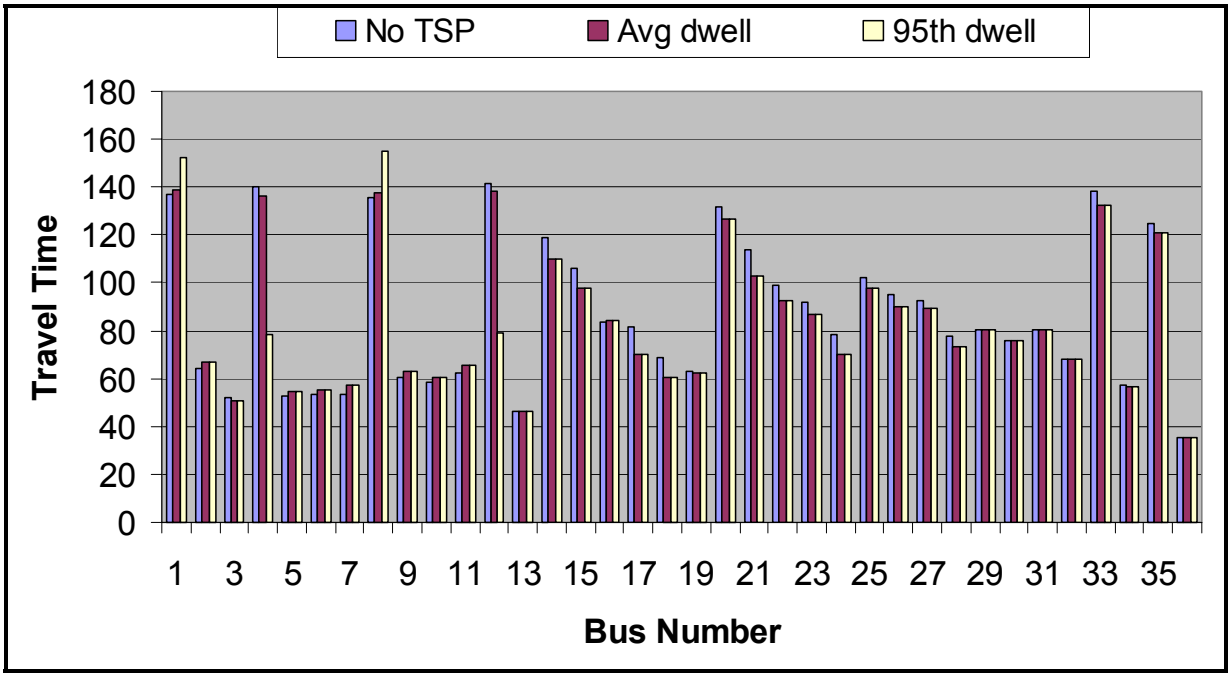

Figure 3. Bus Travel Times

The travel times represented by this graph are the times that it took each bus to get from Collection Point #1 to Collection Point #2. CP #1 was placed immediately before the beginning of the bus stop and CP #2 was placed on the exit edge of the intersection. Because of the CP placements, the times shown on the graph include the dwell time of the bus at the nearside bus stop. As the above graph shows, there were quite a few buses in random seed group #75, as well as one other bus in #44 that experienced additional delay due to the priority systems. With the exception of the first and eighth buses, these increases in delay were relatively insignificant. The reason for the larger magnitude of delay experienced by these two buses can be attributed to their dwell times. The average dwell time for all simulation runs was 40 seconds with a standard deviation of 15 seconds. Both of these buses had dwell times that exceeded 80 seconds which placed them above even the 95th percentile dwell times. Because of this, they were not serviced by either type of priority.

Six of the buses in the system experienced no change at all in their travel times in any of the three cases. These were buses that never had to stop or even slow down at the intersection when no priority was being used, therefore they maintained the same travel time when the priority systems were enabled.

When priority systems were implemented, the majority of the buses saw a small reduction in the delay that they experienced due to the traffic signal. The small magnitude of this decrease can be attributed to the signal cycle timing that was programmed for this intersection. The priority movement, the eastbound through movement, lasted for 43% of a normal cycle phase. The length of this phase created a situation where even buses that had to stop at the intersection typically did not have a long time to wait before the cycle brought this phase up again.

For most of the buses that experienced a decrease in delay due to priority service, the magnitude of this decrease was the same for both average dwell TSP and 95th percentile dwell TSP. The exceptions to this trend were the fourth and twelfth buses which experienced a sharp decline in the delay that they experienced when using 95th percentile dwell instead of average dwell. Not unlike the first and eighth buses, this significant change in delay can be credited to the long dwell times of these two buses. Both of these buses experienced dwell times in excess of 60 seconds.

Figure 4 shows the net total delay experienced by each of the simulation runs. The net total delay is the combined delay for all of the buses in each category where the combined dwell times of the buses have been removed.

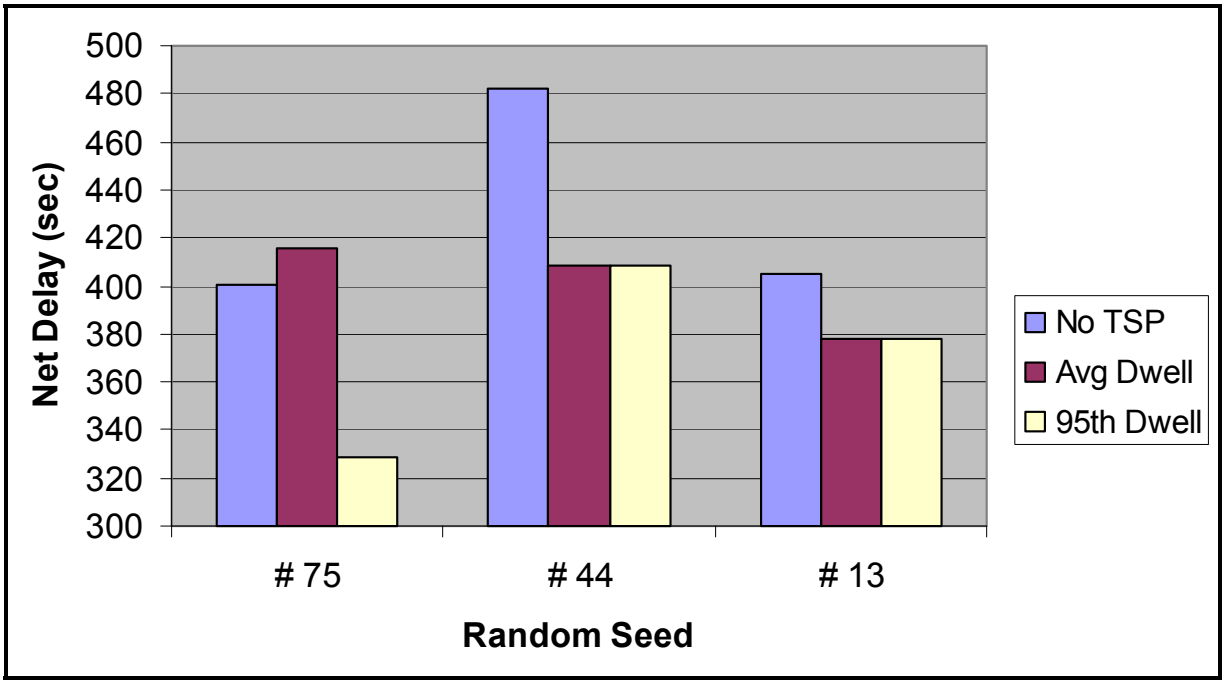

Figure 4. Net Delay Experienced

Figure 4 gives the most useful visual of the effect of the different TSP systems on the buses in the simulation. For example, Figure 2 showed no difference between any of the TSP systems for random seed group #13. Figure 4 shows that, although no additional buses made it through the intersection, the delay that the buses experienced for random seed group #13 did decrease with the implementation of both the average and the 95th percentile dwell priority systems. The only random seed group that experienced different effects with average dwell than it did with 95th percentile dwell was group #75. The sharp decrease in delay present with the 95th percentile dwell TSP can be attributed solely to buses four and twelve which, as previously discussed, each had dwell times in excess of 60 seconds.

CONCLUSIONS

Overall, the majority of the buses observed in the simulation experienced a slight reduction in travel time delay due to the implementation of a transit priority system. In most cases, the decrease in delay due to the use of 95th percentile dwell was equal to the decrease due to the use of average dwell in setting the detection zones. The only vehicles that benefited differently from the two different priority strategies were buses with exceptionally high dwell times. Non-priority phases did not experience any noticeable delay due to the implementation of either TSP system.

RECOMMENDATIONS

The data collected during this research shows no significant difference between the use of average and 95th percentile dwell for setting detection zones. The system that was tested implemented an early return strategy for granting priority, meaning that the extra priority time is added to the beginning of the normal

phase time. Because the extra time is added at the beginning of the phase, using a 95th percentile dwell may cause unnecessary delay for vehicles with short dwell times. The placement of the priority phase also allows for most buses to be accommodated by using average dwell in setting detection zones. Only buses that dwelled longer than one standard deviation away from average, in this case more than 55 seconds, had problems making it through the intersection. Due to the above considerations and the lack of a considerable advantage involved with using the 95th percentile dwell, it is recommended that the average dwell is used in setting detection zones.

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APPENDIX A. RAW INTERSECTION DATA

Table A1. Bus Stop Dwell Time Data

Observation Time	Route #	Bus #	Number of Passengers		Dwell Time (seconds)
			On	Off	
2:24	2	4502	5	7	47.1
2:50	2	4550	7	4	69.0
3:05	2	4542	1	6	17.0
3:07	2	3374	0	0	12.5
3:18	2	4537	8	3	74.0
3:34	2	4558	6	2	37.0

Table A2. Tabular Summary of Vehicle Counts- Southbound Hillcroft

Time Period	Right Turning Vehicles	Through Vehicles	Left Turning Vehicles	Total Vehicles
11:00 AM – 11:15 AM	33	154	37	224
11:15 AM – 11:30 AM	45	153	30	228
11:30 AM – 11:45 AM	38	146	39	223
11:45 AM – 12:00 PM	40	166	38	244
1 Hour Totals	156	619	144	919

Table A3. Tabular Summary of Vehicle Counts- Northbound Hillcroft

Time Period	Right Turning Vehicles	Through Vehicles	Left Turning Vehicles	Total Vehicles
11:00 AM – 11:15 AM	21	98	39	158
11:15 AM – 11:30 AM	17	115	43	175
11:30 AM – 11:45 AM	17	119	35	171
11:45 AM – 12:00 PM	22	145	53	220
1 Hour Totals	77	477	170	724

Table A4. Tabular Summary of Vehicle Counts- Eastbound Bellaire

Time Period	Right Turning Vehicles	Through Vehicles	Left Turning Vehicles	Total Vehicles
11:00 AM – 11:15 AM	38	189	39	266
11:15 AM – 11:30 AM	37	173	42	252
11:30 AM – 11:45 AM	25	173	30	228
11:45 AM – 12:00 PM	31	178	46	255
1 Hour Totals	131	713	157	1001

Table A5. Tabular Summary of Vehicle Counts- Westbound Bellaire

Time Period	Right Turning Vehicles	Through Vehicles	Left Turning Vehicles	Total Vehicles
11:00 AM – 11:15 AM	21	95	34	150
11:15 AM – 11:30 AM	24	91	47	162
11:30 AM – 11:45 AM	32	94	49	175
11:45 AM – 12:00 PM	24	116	51	191
1 Hour Totals	101	396	181	678

APPENDIX B. SIMULATION OUTPUT DATA

Table B1. No TSP Enabled, Trial #1

Bus #	Time That Bus Enters System (sec)	Time at Detection (sec)	Travel Time Through Intersection (sec)	Had to stop? (Y/N)
1	100	122.5	136.8	Y
2	1000	1024.3	64.0	N
3	1900	1924.1	51.8	N
4	2800	2824.1	140.2	Y
5	3700	3722.4	53.0	N
6	4600	4623.9	53.4	N
7	5500	5523.1	53.6	N
8	6400	6423.2	135.6	Y
9	7300	7322.8	60.5	N
10	8200	8223.4	58.2	N
11	9100	9124.1	62.3	N
12	10000	10023.6	141.3	Y

Random seed number-	75
Buses start at-	100 sec
Time between busses-	900 sec

Table B2. No TSP Enabled, Trial #2

Bus #	Time That Bus Enters System (sec)	Time at Detection (sec)	Travel Time Through Intersection (sec)	Had to stop? (Y/N)
1	111	133.9	46.2	N
2	1024	1047.3	118.9	Y
3	1937	1963.3	106.2	Y
4	2850	2876.5	83.7	N
5	3763	3786.2	81.9	Y
6	4676	4699.3	69.1	Y
7	5589	5610.9	62.8	N
8	6502	6525.4	131.9	Y
9	7415	7440.7	113.7	Y
10	8328	8351.7	99.2	Y
11	9241	9264.6	91.7	Y
12	10154	10176.9	78.2	Y

Random seed number-	44
Buses start at-	111 sec
Time between busses-	913 sec

Table B3. No TSP Enabled, Trial #3

Bus #	Time That Bus Enters System (sec)	Time at Detection (sec)	Travel Time Through Intersection (sec)	Had to stop? (Y/N)
1	138	165.4	102.0	Y
2	1045	1072.0	95.3	Y
3	1952	1976.5	92.8	Y
4	2859	2883.7	77.6	Y
5	3766	3789.0	80.5	N
6	4673	4695.7	75.6	N
7	5580	5603.5	80.5	N
8	6487	6509.2	67.9	N
9	7394	7418.1	138.2	Y
10	8301	8324.3	56.9	N
11	9208	9231.2	124.8	Y
12	10115	10138.6	35.6	N

Random seed number-	13
Buses start at-	138 sec
Time between busses-	907 sec

Table B4. TSP Using Average Dwell, Trial # 1

Bus #	Time That Bus Enters System (sec)	Time at Detection (sec)	Travel Time Through Intersection (sec)	Dwell time	Had to stop? (Y/N)
1	100	122.5	135.8	80.6	Y
2	1000	1024.3	66.8	48.0	N
3	1900	1924.1	52.4	32.4	N
4	2800	2824.1	131.4	60.8	Y
5	3700	3722.4	54.7	36.7	N
6	4600	4623.9	55.4	38.1	N
7	5500	5523.1	57.3	37.9	N
8	6400	6423.2	135.6	81.5	Y
9	7300	7322.8	62.9	45.7	N
10	8200	8223.4	60.9	42.3	N
11	9100	9124.1	65.6	46.5	N
12	10000	10023.6	137.1	59.8	Y

Random Seed Number-	75
Buses start at-	100 sec
Time between busses-	900 sec

Table B5. TSP Using Average Dwell, Trial # 2

Bus #	Time That Bus Enters System (sec)	Time at Detection (sec)	Travel Time Through Intersection (sec)	Dwell time	Had to stop? (Y/N)
1	111	133.9	46.2	29.3	N
2	1024	1047.3	109.9	37.9	Y
3	1937	1964.4	97.4	57.6	Y
4	2850	2874.0	84.1	60.0	N
5	3763	3786.2	91.8	47.5	Y
6	4676	4699.2	60.2	41.9	N
7	5589	5610.9	62.6	43.7	N
8	6502	6525.4	126.9	70.7	Y
9	7415	7442.6	103.1	70.4	N
10	8328	8351.5	92.6	47.4	Y
11	9241	9264.7	86.6	52.0	Y
12	10154	10177.1	89.5	42.8	Y

Random seed number-	44
Buses start at-	111 sec
Time between busses-	913 sec

Table B6. TSP Using Average Dwell, Trial # 3

Bus #	Time That Bus Enters System (sec)	Time at Detection (sec)	Travel Time Through Intersection (sec)	Dwell time	Had to stop? (Y/N)
1	138	165.4	98.0	60.0	Y
2	1045	1069.3	89.9	54.4	Y
3	1952	1975.8	89.5	58.7	Y
4	2859	2883.9	73.4	35.5	Y
5	3766	3789.7	80.2	62.5	N
6	4673	4695.7	75.6	57.4	N
7	5580	5603.7	80.4	63.5	N
8	6487	6509.2	67.9	48.0	N
9	7394	7418.1	132.2	65.5	Y
10	8301	8323.9	56.8	39.1	N
11	9208	9231.2	120.7	60.4	Y
12	10115	10138.6	35.6	17.5	N

Random seed number-	13
Buses start at-	138 sec
Time between busses-	907 sec

Table B7. TSP Using 95th Percentile Dwell, Trial # 1

Bus #	Time That Bus Enters System (sec)	Time at Detection (sec)	Travel Time Through Intersection (sec)	Dwell time	Had to stop? (Y/N)
1	100	122.4	152.3	80.6	Y
2	1000	1024.4	66.7	48.0	N
3	1900	1925.5	51.0	32.4	N
4	2800	2824.0	78.7	60.8	N
5	3700	3722.4	54.8	36.7	N
6	4600	4623.8	55.5	38.1	N
7	5500	5523.0	57.4	37.9	N
8	6400	6423.1	154.7	81.5	Y
9	7300	7322.7	63.0	45.7	N
10	8200	8224.0	60.3	42.3	N
11	9100	9124.0	65.7	46.5	N
12	10000	10023.5	79.2	59.8	N

Random seed number-	75
Buses start at-	100 sec
Time between busses-	900 sec

Table B8. TSP Using 95th Percentile Dwell, Trial # 2

Bus #	Time That Bus Enters System (sec)	Time at Detection (sec)	Travel Time Through Intersection (sec)	Dwell time	Had to stop? (Y/N)
1	111	133.9	46.2	29.3	N
2	1024	1047.3	109.9	37.9	Y
3	1937	1964.4	97.4	57.6	Y
4	2850	2874.0	84.1	60.0	N
5	3763	3786.2	69.8	47.5	N
6	4676	4699.2	60.2	41.9	N
7	5589	5610.9	62.6	43.7	N
8	6502	6525.4	126.9	70.7	Y
9	7415	7442.6	103.1	70.4	N
10	8328	8351.5	92.6	47.4	Y
11	9241	9264.7	86.6	52.0	Y
12	10154	10177.1	70.1	42.8	Y

Random seed number-	44
Buses start at-	111 sec
Time between busses-	913 sec

Table B9. TSP Using 95th Percentile Dwell, Trial # 3

Bus #	Time That Bus Enters System (sec)	Time at Detection (sec)	Travel Time Through Intersection (sec)	Dwell time	Had to stop? (Y/N)
1	138	165.4	98.0	60.0	Y
2	1045	1069.3	89.9	54.4	Y
3	1952	1975.8	89.5	58.7	Y
4	2859	2883.9	73.4	35.5	Y
5	3766	3789.7	80.2	62.5	N
6	4673	4695.7	75.6	57.4	N
7	5580	5603.7	80.4	63.5	N
8	6487	6509.2	67.9	48.0	N
9	7394	7418.1	132.2	65.5	Y
10	8301	8323.9	56.8	39.1	N
11	9208	9231.2	120.7	60.4	Y
12	10115	10138.6	35.6	17.5	N

Random seed number-	13
Buses start at-	138 sec
Time between busses-	907 sec

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IMPROVING PLANNING-LEVEL SPEED ESTIMATION MODELS

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SUMMARY

Congestion is a growing concern in the United States, and billions of dollars are spent each year trying to improve mobility. The Texas Transportation Institute's *Urban Mobility Study* (*UMS*) illustrates how congestion has changed over the years and how mobility can be improved. This study is one of the most widely used resources on city and national congestion levels and impacts, and therefore it is important that the information reported in the *UMS* is as accurate as possible. One aspect of the study that has been identified for improvement is the planning-level speed estimation models.

This research describes a data quality checking process using detailed traffic data in the form of speed-flow curves and time-of-day volume profiles. Using specified visual inspection criteria, the data can be categorized as good or suspect. Results indicate that more than half of the data originally thought to be good quality was actually suspect data that account for a portion of the variability seen in previous attempts to improve the *UMS* speed-estimation models.

The good quality data are then examined on a macroscopic level to investigate the causes of the remaining scatter. Although free-flow speed and city size were originally hypothesized to have some effect, the results of this research do not support these theories. However, more research needs to be conducted to validate the results reported in this study. Overall, the current *UMS* planning-level speed estimation models appear accurate, but minor adjustments could be made once additional data can substantiate the needed improvements.

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INTRODUCTION

Traffic congestion has been a concern for traffic professionals since the introduction of the motor vehicle. However, as congestion continues to worsen in many United States cities, additional efforts are being employed to help improve the efficiency of transportation systems throughout the country.

According to the Texas Transportation Institute's *2003 Urban Mobility Study* (*UMS*), the "total congestion invoice" for the 75 largest cities in the United States is $69.5 billion (*1*). The Texas Department of Transportation began the *Urban Mobility Study* in 1982 to help monitor the changes in congestion and identify methods to improve mobility. Several departments of transportation (DOTs) now contribute to this study. The data are stored in the Federal Highway Administration's Highway Performance Monitoring System (HPMS) in the form of average daily traffic volumes. Presently, this nationwide study is used in state DOTs and national decision making.

Additionally, the Federal Highway Administration created a congestion monitoring program that archive data from intelligent transportation systems. The Mobility Monitoring Program (MMP) uses loop detectors that gather detailed, real-time volume and speed data for each lane of numerous highway facilities in 23 cities (*2*). The purpose of this study is to increase the usefulness and availability of the collected data to transportation professionals.

LITERATURE REVIEW

Speed-Flow Relationship

Model Evolution

Since 1935 when Greenshield first examined the speed-flow relationship, researchers have been searching for a model that best describes this relationship. As seen in the Transportation Research Board's (TRB) *Highway Capacity Manual (HCM)* over the years, this model has evolved for many reasons into the most recent speed-flow curve seen in the 2000 *HCM*. One of the prevalent themes in the speed-flow curve evolution is the switch from using theoretical equations to using generalized empirical results (*3*). As stated by Persaud and Hurdle, in reference to curve-fitting, "if one wants to fit a curve to data by statistical methods, one must first specify an algebraic form of the curve… The choice of the algebraic form, however, can be more important in determining the shape of the curve than the data" (*4*). For this reason, many researchers have avoided curve-fitting and simply presented the data alone. Therefore, when trying to determine if detailed traffic data resemble the accepted speed-flow model, interpretations by the researcher must be made based on visual inspection of the data instead of a mathematical model.

Current Model

At present, several aspects of the speed-flow model have been verified by different studies. First, free-flow speeds are maintained until just before the capacity is reached. The decreasing slope of the model at free-flow speed has been a consistent trend, where speeds now remain constant as the flow rate increases, until around half or two-thirds of capacity values (*3*). Secondly, the flow rate at which capacity is reached has increased from Greenshield's (*5*) 1,800 passenger cars per hour per lane to the 2,200 passenger cars per hour per lane shown in the 2000 *HCM*. Finally, a set of curves have been created to account for differing free-flow speeds, also depicted in the 2000 *HCM*. The flow rates at which speeds begin to decrease from free-flow, and the speeds at capacity, have been verified by other studies (*3*). These accepted speed-flow characteristics are telltale indications that a particular data set is behaving as expected under normal, uninterrupted flow conditions. Although the speed-flow model has been improved significantly over the years, uncertainties still exist. The 1985 and 1965 *HCM* both show the lower half of the curves, however in the 1994 edition only the top portion of the model is depicted

because flow conditions in the lower half of the curve are so unstable. Even though the 1994 and 2000 *Highway Capacity Manuals* do not specify the shape of curve after capacity is reached, field data from previous research show that the lower half of the speed-flow relationship curves back around so that as flow rates decrease, the speed also decreases as seen in earlier *HCM* models. Because the data in this study are simply being examined visually and not mathematically, the researcher needs to be aware of the general model behavior when congestion exists.

PROBLEM STATEMENT

Because the *UMS* is used in policy and planning decisions, the data need to be as accurate as possible to properly convey the congestion conditions. However these data are relatively aggregate (e.g. annual daily averages), and as a result, it is difficult to accurately estimate peak-hour or peak-period speeds. Past research using the *UMS* data has shown that the relationship between average daily traffic per lane and speed is variable. Figures 1 and 2 illustrate scatter plots of volume and speed data from the MMP for seven cities during one of the first attempts to improve the speed estimation models for this study (*6*). The trend lines shown are the current *UMS* models for peak and off-peak direction speeds. Clearly, too much variability is present for both the peak and off-peak directions, and the factors that may have caused the scatter need to be investigated.

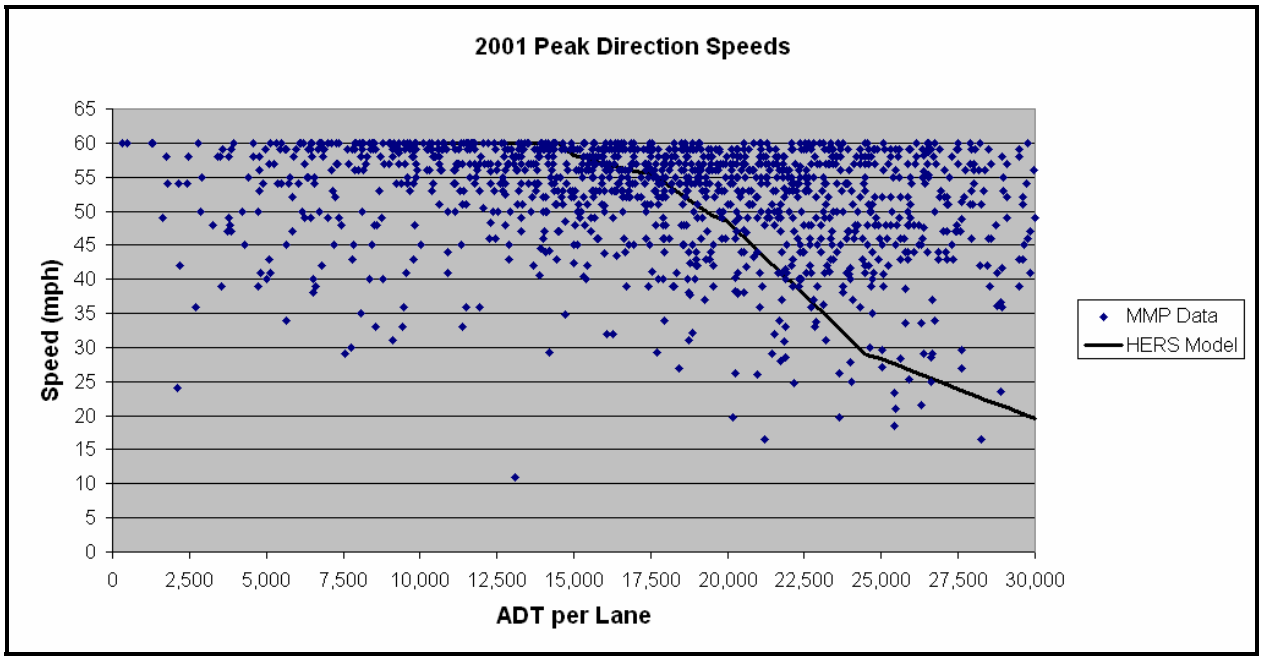

Figure 1. Freeway Peak Period Speeds for the Peak Direction

Conversely, the MMP data are very detailed with speed and volumes measured directly. Analyzing these detailed data should help explain the variability in the *UMS* data, but due to detector maintenance and calibration issues the data quality is sometimes uncertain. Therefore, data quality will need to be confirmed first before continuing the analysis. If the data are good, factors including city size, facility characteristics, and free-flow speed will be inspected to see if stratifying the data by these factors causes the flow-speed plots to become more defined.

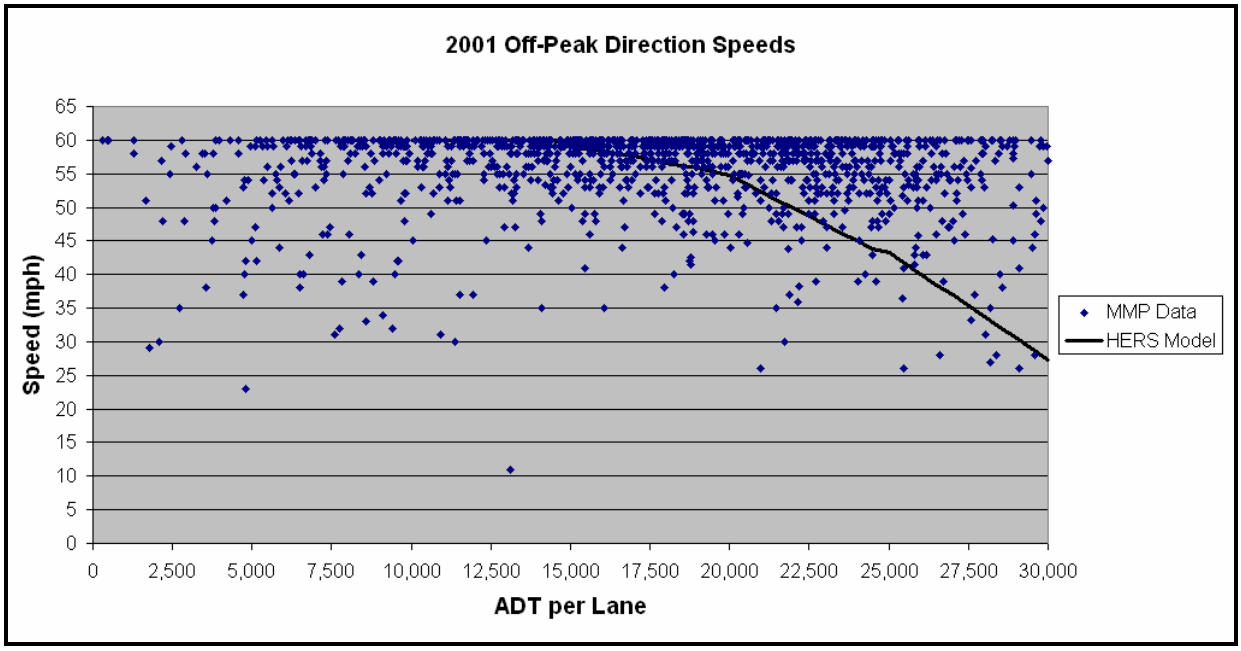

Figure 2. Freeway Peak Period Speeds for the Off-Peak Direction

RESEARCH OBJECTIVES

The overall objective of this research is to improve planning-level speed estimations. This will be accomplished by: 1) ensuring that high-quality archived data are used; and 2) using a number of explanatory factors to reduce variability in existing planning-level speed models.

PROCEDURE

Task 1: Literature Review

A review of previous research completed regarding speed-flow relationships has been done. Details about the data collection and analysis process have helped the researcher understand how to better compare the results of this research with that of previous works. In addition, problems encountered by earlier researchers were avoided and allow the data to be properly interpreted. The following sources were consulted initially and more sources were located as needed.

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Task 2: Proposal

An oral presentation was prepared to allow mentors and other researchers to ask questions and make suggestions about the research topic and methods that were to be used. A formal written proposal was also submitted for review.

Task 3: Select Study Location

In order to investigate the effects of city size on the field data in addition to the other factors under investigation, three different city sizes were chosen as follows: Houston, Texas; Austin, Texas; and Hampton Roads, Virginia for the large, medium, and small sized cities, respectively.

Task 4: Manipulate and Reduce Data

Calculations specified in Chapter 23 of the 2000 *HCM* (7) were used to apply a heavy vehicle factor to the 15-minute flow rates for Austin, Texas. Truck percentages were not available for Houston, Texas and Hampton Roads, Virginia. The percentage of trucks was estimated using historical data; however the accuracy of these values may not be as high as actual truck percentages. The data were initially represented as annual averages, but detailed day-by-day flows and speeds were also used. Equation 1 was used to calculate the heavy vehicle factor.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)} \qquad (1)$$

Where:

E_T = passenger-car equivalents for trucks,

P_T = the proportion of trucks in the traffic stream, and
f_{HV} = the heavy-vehicle adjustment factor.

Note that a passenger-car equivalent for trucks on level terrain, where E_T is equal to 1.5, was implemented because few steep grades exist on the Austin freeway segments. Typical heavy vehicle factors for Austin typically ranged from 0.9 to 1.0. Equation 2 was used to calculate the hourly flow equivalent from 15-minute volume data.

$$V = \left[\frac{v_p}{N * f_{HV}} \right] * 4 \qquad (2)$$

Where:

V = the hourly passenger-car equivalent flow rate (pcphpl),
v_p = the 15-minutes vehicle count (vehicles),
N = the number of lanes, and
f_{HV} = the heavy-vehicle adjustment factor.

Task 5: Create Speed-Flow Curves

Using Microsoft® Excel, speed-flow scatter plots were created for each detector location for each city. These plots were then compared to those documented in previously conducted research and in the TRB's 2000 *HCM* (7), as shown in Figure 3. The detailed traffic data are from a study by J.H. Banks (8) that used data similar to that of the MMP. This trend line is for a free-flow speed of 60 mph, however this line will shift vertically, up or down, to accommodate different free-flow speeds.

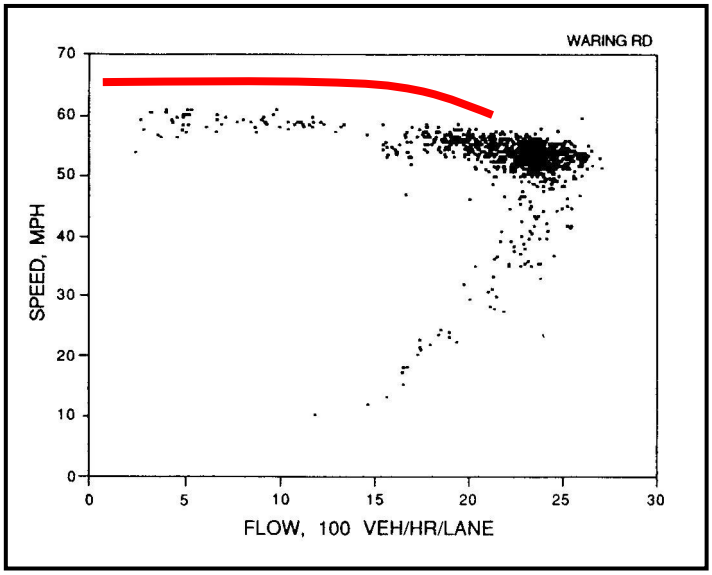

Figure 3. Typical Speed-Flow Traffic Data with Trend Line Depicted in the 2000 *HCM*

Task 6: Determine Detector Locations with Best Data

Detector locations with the best data were determined by examining the following data quality indicators for each detector location: speed-flow curves and time-of-day volume profiles. These checks required visual inspections and educated interpretations by the researcher. Additional indications of good

locations include the detector's distance from major interchanges and nearby construction. Data may be skewed if a detector is near these areas because bottlenecks may form. Only uninterrupted freeway segments were studied by removing the service road and entrance and exit ramp data from the freeway data.

Task 7: Apply Microscopic Flow Characteristics to Macroscopic Flow Characteristics

The data from the best detector locations was aggregated to a macroscopic level. Average daily traffic volumes and average speeds for both peak and off-peak directions were calculated and plotted against the current *UMS* models. Adjustments were made to these values as needed for missing data to account for every 15-minute period of the day, for every day of the year. SAS®, a statistical analysis program, was utilized to automate this calculation process. Different factors including city size and facility characteristics were examined to determine how these aspects affect the speed-flow relationships at the macroscopic level. Another factor that was also examined is the variations in free-flows speeds at different locations. As seen in the 2000 *HCM*, there are three separate speed-flow curves drawn for free-flow speeds of 50, 60, and 70 mph, which may also be the case for speed-estimation models (*7*).

Task 8: Interpret Results

The results of this research were examined in their entirety to interpret the findings and determine if the tested hypotheses are correct. Conclusions were also drawn as to why this research presented these results.

Task 9: Final Report

An oral presentation of the research was presented to mentors and other researchers to demonstrate the findings of the work completed and to answer any final questions about the research. This report is the formal written final report for this research.

RESULTS

Study Locations

Three different cities were analyzed including Houston, Texas; Austin, Texas; and Hampton Roads, Virginia. However, slight differences in the data sets for each city exist as summarized in Table 1. The data collection years varied as a result of ease of data accessibility. Additionally, the number of stations analyzed varied because these stations were most likely to have good data and have data for every 15-minute time period of the day.

Table 1. Study Location Characteristics

City	City Size	Data Year	Total Number of Stations Analyzed
Houston, TX	Large	2001	75
Austin, TX	Medium	2002	155
Hampton Roads, VA	Small	2003	115

Data Quality

Initially, all the data were filtered in SAS® to ensure that unreasonable values are not used in subsequent data analysis. Minimum and maximum values were specified to the analysis program, and if any data points did not fit into this range, they were removed from the data set. This filtering process examined the speed and volume values on an individual basis, however, no relationship was established between speed and volume or speed and flow rate. Therefore, there were two additional data quality checks used in this study to determine if the detector data was good: 1) speed-flow plots and 2) time-of-day volume profiles. This section describes the characteristics of good data and the data quality statistics for Houston, Texas; Austin, Texas; and Hampton Roads, Virginia.

Speed-Flow Curves

Using Microsoft® Excel, speed-flow plots were created for all stations, and then each plot was categorized into one of three groups: suspect data, good data at a congested station, or good data at an uncongested station. Good data have several characteristics that are visible in the speed-flow relationship. For uncongested stations, constant, reasonable free-flow speeds close to the posted speed limit are evident. For congested stations, the free-flow speeds will also be constant and reasonable, until the onset of congestion. Capacity should be reached at about 2000 vphpl (or pcphpl when considering heavy vehicles), and then speeds and flow rates will begin to drop as seen in the *HCM* models prior to 1994. Because the lower half the speed-flow curve is so unstable, the bottom portion of the curve is no longer shown in the *HCM* after 1985. Congestion at a station is apparent when the flow rate reaches a maximum and begins to drop again. Flow rates of an uncongested station will peak but will not decline. Figures 4 and 5 illustrate good data at an uncongested and a congested station, respectively.

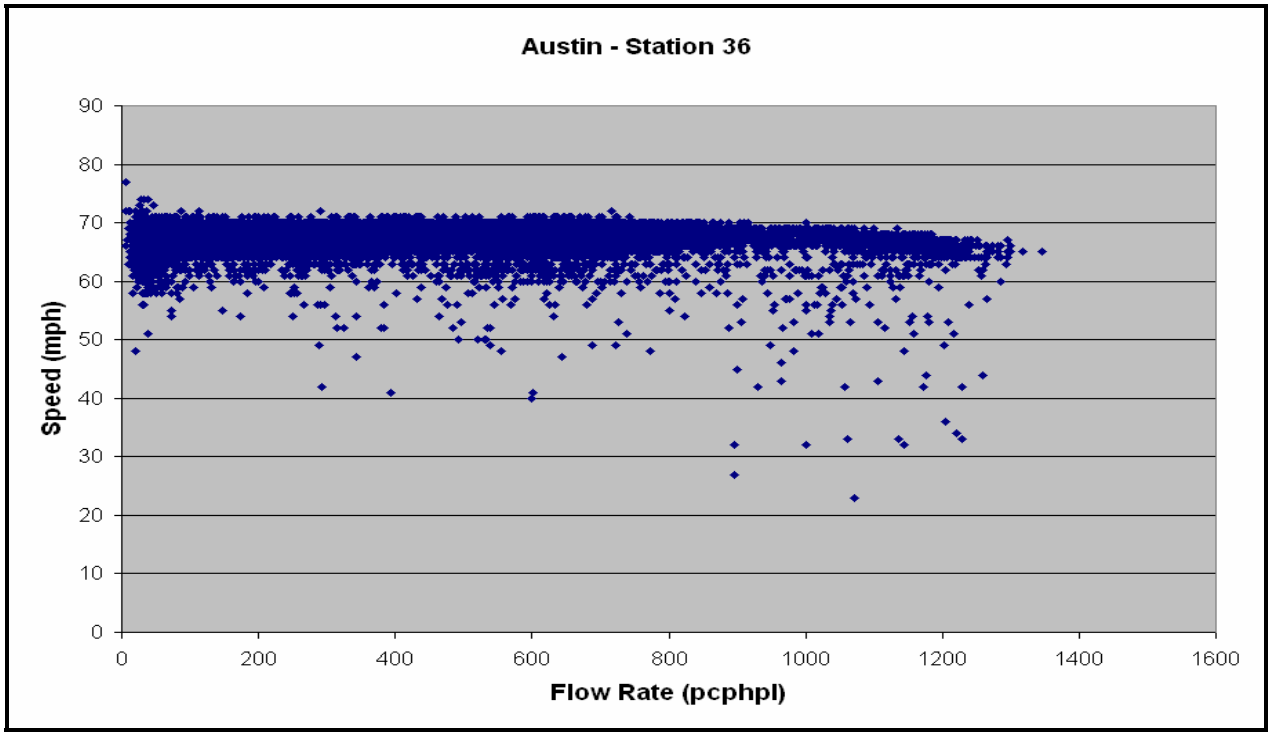

Figure 4. Speed-Flow Plot of Good Detector Data at an Uncongested Location

Conversely, suspect data lack one or more of the good data characteristics by having low free-flow speeds, reaching capacity at much higher or lower flow rates than 2000 vphpl, and/or generally failing to resemble the *HCM* speed-flow model. Figure 6 shows a station with suspect detector data.

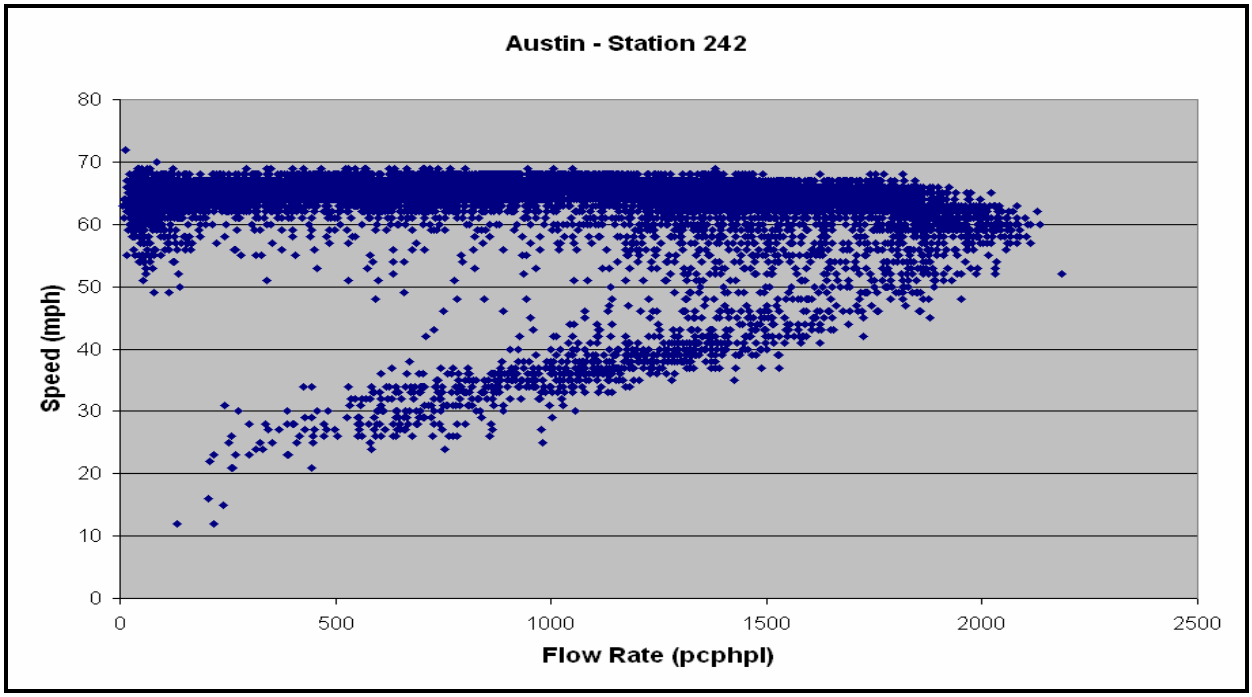

Figure 5. Speed-Flow Plot of Good Detector Data at a Congested Location

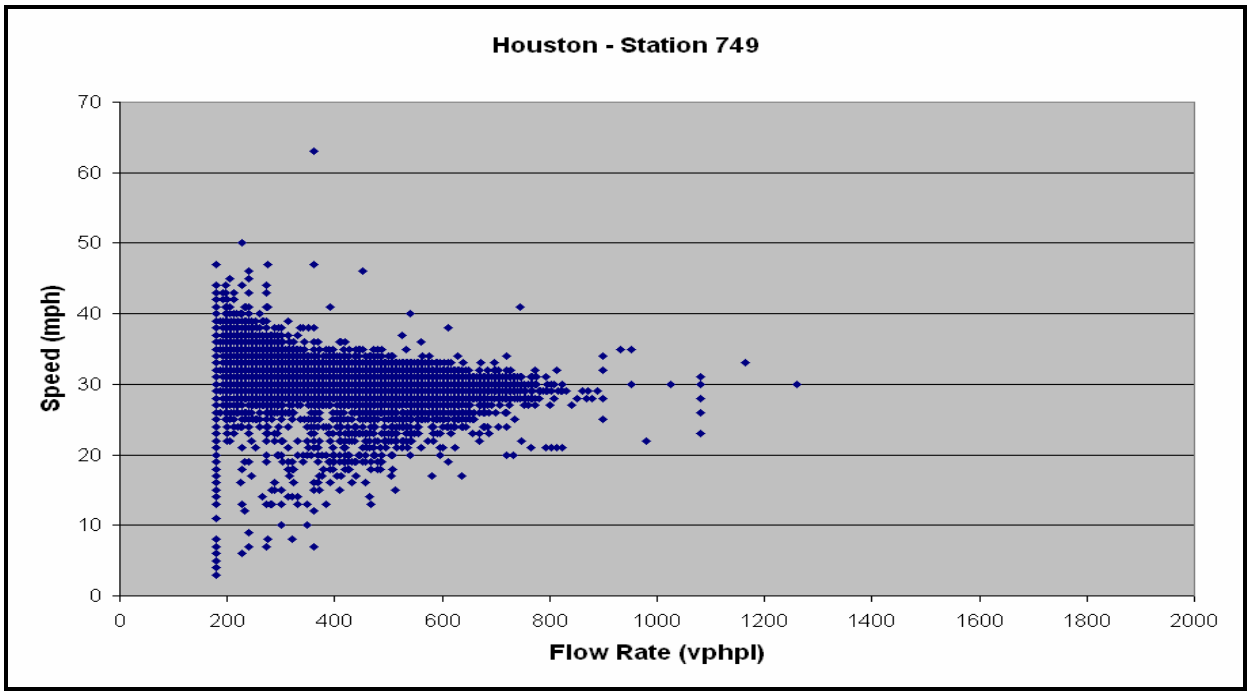

Figure 6. Speed-Flow Plot of Suspect Detector Data

Time-of-Day Volume Profiles

The second type of data quality check is the time-of-day volume profile where volume is plotted using Excel for the each 15-minute period of the day. This check is important because suspect data are more

easily seen on these profiles than on the speed-flow plots. Even if the data appear to be good based on the speed-flow curve, a few days worth of suspect data will be evident using the volume profiles. Good volume profiles will have at least a morning peak, an evening peak, both peaks, or a plateau shape during the day. The peaks will also correspond with the direction of traffic flow, whereas morning peaks should indicate an inbound flow direction and evening peaks should indicate an outbound flow. Additionally, there will not be any scatter in the form of constant flow rates over an extended period of the day where data should not exist. Figures 7 and 8 illustrate good and suspect volume profiles. As seen in Figure 7, there are clearly defined morning and evening peaks.

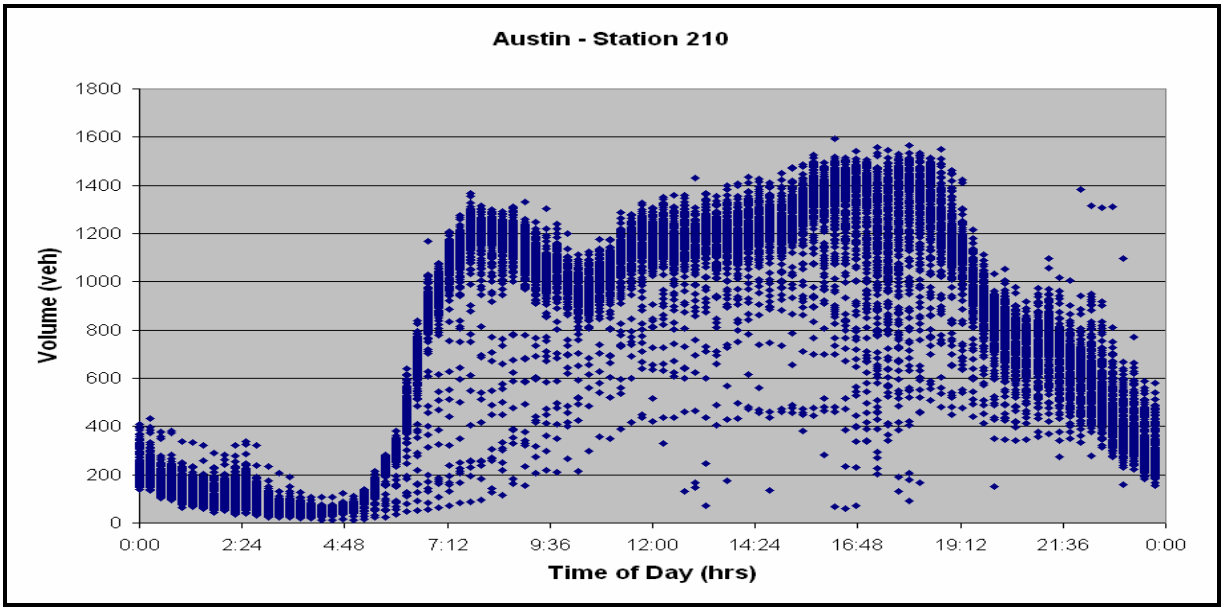

Figure 7. Time-of-Day Volume Profile of Good Detector Data

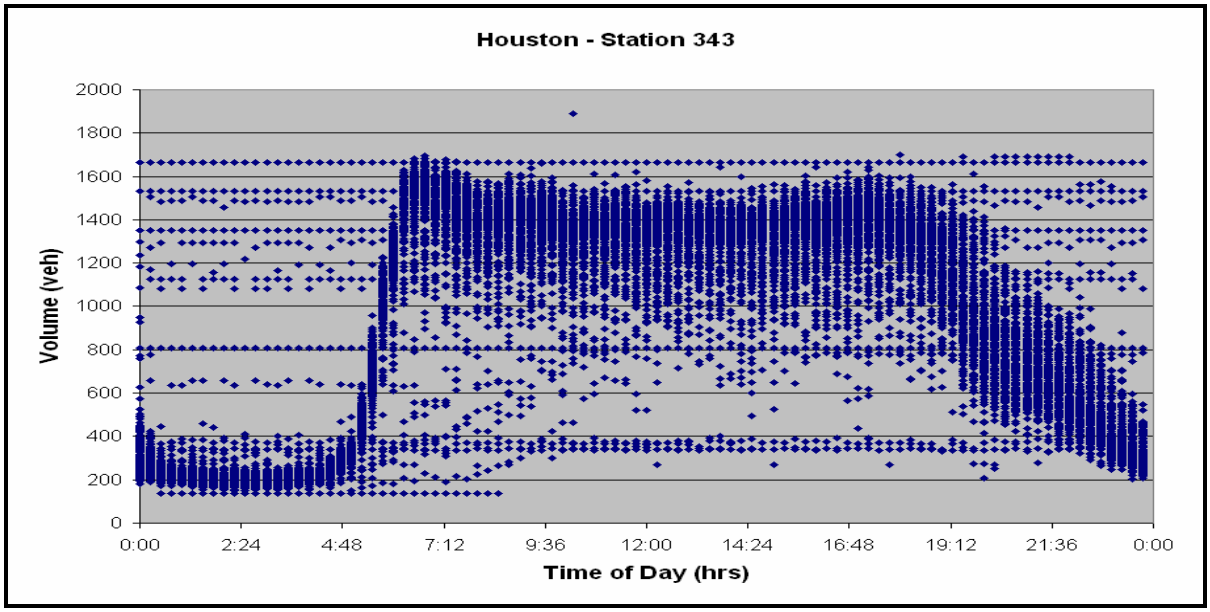

Figure 8. Time-of-Day Volume Profile of Some Suspect Detector Data

Although the station in Figure 8 has a reasonable shape, the scatter of suspect data from a few weeks is apparent throughout the plot. Further investigation indicated that these suspect data points skewed the ADT and speed values. Consequently, an effort was made to remove all the suspect data points from the plot. Approximately three weeks worth of data was suspect for the stations that passed the initial data quality check using speed-flow curves.

Detector Locations

The results of these two visual inspections indicated that there are fewer detectors with good data than had been thought prior to this study. Table 2 summarizes the percentage of stations with good detector data for each city. Good stations are those stations that had good data based on speed-flow plots as well as volume profiles. Detector locations were only analyzed if at least one volume measurement for each 15-minute period of the day, for each day of the year was available. All stations chosen for analysis had speed-flow plots created for that station. Time-of-day volume profiles were analyzed if the station was classified has having good data using the speed-flow curve analysis, congested, reached capacity around 2000 vphpl (or pcphpl when considering heavy vehicles), and generally had a greater resemblance to the 2000 *HCM* speed-flow model when compared to the other stations of a particular city. Table 3 summarizes the number of congested and uncongested stations examined from each city. Stations that were analyzed but had few data points were excluded from these counts. The locations of each station with good data are shown in Figures 9 to 11.

Table 2. Percentage of Good Data by City

City	Good Stations	Total Stations	Good Data (%)
Houston, TX	12	75	16
Austin, TX	75	155	48
Hampton Roads, VA	38	115	33

Table 3. Percentage of Congested and Uncongested Stations by City

City	Congested Stations (%)	Uncongested Stations (%)
Houston, TX	71	29
Austin, TX	57	43
Hampton Roads, VA	42	58

Austin detectors provided the largest percentage of good data stations based on speed-flow curves, whereas Houston and Hampton Roads had much lower percentages. Also, all of the Austin and Hampton Roads volume profiles are good quality, while Houston still has a lower percentage of stations with good data based on volume profiles. On the other hand, Houston had the most congested stations studied, followed by Austin, and finally, Hampton Roads. The number of stations with congestion directly correlates to the ability of the speed estimations models to be developed from the data with a high level of confidence, and therefore it is difficult to validate the speed estimation model for cities with little or no

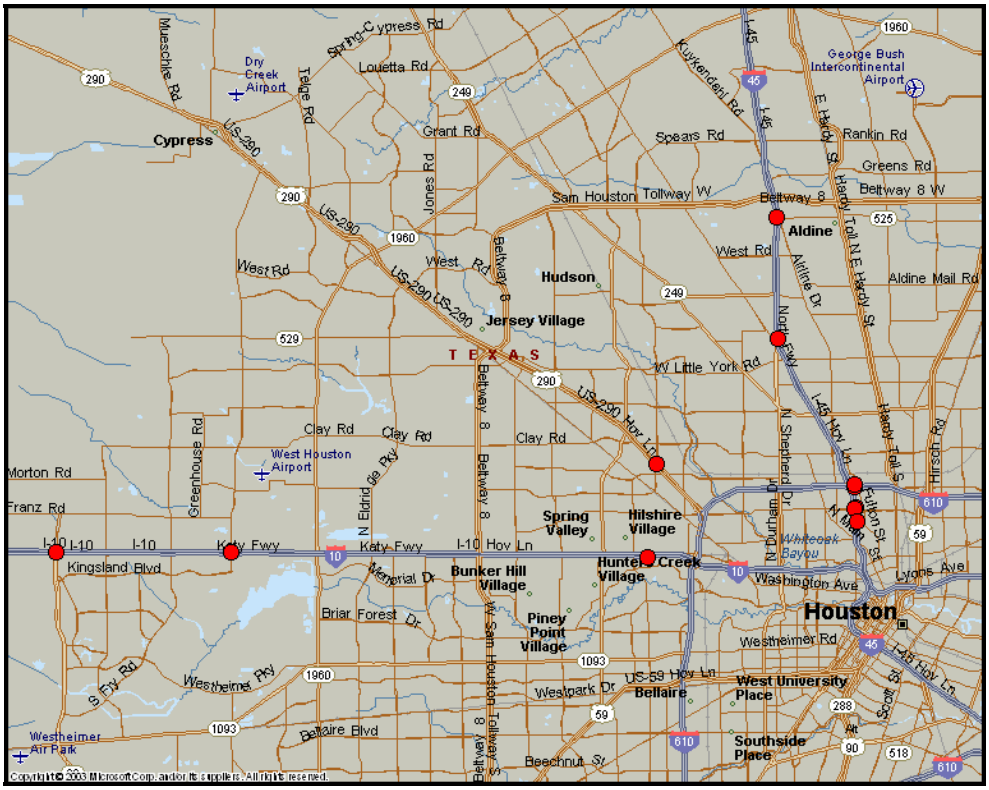

Figure 9. Station Locations with Good Data in Houston, Texas

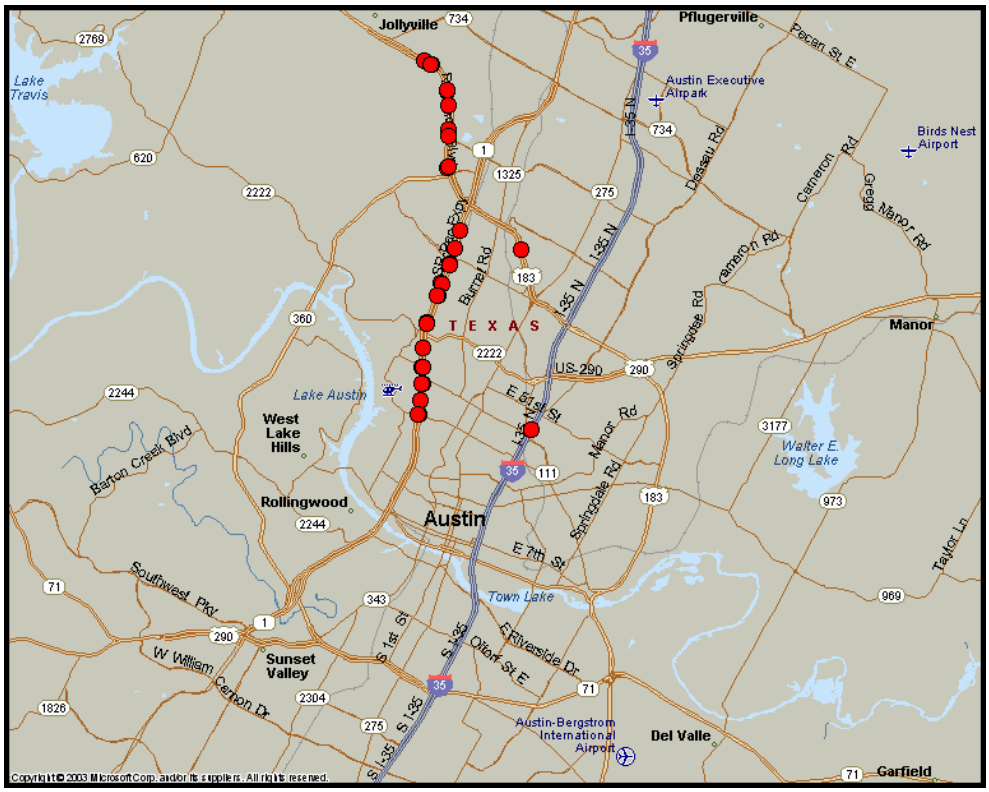

Figure 10. Station Locations with Good Data in Austin, Texas

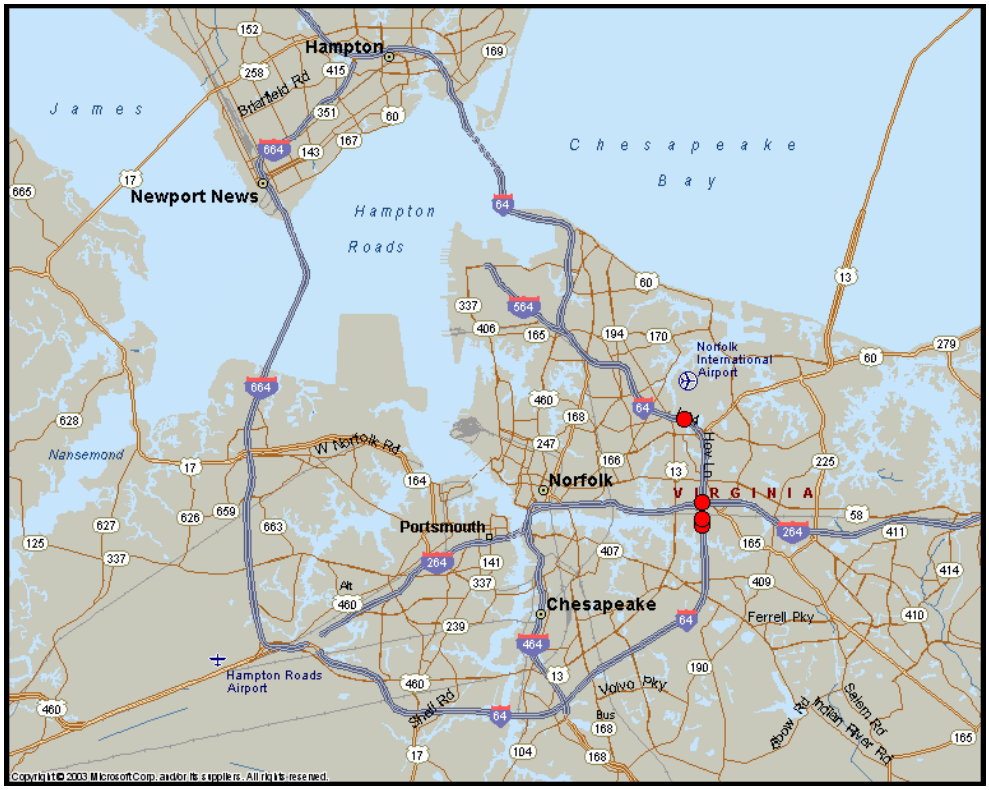

Figure 11. Station Locations with Good Data in Hampton Roads, Virginia

congestion. A final check of the good stations based on volume profiles was conducted to determine if any of the locations were near geometric bottlenecks. Generally, bottleneck locations were considered to be any station within approximately one-half mile of a major interchange, activity center, or construction zone. Overall, 48 stations from all three cities combined were determined to have good enough data based on both data quality checks to be analyzed at the macroscopic level.

Macroscopic Flow Analysis

In order to test the validity of the *UMS* speed-estimation models, average daily traffic volumes and average speeds for morning peak, evening peak, and off-peak directions needed to be calculated for each station. To decrease the computation time, SAS® was used to calculate these values. A few adjustments were made before the computations were completed, however. Days that had volume measurements for less than 90 15-minute periods or volumes less than one were not used. Additionally, a 60 mph cap was placed on all speed measurements because the *UMS* models were also created using this same speed cap. Therefore, the cap is needed in order to accurately compare the field data to the models. The results are tabulated in Tables 4 through 6 and shown below in Figures 12 and 13. Clearly, the field data in Figure 12 has much less variability than the data shown in Figure 1, during the first attempt to improve the peak direction speed estimation model. For example, at 15,000 ADT per lane the speeds range from 30 mph to 60 mph in Figure 1; however, in Figure 12 the speeds only range from 50 mph to 60 mph. Similarly, for ADT per lane values greater than 20,000, Figure 1 indicates speeds that range from 25 mph to 60 mph, whereas the data in Figure 12 shows speeds that only range from 40 mph to 60 mph. This implies there are a 67% and 43% decrease in the difference between the highest and lowest speed values for 15,000 ADT per lane and greater than 20,000 ADT per lane, respectively. From this observation, removing suspect data helps reduce the amount of scatter in the field data.

Table 4. Macroscopic Flow Data for High Data Quality Stations in Houston, Texas

City	Station Number	ADT/Lane (vpdpl)	Peak Direction Speed (mph)	Off-Peak Direction Speed (mph)
Houston	214	17,600	40	51
	222	23,816	43	53
	271	25,637	39	58
	307	23,962	56	57
	314	21,767	40	53
	343	29,680	48	50
	419	30,885	39	50
	420	21,474	37	55
	468	21,160	59	60
	470	19,630	47	56
	510	13,764	60	60
	651	18,327	51	59

Table 5. Macroscopic Flow Data for High Data Quality Stations in Austin, Texas

City	Station Number	ADT/Lane (vpdpl)	Peak Direction Speed (mph)	Off-Peak Direction Speed (mph)
Austin	26	19,853	43	46
	48	19,957	48	56
	50	19,040	52	59
	64	17,998	56	60
	69	14,485	57	60
	74	21,966	58	60
	81	18,640	59	60

Table 5. Macroscopic Flow Data for High Data Quality Stations in Austin, Texas (Continued)

City	Station Number	ADT/Lane (vpdpl)	Peak Direction Speed (mph)	Off-Peak Direction Speed (mph)
Austin	82	19,376	43	50
	89	13,470	56	60
	90	15,615	54	60
	95	15,600	55	60
	112	21,200	49	58
	113	17,818	47	57
	198	19,482	48	60
	200	18,826	51	59
	209	16,891	49	57
	210	23,379	52	60
	212	24,248	50	59
	214	20,923	53	60
	216	20,222	53	55
	218	23,315	54	60
	219	16,574	53	53
	223	21,088	56	60
	224	18,347	51	55
	227	21,183	57	60
	229	18,504	55	60
	231	20,978	56	59
	233	16,955	55	60
	236	20,949	57	60
	238	17,392	59	56

Table 5. Macroscopic Flow Data for High Data Quality Stations in Austin, Texas (Continued)

City	Station Number	ADT/Lane (vpdpl)	Peak Direction Speed (mph)	Off-Peak Direction Speed (mph)
Austin	242	18,442	55	60
	248	19,231	56	60

Table 6. Macroscopic Flow Data for High Data Quality Stations in Hampton Road, Virginia

City	Station Number	ADT/Lane (vpdpl)	Peak Direction Speed (mph)	Off-Peak Direction Speed (mph)
Hampton Roads	6	25,015	46	54
	17	26,857	49	56
	26	17,591	48	54
	50	26,439	59	60

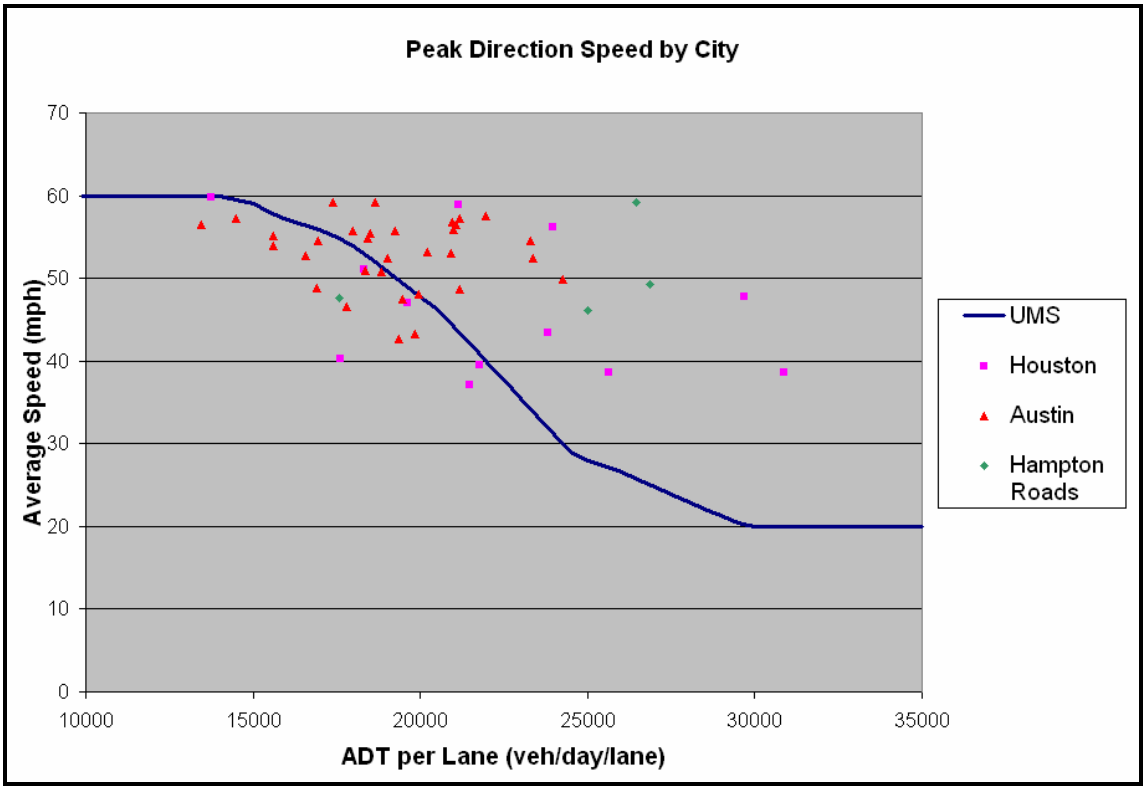

Figure 12. Peak Direction Speed Estimation Model with Field Data

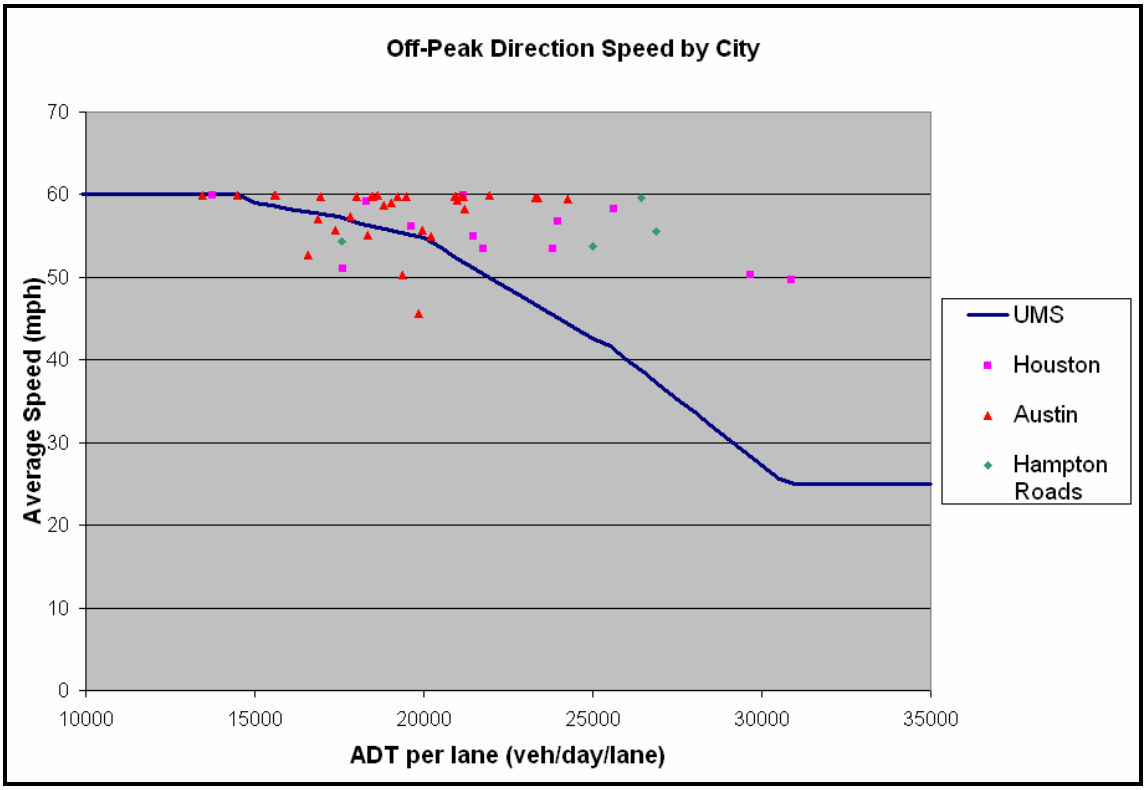

Figure 13. Off-Peak Direction Speed Estimation Model with Field Data

As shown in Figure 13, speeds vary only slightly in the off-peak direction, between 50 mph and 60 mph, for most flow rates. *UMS* researchers have hypothesized that the off-peak direction model curve should be shifted to the right slightly so that the speeds do not begin to drop until closer to 20,000 ADT per lane. The data in Figure 13 would help to validate this hypothesis because a large number of points are still at speeds of 60 mph past the 15,000 ADT per lane threshold that currently exists.

CONCLUSIONS

Data Quality

One of the main objectives in this study was to determine whether archived data being used in the MMP were good by examining data from three cities of different sizes. Presently, the data that are utilized in the MMP are assumed to be entirely reliable; however, this research indicates that not all of the data are good quality. By visually inspecting the detailed traffic data for Houston, Austin, and Hampton Roads using speed-flow curves and time-of-day volume profiles, the data are clearly not all good. The speed-flow curves were best used as an initial data quality check to determine which stations have good data overall by comparison to the 2000 *HCM* speed-flow models. The time-of-day volume profiles served as a more detailed data quality check to determine if any days of suspect data were present within station data that is generally good quality. Although only a few weeks of data may be inaccurate, the ADT per lane and speed values were skewed if the suspect data points were not removed. Additionally, station locations near major interchanges, activity centers, and construction zones were not used because bottlenecks may form at these locations and cause the resulting data for these areas to be skewed as well.

Macroscopic Flow

The second objective of this research was to determine why so much variability exists in the field data. A significant amount of scatter can be attributed to the use of suspect data. Once this data were filtered out and only the good quality data points were plotted against the *UMS* model curves, much less scatter was visible in the ADT per lane versus speed plots. However, the remainder of the factors that cause variability have not been pinpointed by this research. Initial hypotheses considered city size and free-flow speed as two possible factors, but the results of this study do not support these theories.

Speed Estimation Model

The overall goal of this research was to improve planning-level speed estimation models used in the *UMS*. Based on the results obtained in this study the present *UMS* models appear to be accurate when good field data is plotted against the models. However, as more data are analyzed, slight adjustments may need to be made to the models to better fit the more scrutinized data.

FUTURE RESEARCH

Clearly, this study provides the opportunity for future research on improving planning-level speed estimation models. One of the most obvious improvements that needs to be made before more data analysis is conducted, is to develop an automated data quality checking system. Currently, the visual data quality checks were done using the researcher's best judgment. The processes is labor intensive as 680 scatter plots had to be viewed individually to obtain only 48 data points that were acceptable for use. If a computer program could automatically perform these checks, the number of acceptable points will greatly increase and results could be determined much more quickly and objectively.

Once high quality data can be easily identified, more effort should be made to determine the causes of the remaining variability not resulting from suspect data. If these factors are known, the speed estimation models can be readjusted as necessary to better fit the data.

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Erin is actively involved with the Texas A&M University Student Chapter of the American Society of Civil Engineers, serving as Membership Chair since Spring 2004 as well as the Texas A&M University Student Chapter of the Institute of Transportation Engineers, serving as Librarian since Spring 2004.

ANALYSIS OF QUICKRIDE USERS AND NONUSERS

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August 6, 2004

SUMMARY

Travelers often have many options as to the exact characteristics of their trip- even after selecting their route. Typical choices include a combination of time of day (peak or off-peak) and mode (drive alone, carpool, and transit). This research examines travelers on two corridors in Houston, Texas who have several additional choices, including HOV-2+ on the general purpose lanes, HOV-3+ on the HOV lane, HOV-2+ on the HOV lane off-peak, HOV-2 plus a $2 toll on the HOV lane during the peak, and casual carpooling (slugging). Travelers using all of these modes were surveyed in 2003 and significant differences between groups of travelers were observed, including: trip purpose, travel time, gender, age, household type, travel partner, occupation, education and income. This information is another early step in better understanding travel behavior and the values different people place on different, and in this case unique (no other location offers HOT lanes plus casual carpooling) travel options.

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INTRODUCTION

A metropolitan area's economic and social health depends to a large extent on the performance of its transportation system. (*1*) Harris County is the third most populous county in the United States of America (*2*). The metropolitan and modern city of Houston is part of the Harris County, being the fourth largest city in the nation (*2*) with a population of 1,953,631 (2000 Census) (*2*). As a metropolitan city its freeways are heavily traveled and often being reconstructed to meet the demands of continuing growth, traffic congestion is present every day in Houston; resulting in a real problem for the travelers on the corridors. One of the solutions to this problem was the implementation of the High Occupancy Vehicle lanes (HOV) first in North Freeway (I-45) in 1979, and then later as a result of the success of this implementation, the opening of more HOV lanes in the Katy Freeway (I-10), another one on the I-45 south of downtown Houston, and another one on the Northwest Freeway (US 290). In 1984, when the Katy HOV lane opened, (see Figure 1) only registered vanpools and transit buses could use the lane. To use in a more effective way the capacity of the lane, only vehicles with two or more occupants (HOV2+) were allowed. Because of this restriction, the lane became congested during the peak traffic periods. Thus, in 1988 the Metropolitan Transit Authority of Harris County (METRO) decided to restrict usage of the lane to vehicles with three or more occupants (HOV3+) during the peak traffic periods between 6:45 a.m. to 8:00 a.m. and also between 5:00 p.m. to 6:00 p.m. This restriction was also implemented on the Northwest Freeway (US 290) during the morning peak period from 6:45 a.m. to 8:00 a.m.

The tightening in restriction from a HOV2+ to HOV3+ resulted in a considerable reduction in peak period traffic and available capacity in the HOV lanes (*3*). There was available capacity in the HOV lane. Therefore, Houston METRO decided to allow HOV2s to use the lanes for a price during the peak periods (3). In this way, Houston's QuickRide program was created, and some benefits came with the program, including: limitation of the demand to an acceptable level, a more efficient use of the lane, and the generation of a revenue source to help pay the program (*3*).

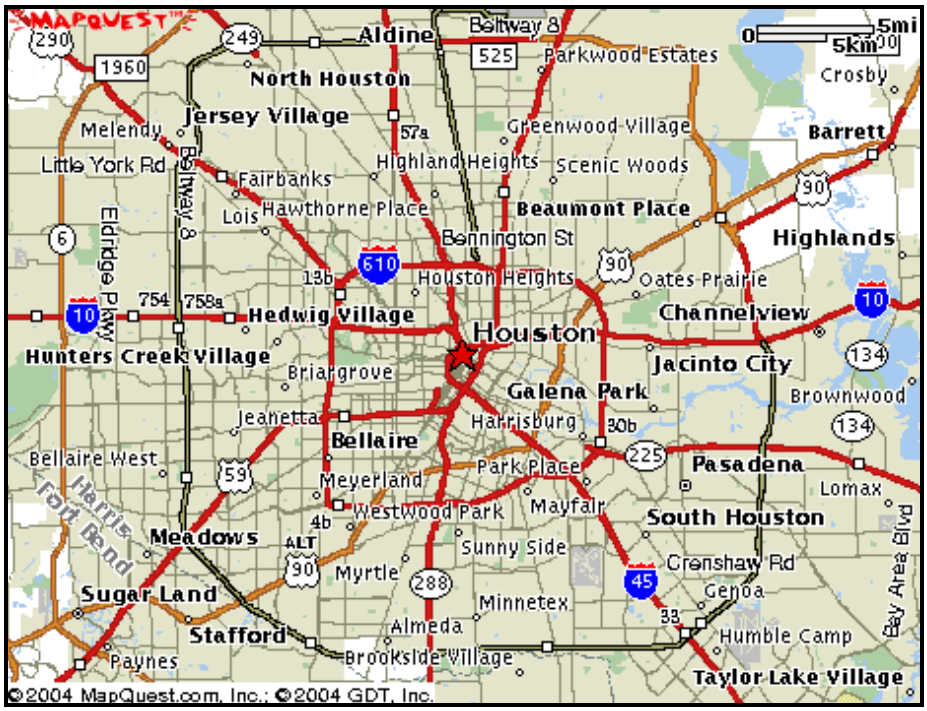

Figure 1. Houston Area Freeways (*4*)

The QuickRide program was created in January 1998 to allow vehicles with two occupants to use the HOV lane during the peak periods for a $2 toll and a $2.50 monthly fee. With the implementation of this toll, this lane became a High Occupancy /Toll lane or HOT lane. Also, with this program appeared a total of six travel modes:

- Driving alone on the main lanes,
- Carpooling on the main lanes,
- Use of the METRO buses,
- Casual Carpooling on the HOV lanes (slugs),
- Regular Carpooling on the HOV lanes, and
- Using the QuickRide program.

So far, in spite of all the possible benefits that QuickRide offers to both users and the agencies in charge, the program has had a slow and steady increase in its usage since it began in 1998. Therefore, to help solve this situation, this paper examines the socioeconomic and commute characteristics of people who choose to travel on the corridors among the six options mentioned before. The paper investigates the age, gender, income, education, household type, occupation and other characteristics of the people traveling by these options along Houston Freeways. Also it investigates what could be influencing these people to choose to travel in a specific mode. The paper looks for significant differences in the characteristics of the six travel groups. In the study is mentioned one of the factors that may be influencing why QuickRide has not reached its optimum capacity (advertisement) and the suggested ways to run the advertisement campaign to improve QuickRide's usage.

PROBLEM STATEMENT

Despite all the benefits that QuickRide has to offer, the current level of QuickRide use is less than the expected. Therefore, this research will examine:

- The socioeconomic and travel characteristics of QuickRide users and other travelers on the corridors, with the objective to improve the effectiveness of the system.
- Who uses and who does not use QuickRide.
- Who is benefiting or not benefiting from QuickRide.

From previous studies it has been found that the primary reason preventing additional usage of QuickRide is difficulties finding a passenger (*5*). Therefore, it is important to know the drivers' opinions and what they have to say about the different alternatives that can be offered, in order to achieve a balance between level of service and capacity. Thus, in that way, QuickRide is used as expected with a constant demand and also can accomplish a desire level of service for the users.

RESEARCH OBJECTIVES

The goal of this project is to define the users and nonusers of QuickRide, learn their reasons for using or not using QuickRide, and provide suggestions to improve the use of the program. The specific objectives are:

- Establish a comparison between the different groups that exist in the users and nonusers; **similarities and differences,**
- Know why they do or do not use QuickRide,
- Learn how they value their time,

- Obtain a better prediction of the HOT lane use in other cities, and
- Provide greater understanding of how travelers value different travel options.

This knowledge will:

- Allow for better prediction of the HOT lane use in other cities,
- Provide greater understanding of how travelers value different travel options, and
- This research will help QuickRide to be used as expected with a constant demand and also accomplish a desired level of service for the users.

RESEARCH METHODOLOGY

The research methodology has been divided into: **data collection**, **cleaning/segregation of data**, **basic descriptive analysis**, and **statistical analysis**.

Task 1: Data Collection

The data analyzed in this research were collected in two separate surveys. The first survey was conducted in March 2003 and was mailed to all 1459 people who were enrolled in the QuickRide program as of December 2002. A total of 93 surveys were returned by the post office due to an incorrect address. Of the remaining 1366 surveys, 525 were completed and returned on time for a response rate of 38.4 percent.

The survey included 36 questions with regards to the respondent's

- Most recent QuickRide trip,
- Most recent Non-QuickRide trip,
- Typical use of QuickRide,
- Feelings towards alternate QuickRide tolling scenarios, and
- Socioeconomic characteristics.

For a detailed analysis of this survey see Burris and Appiah (2004).

The second set of data analyzed here was obtained in a survey conducted in November 2003. This survey collected data from travelers in the QuickRide corridors who were using modes other than QuickRide. To ensure all other modes were captured, surveys were distributed to travelers on the general purpose lanes, the HOV lanes, on transit vehicles, and in casual carpool (slug) lines. To distribute surveys to travelers in the general purpose and HOV lanes the license plates of vehicles in these lanes were recorded approximately four weeks before the survey was mailed.

Capturing these license plates while maintaining a low profile proved somewhat challenging. Due to some driver's extremely negative reaction to being video taped, video cameras were located on freeway overpasses and recorded vehicles traveling below on Katy and Northwest Freeways. The cameras were positioned such that the travelers being video taped were not likely to see the cameras (see Figure 2). This configuration worked extremely well during periods where traffic was congested and traveling at low (less than 30 mph) speeds. However, at higher speeds, it was difficult to capture the vehicle's license plate such that the plate could be read while watching the video. Difficulties arose due to the speed of vehicles and angle of video. In an ideal camera configuration the camera can zoom in on a license plate (such that the plate takes up between 20 percent to 25 percent of the screen width) without the vehicle behind it blocking the plate. In cases with high speeds the license plate might not remain in the video frame long enough to get a good read. Thus you would want to reduce the angle, videotaping vehicles further away,

and increasing the zoom. This often resulted in the lead vehicle's license plate being blocked by a following vehicle. A steeper angle for the camera resulted in a plate that remained in the video frame too short a time to read. After some practice the best angles for given speeds were determined, but in high-speed conditions with low light (for example just prior to the start of the morning rush hour) very few plates were captured regardless of how the camera was deployed. Alternatively, placing the cameras at freeway level would have offered better video of license plates – but the added likelihood of negative reaction from drivers made this option unattractive.

Figure 2. Capturing License Plates on Northwest Freeway

It was also found that cameras that recorded a digital image provided relatively little advantage over a Hi8 camera with professional grade playback equipment. Approximately 75 hours of license plate data were recorded. Anywhere from approximately 800 plates per hour of tape to 0 plates per hour could be identified when examined in the laboratory. In all, 19,260 plates were identified for an average of approximately 250 plates per hour of video. Next, 1,580 duplicate plates and a handful of QuickRide enrollee plates were removed. QuickRide enrollees were removed as they had been surveyed months before. The remaining plate numbers were sent to the Texas Department of Public Safety (DPS) and they provided names and addresses for all but 2,080 plates for which they had no record. In addition, 430 plates originated outside of Texas and 1,220 were assigned to a business. This left slightly fewer than 14,000 names and addresses to mail surveys. Of those, approximately 1,150 were returned by the post office due to a bad address. Therefore, approximately 66.5 percent (12,800/19,260) of the original plates could be used, for an average of 170 plates per hour of video tape. The plates were then categorized as to the time of the day (morning peak, morning off-peak, evening peak, evening off-peak) the Freeway (Katy or Northwest) and the lane (general purpose or HOV) where they were recorded. This resulted in 16 categories of license plates. These plates, collected four weeks before the survey, were supplemented with 2,847 plates collected on the HOV lanes two months before the survey (the plates were collected for an earlier effort involving mailing warning letters to HOV violators but were never used). A minimum of 850 plates were available in each of the 16 categories. On the general purpose lanes, during peak periods, a greater number of plates (between 1,300 and 1,500) were available.

The roadway (Katy or Northwest) and time of day (morning or afternoon) when vehicles were observed dictated which version of the survey was mailed to the travelers. In this manner questions could specify a

roadway and time of day. For example: "Please tell us about your most recent morning trip on Katy Freeway traveling towards downtown Houston". This was done to reduce potential respondent confusion that might occur with a completely generic survey. Note that the survey never mentioned that the respondent was observed on any roadway at any time. Also, the survey did not change based on whether or not the vehicle was video taped in the HOV or general purpose lanes. The respondent indicated which lane they traveled in as part of the survey. The survey also varied by which stated preference questions were asked. This process is described in detail in the next section.

Respondents had the option of replying on-line or by filling out the survey and mailing it back in a postage paid return envelope supplied with the survey. Responses post-marked or submitted online within 4 weeks of the date the surveys were mailed were entered into a database. Surveys returned after that date were not entered as traffic conditions were likely changing due to the Christmas holiday season approaching. Response rates were generally high, as shown in Table 1.

Table 1. Survey Distributions and Response Rates

Target Market	Approximate # Travelers in Target Market	Surveys Distributed	Surveys Returned (Mail)	Surveys Returned (Web)	Survey Response Rate (percent)
General Purpose Lanes	Unknown[1]	8,670	1,441	680	24.4
HOV Lane (non-QuickRide)	13,500	5,330	490	94	11.0
Transit[2]	5,350	700	546	38	83.4
Casual Carpool	580	540	200	16	40.0
Total	54,930	15240	2677	828	23.0

1. Each roadway has an annual average daily traffic volume in excess of 200,000.
2. For Transit the majority of completed surveys were handed to a surveyor on the bus. Transit riders were also given a postage paid return address envelope to mail the survey back if they choose to.

STATED PREFERENCE QUESTIONS

Base surveys were developed that contained (mostly) minor word changes that made the survey easier for the respondent to answer, as discussed in the previous section. The matrix of base surveys is shown in Table 2. One set was developed for Katy Freeway travelers and another for Northwest Freeway travelers (except in the case of casual carpool passengers where three sets were developed for the three locations casual carpooling occurs). Therefore, a total of 23 different base surveys were created.

The next step was to develop the stated preference portion of the survey. Based on focus group responses, literature reviews, and experience with HOT lanes it was clear three main factors influenced travelers choice of mode: (1) travel time, (2) travel cost, and (3) travel time reliability. Initially, stated preference questions were designed with multiple levels of these three factors for respondents to choose between the following modes of travel:

Table 2. Matrix of Base Surveys

Mode	AM Peak	PM Peak	AM off Peak	PM off Peak
Automobile on general purpose lane	√	√	√	√
Transit	√	√		
Casual Carpool	√			
Automobile on HOV lane	√	√	√	√

1. Single occupant vehicle on the general purpose lanes in the peak/off-peak period,
2. Two-person carpool on the HOV lane in the peak period (the current QuickRide operation),
3. Two-person carpool on the main lanes during the peak period,
4. Single occupant vehicle on the HOV lane during the peak/off-peak period,
5. Transit during the peak /off-peak period,
6. Two person carpool on the HOV lane in the off-peak period,
7. Three-person carpool on the HOV lane in the peak period, and
8. Casual carpool on the HOV lane in the peak period.

From pilot survey responses, it was clear that the travel choice options were too complex with three main factors per choice. Therefore, the stated preference questions were simplified to contain only travel time and toll rate factors (see Figure 3).

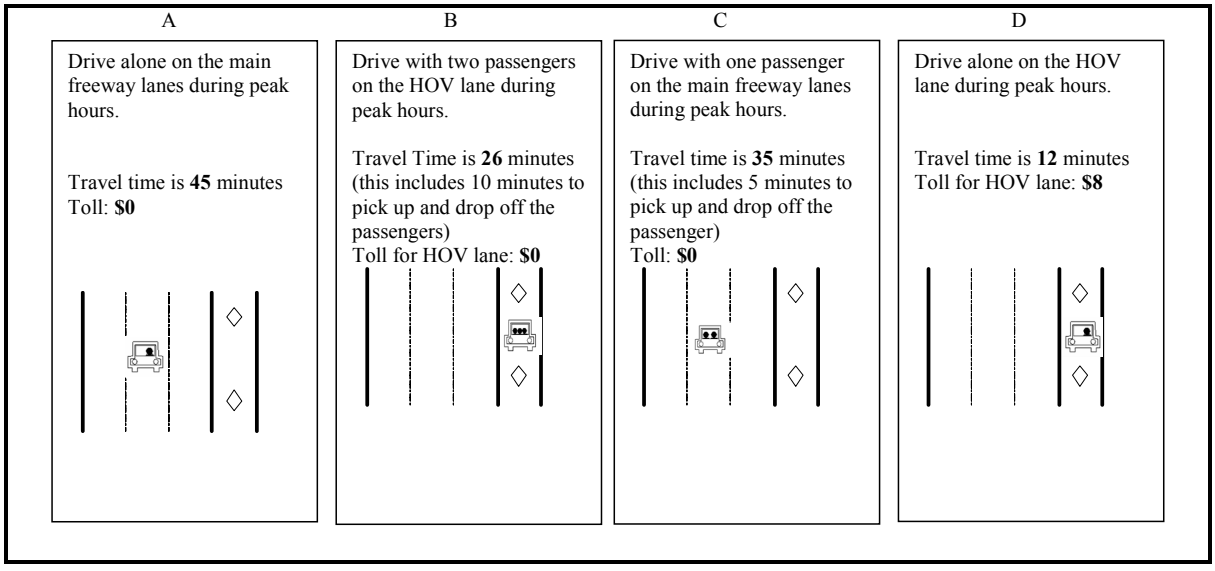

Figure 3. An Example of a Stated Preference Question

Next, the toll rate and travel time levels were developed. For the entire array of choices three factors had three levels and seven factors had two levels (3^3 2^7). To capture the majority of the main effects between variables an orthogonal array was developed to facilitate selection of levels for individual questions. The

fractional factorial design required 36 questions to cover the main effects. Since each respondent would be asked four stated preference questions, nine different survey versions were required for each base survey. This resulted in 207 different surveys mailed to Katy and Northwest Freeway travelers. The levels of the factors were based on realistic toll levels and travel times. Table 3 indicates the levels used in the survey.

Table 3. Stated Preference Survey Factor Levels

Option	Toll Rates ($)	Travel Times (minutes)
SOV on general purpose lanes (peak)	0	25, 35, 45
HOV-2 on HOV lane (peak)	1, 2, 3	18, 21
SOV on HOV lane (off-peak)	1, 2 ,3	13, 15
SOV on HOV lane (peak)	4, 6, 8	12, 16
Transit (peak or off-peak)	2, 3	17, 20
HOV-2 on HOV lane (off-peak)	0	17, 19
HOV-3 on HOV (peak)	0	22, 26
HOV-2 on general purpose lanes (peak)	0	35, 45
SOV on general purpose lanes (off-peak)	0	18, 25, 33
Casual carpool on HOV lane (peak)	0	16, 21

Responses were obtained from respondents from almost all versions of the survey. Only 9 versions of the survey (out of 207) did not have any responses. However, five of those 9 missing versions were from the casual carpool people at Kingsland Park and Ride lot on Katy Freeway. Therefore, particular attention will be paid to any analysis that includes stated preference questions from this group. Otherwise, the responses will provide ample data to develop discrete choice models on stated preference questions and more than enough data from the larger groups (delineated as different base surveys) to analyze for significant differences between groups.

Task 2: Data Analysis

Step 1: Cleaning the Data

As part of the process of data cleaning, the common questions in both surveys were chosen to make the descriptive and statistical analyses. Even questions that were similar in both of the surveys (users and nonusers); there were some changes that had to be made to some of the questions. For example, in the

question that asks: "How did you hear about the QuickRide?" in the nonusers' survey there were nine alternatives and in the users' survey there were only eight alternatives. The "METRO website" alternative from the nonuser's survey was removed and was included as part of the alternative "other". Similarly the question that asked: "What category best describes your occupation?" in the nonusers' survey there were eleven alternatives, and in the users' survey were eight alternatives. The three extra alternatives in the nonuser's survey: "retired", "student" and "self employed" were included in the "other" choice. The last question that this happened was the one that asks: "What was your annual household income before taxes in 2002?" In the nonusers' survey there were nine alternatives and in the users' survey were eight alternatives. Here, the alternatives "$200,000 or more" and "$100,000 to $199,999" were included as part of the "$100,000 or more" alternative as it shown on the users' survey. In other words, on the nonusers' survey there were more options to choose than in the users' survey, so that's why they were reduced to the same number as in the users' survey, so in that way they could match and make the statistical analyses.

Another thing that was found in this part of the project was that there were some errors in both of the surveys, specifically in the answers of the questions that asked: "When did your trip start?" and "When did your trip end?" The errors were found when the calculation of the total travel time was made. In some cases, it resulted six, eight, twenty or more hours in a travel time that the maximum allowed is two hours. Even, in other cases, the travel time resulted in negative time. All of these answers were deleted and not considered for the analyses. Some of the reasons that caused this problem were that some of the people did not write down their ending trip time. Also, some of the persons wrote that their trip began in the morning, for example at 7:30 a.m. and that the trip finished on the evening, for example 6:30 p.m. Another reason is that some of the people skipped that question.

Some of the data had to be deleted, because in some cases the persons did not respond or mark any of the choices and if such data were not removed, they would have introduced some errors in the final results. This situation happened in most of the categorical and ordinal questions such as: income, travel partner, awareness of QuickRide, age, household type, person's occupation and level of education.

Step 2: Segregation of Data

This step consisted in separating the data into the different groups for the analysis. These groups are:

- People who drive alone on the main lanes,
- People who carpool on main lanes,
- People who travel by bus,
- Casual Carpool (they carpool strangers) on HOV lane,
- Regular Carpool (they know each other) on HOV lane, and
- QuickRide users.

This segregation was realized creating and defining these six variables in the software program Statistical Package for the Social Sciences (SPSS) in which the analyses are made.

After segregating the data, there were eleven persons that were not classified into these six alternatives. The problem was that they answered that they traveled on the main lanes, but they did not answer if they traveled alone or with passengers. In terms of the analysis these eleven persons did not were taken in consideration.

Step 3: Descriptive Analysis

Once all the data were cleaned and segregated, the descriptive analysis started. This analysis consisted in an overall description of all the participants (six groups) in which the use of cross tabs was needed. In this

stage it was very important to check out the results and to compare them with the previous papers results. These results had to be the same or close enough to the ones in the previous papers. Fortunately, most of them were the same, and a little amount of them were pretty close to the previous results.

Step 4: Statistical Analysis

When the descriptive analysis was ready, the statistical analyses were run. Here was important to classify the variables in order to run the correct test for each variable in the analysis. The purpose of these analyses was to look for significant differences among the six different traveling groups in the questions asked in the surveys. The use of programs as Excel and SPSS was needed at this stage, to make cross tabs, charts, tables, and graphics. To find a significant difference among the categories, the probability value of the tests (in this case Chi-Square test, ANOVA test of Kruskal-Wallis test) had to be less than 0.05. The 0.05 is because it was used a 95 percent of confidence interval.

In this stage were compared the different travel choices versus different socioeconomic characteristics such as: age, gender, education, income, household type, occupation, number of people living in household and other. Also, in these analyses it was studied the time travel versus the travel mode, the trip purpose versus the travel mode, the total trips during per week among the six travel options, the travel partner versus travel mode and others.

Another objective of these analyses was to look for some correlation coefficient if existed between the any of the variables. A correlation coefficient is a number between -1 and 1 which measures the degree to which two variables are linearly related. If there is perfect linear relationship with positive slope between the two variables, we have a correlation coefficient of 1; if there is positive correlation, whenever one variable has a high (low) value, so does the other (*5*). If there's a perfect linear relationship with negative slope between the two variables, we have a correlation coefficient of -1; if there is negative correlation, whenever one variable has a high (low) value; the other has a low (high) value (*5*). A correlation coefficient of 0 means that there is no linear relationship between the variables (*5*).

RESULTS

Section 1: Socioeconomic characteristics of the six travel modes

When asked about their trip purpose, 79.2 percent respondents were commuting. There was a significant difference between the six groups of participants in each of the five trip purposes.

The slugging participants were significantly more likely to travel for commuting purposes (96.3 percent commuted) and significantly less likely to travel for school purposes (0 percent). Also, the transit participants were significantly more likely to travel for commute purposes. The QuickRide users were significantly less likely to be on a commute trip. QuickRide users were significantly more likely to be on a school trip. For recreation purposes, the two highest percentages were the people who carpool on the main lanes and the QuickRide users. This is not surprising as both groups have two or three people with them in their car.

There was significant difference between the six travel times of the six groups. The QuickRide participants experienced the shortest travel time with an average of 46.4 minutes per trip. The slugging participants were the ones with the highest travel times, with an average of 60.33 minutes

A significant difference existed when asked if the participants knew about the QuickRide program before the survey. Fifty-eight point three percent of all the participants answered that they knew about the program before the survey. Among QuickRide non-users, slugging participants had the highest percentage (64.8) of those who knew about QuickRide before the survey.

The slugs had a significantly higher number of weekly trips, 9.68, than any other group. In second place, were the regular carpoolers with 9.48 trips and in third place the transit participants with 9.32 trips. There was also significant difference between the six groups of participants.

There was significant difference too between the six groups in the question about how much time does it take to pick up and drop off a passenger. QuickRide participants had the least time of all the groups with an average of 4.33 minutes. The group with the highest time was the people who carpool on the main lanes, with an average 7.94 minutes.

There was a significant difference in the results to the question: "How many people live in your household? Regular carpool group had the largest number of persons with a 3.22 average people per household. The group of the people who drive alone on the main lanes had the least number of people living in the household with a 2.98 average people per household. These two results can help explain in a better way, why the first group usually carpools and why the last one chooses to drive on the main lanes. Once again, it can be seen from these results that the problem of QuickRide is the availability to find a passenger.

Significant difference existed in the results about the number of motor vehicles per household. Among all the groups, there is an average of 2.35 vehicles per household. The people who have more vehicles are the people who drive alone on the main lanes with an average of 2.42 vehicles per household and the people that have fewer cars are the slugging participants with an average of 2.20 vehicles per household.

Next, people who knew about QuickRide were asked how they learned about the program. The largest percentage, 35.7 percent learn about the program from their family or a friend, and just 1.9 percent of all participants learned about the program on the bus. There was significant difference in each of the alternatives between the six types of participants. From the QuickRide participants a 39.7 percent of them heard about the program by family or friend, being the highest of all the six groups. From the slugging participants a 35.8 percent heard of the program by other methods than the ones included in the survey**.** QuickRide has not been extensively promoted, as can be seen in, the "TV", "Radio", "Mail" and "on the bus" alternatives resulted very low in comparison with the family or friend alternative. Their percentages were 5.1, 4.8, 3.9 and 1.9 respectively.

Among respondents who traveled with someone, the most common travel companion (37.9 percent) was an adult family member, while the least common (2.9 percent) was a neighbor. In the QuickRide group, 40.5 percent of the QuickRide participants said that the travel with a co-worker, 35.9 percent said that they travel with an adult family member and 24.7 percent of the participants said that they travel with children. In the Transit participants 43.8 percent answered that they travel with an adult family member. In the regular carpoolers category most of the people travel with an adult family member and then with a co-worker. There was significant difference in the co-worker, adult family member, slugging and children alternatives between the six groups of participants. In the neighbor and other alternatives there was no significant difference found.

Significant differences existed in all of the categories of ages, except for 16-24 and 55-64 ages. It was found that less than 50 percent of the participants of both surveys are in the range between 45-54 years old, being this category the largest between all of the results. The people who most use the QuickRide program are between the 45-54 years old. The transit participants are mostly between 45-54 years old too. In the slugging participants, most of the people are likely to have between 35-44 years old.

Among all the participants, 54.5 percent were males and 45.5 percent were females. The most likely participants of QuickRide were the females with 53.0 percent. Among males of all the travel modes, the people who drive alone on the main lanes were the highest percent with a 64.4 percent. In the other travel modes, the results were around 50 percent and 50 percent for every gender.

In the household type category, most of the participants of the surveys (55.8 percent) were married and had a child or children. Few respondents (2.1 percent) had a household type of unrelated adults. There was significant difference in each of the different categories. QuickRide participants were significantly more likely to be married and having a child than any other group. Transit users were significantly more likely to be married and having children too. In the category of the people who is married with no children, the highest percentage resulted in the QuickRide users too, with 29.9 percent. The results in unrelated adults and single parent family were pretty low in comparison to the results of the people who are married with children and the people who are not married with children.

Significant differences resulted in all of the categories, except for the technical and the alternative "other." In the person's occupation question, the professional/managerial occupation was the greatest between all the participants, with 61.9 percent. In the QuickRide program and in all of each of the other travel modes, the professional occupation is the highest, with over 60 percent in some of the groups and with over 51 percent in other cases. In the professional category, the slugging participants were the highest percentage with 65.7 percent. The transit participants were the highest participants in the category of administration/clerical occupation and in the technical occupation too. In the unemployed category all the percentages were really low, being 1.6 percent the highest one.

College graduated persons had the highest percentage (44.0 percent) of all the survey participants, in terms of education categories. In the QuickRide group, 38.6 percent of the respondents were college graduated persons, followed by postgraduate degree education with a 35.4 percent of the respondents. Most of the college/vocational education persons use the METRO buses as their travel mode and most of the college graduate persons carpool on the main lanes. In the high school category, most of the people are QuickRide users with 8.8 percent. There was significant difference in four of the five categories; the people with less than high school education did not have any significant difference.

In the income question there was significant difference in all the categories except for the category of $10,000 to $14,999. The people with more than $100,000 of income were the highest people who responded in total, with 46.7 percent. Also in this category, the QuickRide users were the most likely with this income (60.8 percent). In the $75,000 to $99,999 the people who carpool on the main lanes are the ones who are more likely to have that income (24.1 percent). Transit participants are more likely to have an income of $100,000 or more.

Section 2: Specific comparisons

QuickRide had the highest percentage, in the school category among the trip purposes (11.0 percent). This is an interesting result and it will be explore further among age, occupation, household type, number of trips and number of trips with out unemployed people.

In the group of age between 16 and 24 years, 53.2 percent of the people said that their trip purpose was school (see Figure 4), being this one the highest one among all the different groups of ages. In the groups of 25 to 34, 55 to 64 and 65 and over the percent was zero (see Figure 4). A total percent of 11.5 was the result among all the ages for school trip purpose. A significant difference existed in these results.

In terms of people's occupation, the "stay at home parents" alternative accounted for the highest percentage (47.5 percent) of school trips (see Figure 5). This result makes sense because most of these people are the ones who drive their children to school. A significant difference existed in this comparison.

The alternative "other" had 87.0 percent among the different house hold type alternatives when compared with school trip purpose (see Figure 6). People who are married with children followed the "other" alternative with a 16.2 percent (see Figure 6). An 11.8 percent was the result among all categories. This 87.0 percent it could be people who work in schools and answered their trip as a school trip, or people

who has another type of house hold. There was a significant difference between the groups of this comparison.

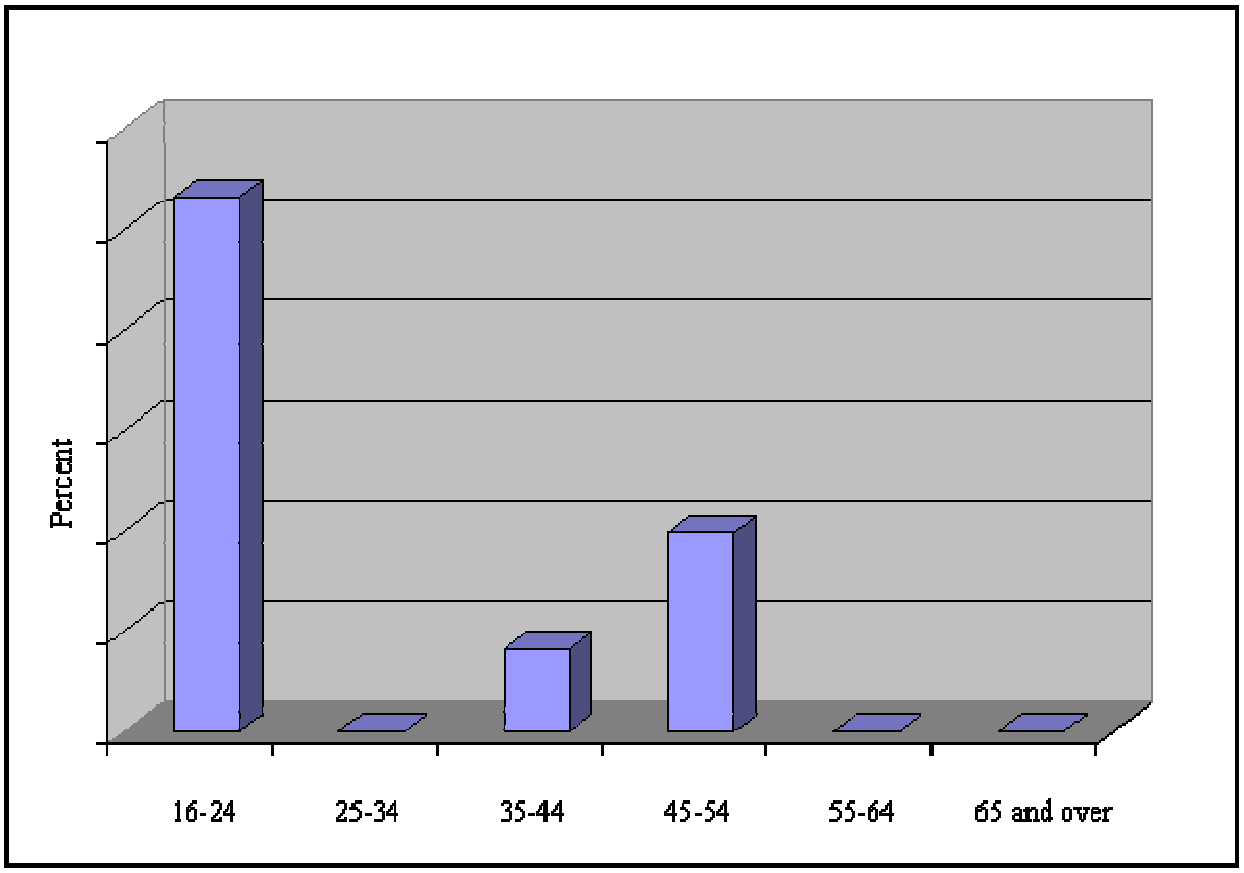

Figure 4. Percent of people that travel for school purposes by age

The school purpose trip was compared with the total number of trips during a week and with the total number of trips during the week with out the unemployed people. The first result was 9.17 trips per week and the second one was 9.13 trips per week. In other words, there was no big difference between having all the occupation groups and having all the occupation groups with out the unemployed people. As a consequence, no significant difference resulted in both comparisons (with and with out unemployed people).

The category "other" had an average of 69.31 minutes in travel time (see Figure 7), among the five trip purposes. The school trip purpose had an average of 50.37 minutes (see Figure 7) being the shortest travel time of the five trip purposes. An average of 54.85 minutes (see Figure 7) was the travel time for all the alternatives. A significant difference existed in these results.

The alternative adult family member was the easiest and quickest travel partner to pick up and drop off with an average of 3.58 minutes (see Figure 8). The children were the second easiest and quickest to pick up and drop off, with an average of 4.72 minutes (see Figure 8). A significant difference existed in this comparison.

Not surprisingly, a positive correlation existed between education and income (see Figure 9). Note that only 16 people with less than high school education provided their household income, which may account for the fact it was higher than the next two education levels.

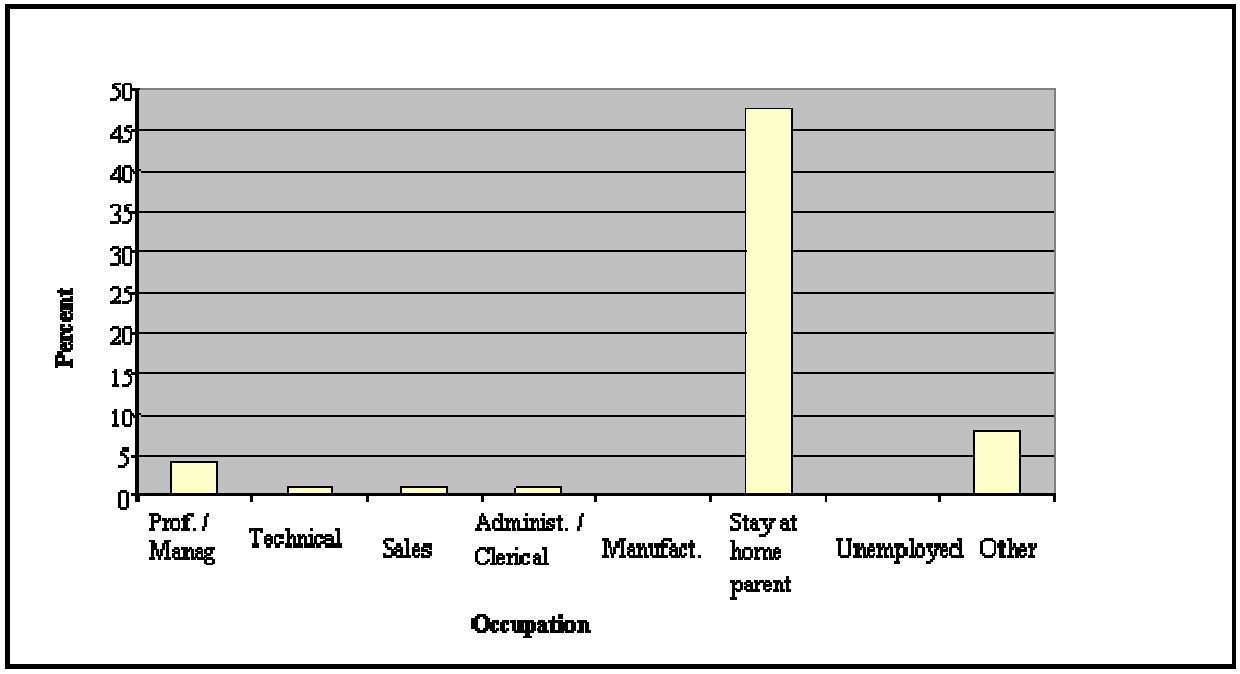

Figure 5. Percent of people who travel for school purposes by occupation

A significant difference existed when analyzing travel partners among trip purposes. The adult family member travel partner option had the highest percentage (32.8) in the all travel purposes alternative (see Table 4). In the "other" category among trip purposes, the adult family member travel partner had the highest percentage with 79.7 percent. In the commute trip purpose alternative the co-worker had the highest percentage among all travel partners with 38.6 (see Table 4). The children had the highest percentage as travel partners for school trip purposes with 72.8 percent (see Table 4). Among all travel partners, the adult family members were more likely the travel partner for recreation purposes (49.2 percent) (see Table 4).

CONCLUSIONS

QuickRide is a convenient way to travel, that may be the main reason for the shorter travel time among all travel modes. Still, it is a convenient way to travel, the main problem with it, is the availability to find a passenger to travel with. We know is a good concept and a good idea, but finding a passenger is not that easy for the users. That may be because:

- A person does not like to spend time in picking up and dropping off a passenger; they consider there's no travel saving if they have to pick up and drop off a passenger.
- People like to drive their own car every day for whatever their trip purpose is; they think is more comfortable and practicable.

Another factor that has influenced QuickRide to work below it's capacity is the advertisement. This is shown when the participants responded that they knew about the program because a family member o a friend told them before. That means that the advertisement has to be stronger and has to be run in other ways. For example, the second highest form of learning about the program was the newspaper. That means that the newspaper is a good way of advertisement and is having a good result, so the other advertisement methods like TV, radio and mail have to be strengthened in terms of advertisement.

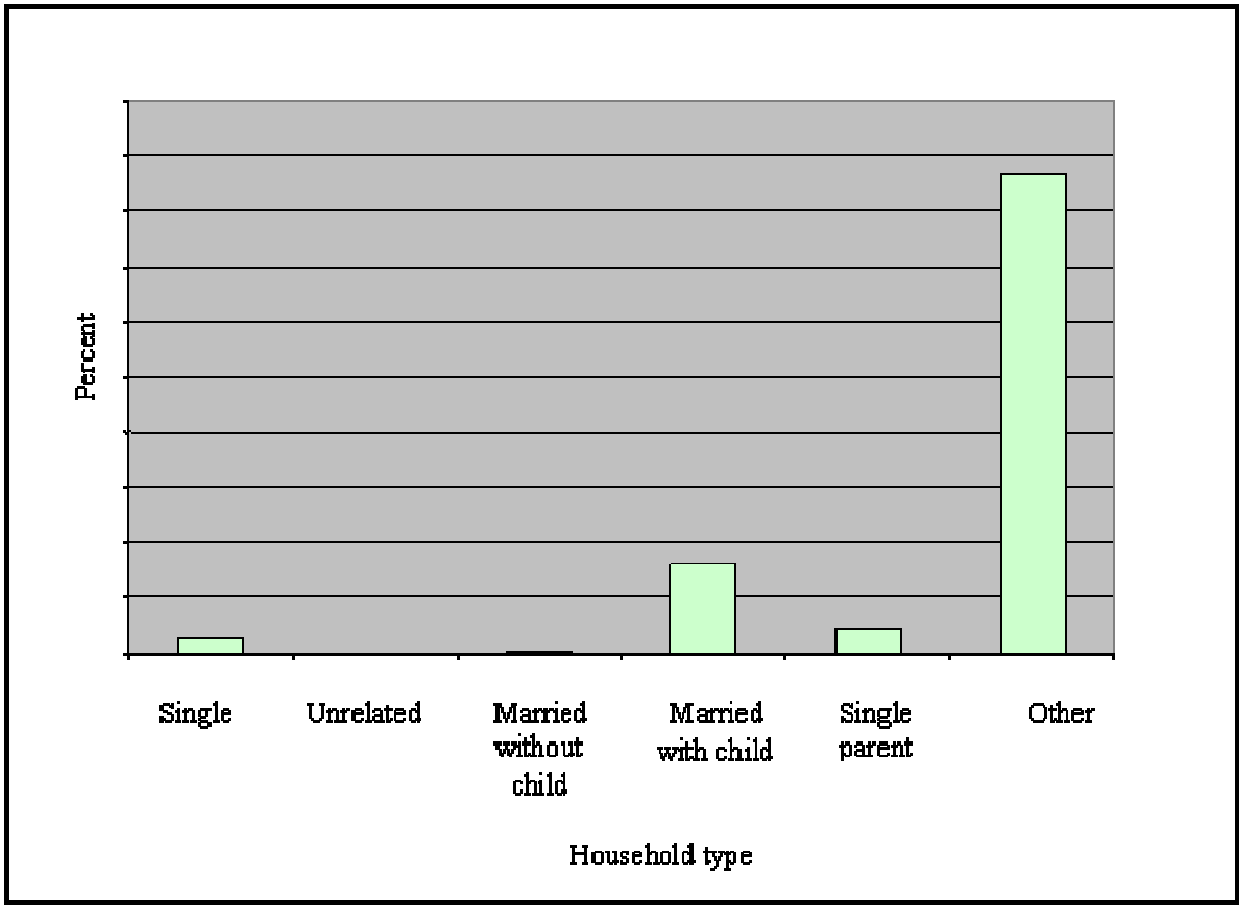

Figure 6. Percent of people who travel for school purposes by household type

Most QuickRide users are wealthy people with high levels of education and income. Also, most of the QuickRide users are: female, 45-54 years old, have professional or managerial occupation, and have earned a college degree.

Significant difference resulted in almost all the questions among the travel modes, that means that in general their trip purposes, travel times, travel partners, total trips per week, age, household type, occupation, education and income are really different.

One of the solutions that may help QuickRide's demand problem is to decrease the occupancy minimum to 1 person per car. To make this possible, a study of toll price has to be done, so it can be determined the toll for a 1 person vehicle using the HOV lane.

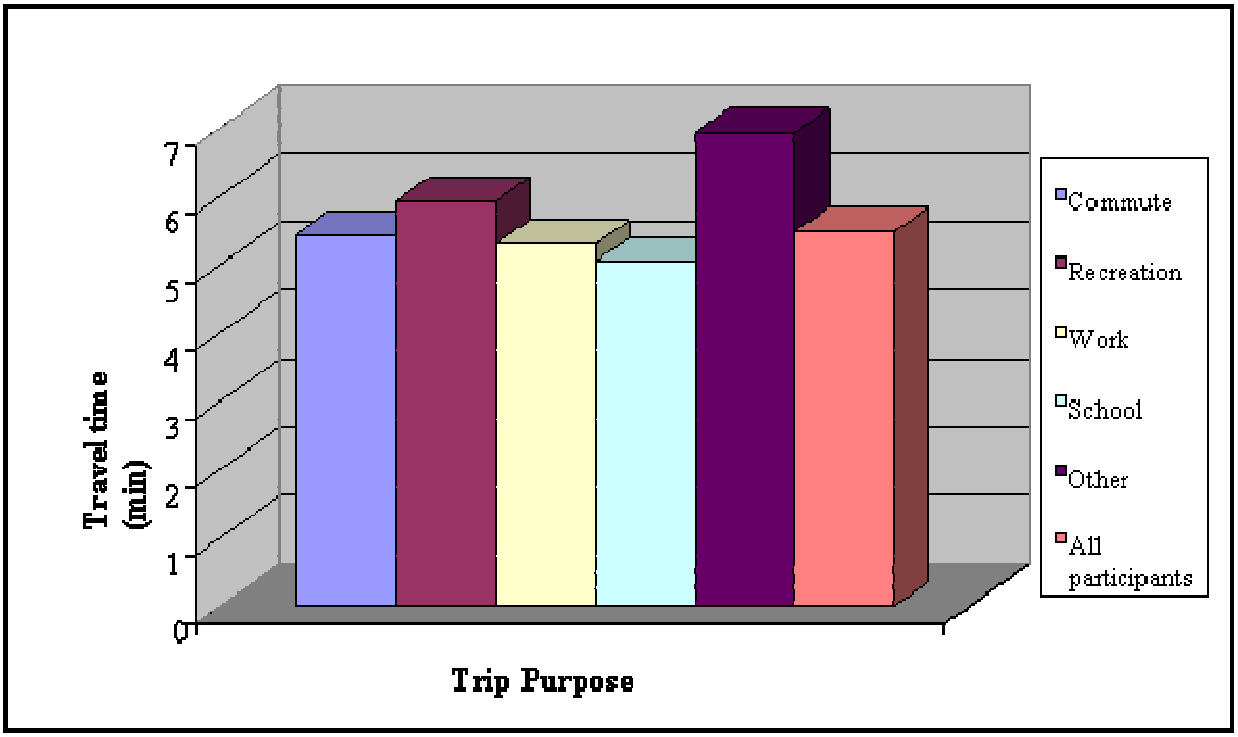

Figure 7. Travel time vs. trip purpose

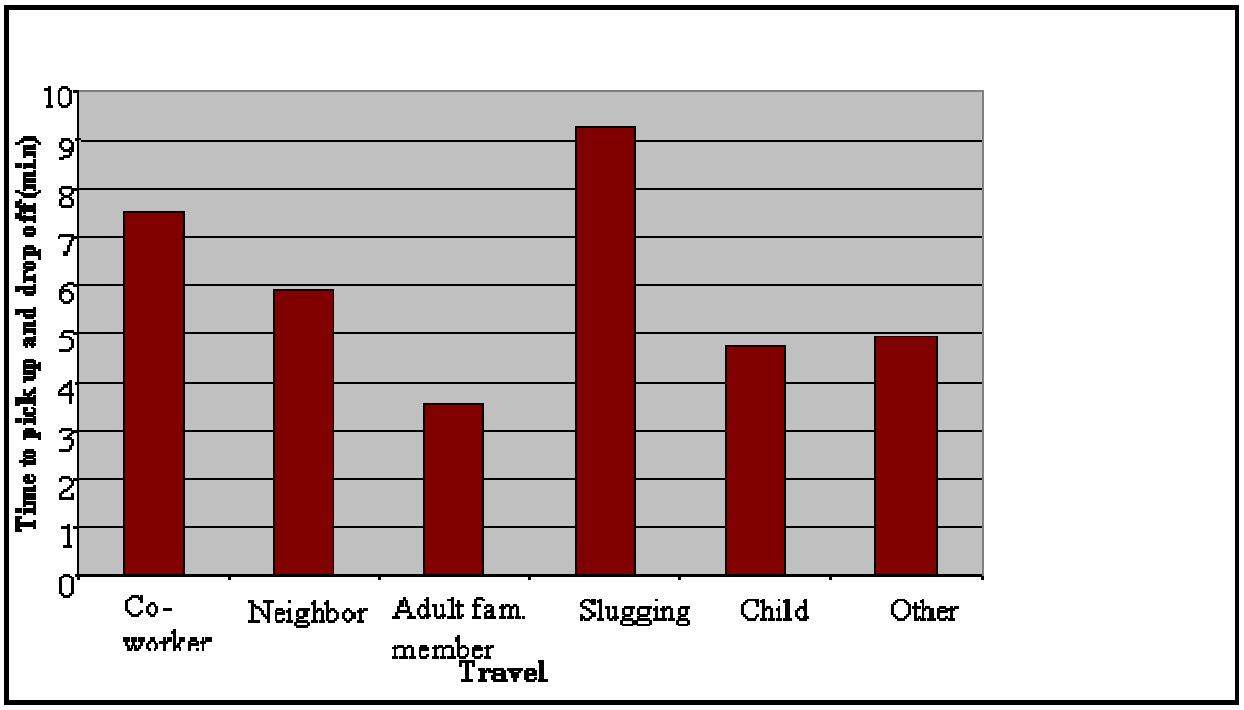

Figure 8. Average time to pick up and drop off passenger among travel partner

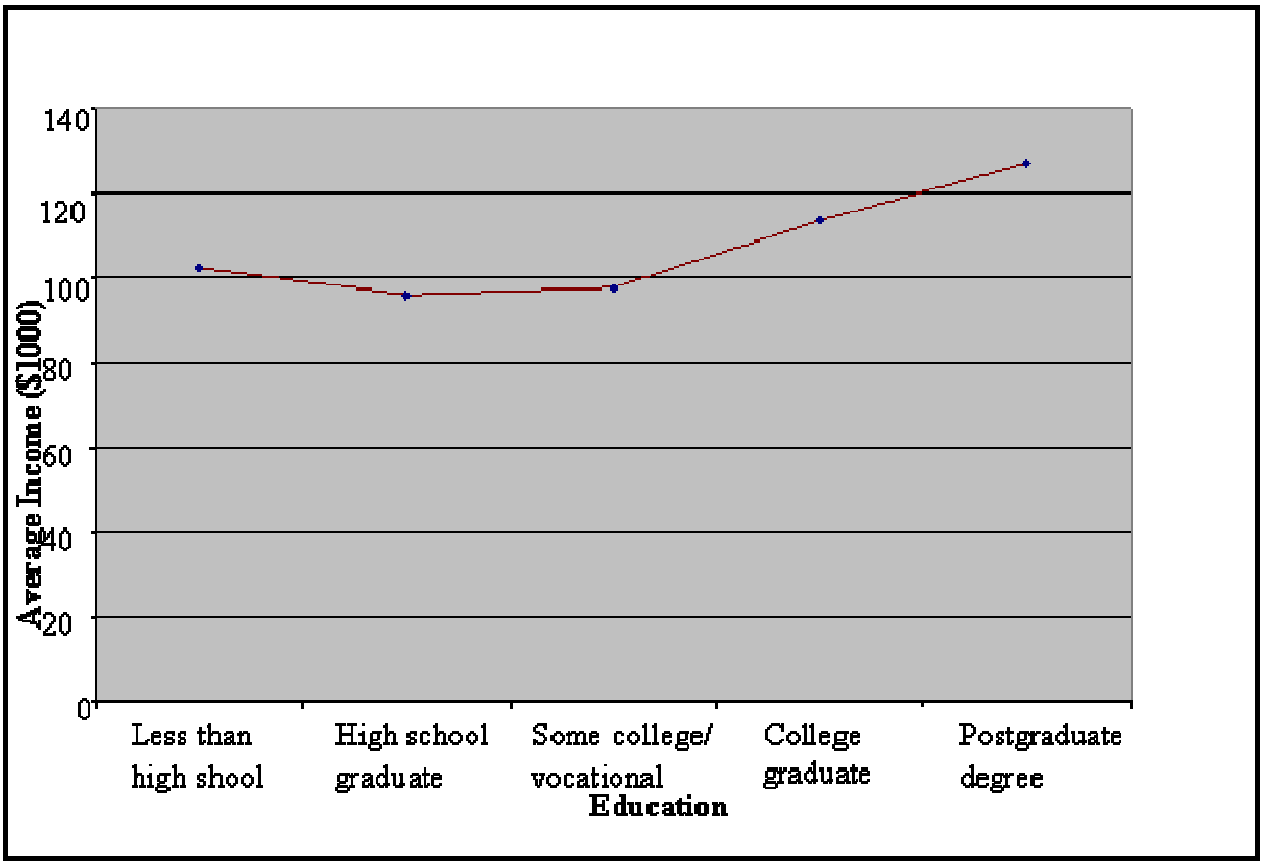

Figure 9. Correlation among average income and education

Table 4. Trip Purposes among Travel partners

Travel Partner	Commute	Recreation	Work	School	Other	All Purposes
Co-worker	38.6	0	39	1.2	1.4	28.6
Neighbor	2.5	2.6	0	0.6	0.0	2.1
Adult family member	29.8	49.2	19.5	5.3	79.7	32.8
Slug	7.4	10.4	25.6	3.0	0.7	7.6
Child	18.2	24.4	12.2	72.8	13.0	23.1
Other	3.5	13.5	3.7	17.2	5.1	5.8
All Participants	100	100	100	100	100	100

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APPENDIX A

Table A1. Socioeconomic and Commuting Characteristics of Survey Respondents by Participant groups

Characteristic (Percent of Respondents in Each Category)	Participants						
	All (N=4,005)	Drive alone on main lanes (N=1,808)	Carpool on main lanes (N=302)	Transit (N=584)	Slugging (N=216)	Regular Carpool on HOV lanes (N=584)	Quick Ride (N=511)
Q1:Trip Purpose							
Commute*	79.2	82.5	58.9	93.2	96.3	82.5	66.7
Recreation*	5.9	4.1	21.5	0.2	0.5	3.6	9.90
Work*	6.4	9.7	5.4	4.7	3.3	4.3	4.10
School*	4.8	2.3	5.7	1.4	0.0	5.5	11.00
Other*	3.7	1.4	8.4	0.5	0.0	4.9	8.30
Q2: Time trip started*	613.11	664.79	670.71	651.88	436.27	600.74	536.18
Q3: Time trip ended*	693.36	751.29	769.94	736.73	489.48	704.68	596.39
Q4: Travel Time*	54.65	56.87	57.59	58.81	60.33	58.85	46.43
Q5:Number of Vehicle Occupants							
1*	40.4	100.00	0.0	17.80	n/a	0.0	0.0
Motorcycle*	0.2	0.0	3.0	0.0	n/a	0.0	0.0
Took a bus*	10.6	0.0	17.90	76.70	n/a	0.0	0.0
2*	42.0	0.0	58.60	3.10	16.30	67.0	100.00

Characteristic (Percent of Respondents in Each Category)	Participants						
	All (N=4,005)	Drive alone on main lanes (N=1,808)	Carpool on main lanes (N=302)	Transit (N=584)	Slugging (N=216)	Regular Carpool on HOV lanes (N=584)	Quick Ride (N=511)
3*	7.6	0.0	14.90	2.10	78.10	26.0	0.0
4*	1.0	0.0	4.0	0.3	3.7	4.8	0.0
5 or more*	0.4	0.0	1.70	0.0	1.9	2.20	0.0
Q6: HOV lane use							
No*	10.0	n/a	100.0	40.6	0.0	0.0	0.0
Yes*	90.0	n/a	0.0	59.4	100.0	100.0	100.0
Q7: Prior to this survey have you heard of QuickRide?	58.3	31.4	37.4	45.5	64.8	58.6	100.0
Q8: How people fist learned about QuickRide?							
TV*	5.1	15.9	9.3	7.5	3.7	6.1	0.4
Radio*	4.8	12.0	4.6	6.6	1.5	3.1	2.5
Mail*	3.9	2.7	8.3	0.4	2.9	9.2	3.5
Newspaper*	20.1	21.7	16.7	16.2	6.6	12.0	23.6
Family/Friend*	35.7	29.9	33.3	33.6	25.0	34.4	39.7
On the bus*	1.9	1.7	3.7	7.9	11.0	1.2	0.1

Characteristic (Percent of Respondents in Each Category)	Participants						
	All (N=4,005)	Drive alone on main lanes (N=1,808)	Carpool on main lanes (N=302)	Transit (N=584)	Slugging (N=216)	Regular Carpool on HOV lanes (N=584)	Quick Ride (N=511)
Don't remember*	16.3	17.9	13.9	12.0	13.2	11.3	18.1
Other*	18.7	25.4	31.2	25.8	35.8	21.9	11.6
Q9: Total Trips during week*	8.67	9.21	8.53	9.32	9.68	9.48	7.32
Q10: Who did you travel with?							
Co-worker*	36.9	n/a	19.2	15.6	n/a	36.1	40.5
Neighbor	2.9	n/a	4.2	0.0	n/a	2.7	2.8
Adult family member	37.9	n/a	47.7	43.8	n/a	38.7	35.9
Slugging*	8.0	n/a	5.4	37.5	n/a	9.6	7.1
Child*	24.0	n/a	28.0	6.3	n/a	21.6	24.7
Other	4.8	n/a	5.9	9.4	n/a	4.1	4.7
Q11: Time to pick up and drop off *	5.59	n/a	7.94	7.46	n/a	7.88	4.33
Q12: Age							
16-24	3.6	4.3	3.8	3.5	1.9	2.7	3.5
25-34*	19.5	22.5	22.0	19.4	24.6	20.4	14.3

Characteristic (Percent of Respondents in Each Category)	Participants						
	All (N=4,005)	Drive alone on main lanes (N=1,808)	Carpool on main lanes (N=302)	Transit (N=584)	Slugging (N=216)	Regular Carpool on HOV lanes (N=584)	Quick Ride (N=511)
35-44*	28.4	28.0	32.0	27.0	35.1	32.3	26.0
45-54*	32.9	29.9	23.4	38.0	29.4	29.3	38.4
55-64	11.9	12.6	12.7	11.7	8.1	11.5	11.6
65 and over*	3.8	2.7	6.2	0.4	0.9	3.9	6.3
Q13:Gender							
Female*	45.5	35.6	46.0	51.9	49.8	48.7	53.0
Male*	54.5	64.4	54.0	48.1	50.2	51.3	47.0
Q14:Household type							
Single Adult*	9.9	13.4	7.9	13.5	10.6	6.8	5.7
Unrelated Adult*	2.1	2.8	3.4	2.8	3.4	2.7	0.4
Married (no child)*	25.1	25.1	20.7	17.6	21.2	24.8	29.9
Married with child*	55.8	51.3	59.7	56.0	53.8	56.9	60.5
Single Parent*	4.2	4.6	3.4	7.4	7.7	4.6	1.7
Other*	2.8	2.9	4.8	2.7	3.4	4.3	1.7

Characteristic (Percent of Respondents in Each Category)	Participants						
	All (N=4,005)	Drive alone on main lanes (N=1,808)	Carpool on main lanes (N=302)	Transit (N=584)	Slugging (N=216)	Regular Carpool on HOV lanes	Quick Ride (N=511)
Q15: How many people living in household*	3.04	2.98	3.20	3.10	3.09	3.22	2.99
Q16: Number of motor vehicles*	2.35	2.42	2.39	2.24	2.20	2.35	2.32
Q17: Occupation							
Professional/ Managerial*	61.9	62.3	52.9	57.7	65.7	61.1	64.8
Technical	11.0	11.1	10.7	14.4	11.3	9.1	10.1
Sales*	5.0	7.3	3.8	1.1	1.4	3.2	5.5
Administration/Clerical*	10.6	7.6	6.9	21.8	19.2	9.9	9.3
Manufacturing	0.3	0.6	0.0	0.7	0.0	0. 0	0.0
Stay at home* parents	1.0	0.5	5.9	0.0	0.0	2.3	0.5
Unemployed*	0.7	0.4	1.0	0.0	0.5	0.0	1.6
Other	9.6	10.5	10.2	9.5	7.2	10.4	8.3
Q18: Education							
Less than high school	0.4	0.4	0.7	0.5	0.0	0.4	0.3
High school grad.*	6.8	5.8	2.8	7.1	5.7	7.0	8.8

Characteristic (Percent of Respondents in Each Category)	Participants						
	All (N=4,005)	Drive alone on main lanes (N=1,808)	Carpool on main lanes (N=302)	Transit (N=584)	Slugging (N=216)	Regular Carpool on HOV lanes (N=584)	Quick Ride (N=511)
Some college/vocational*	21.3	22.9	24.0	24.6	23.2	21.2	17.0
College Graduate*	44.0	46.1	49.5	45.4	48.8	45.3	38.6
Postgraduate degree*	27.6	24.8	23.0	22.3	22.3	26.2	35.4
Q19: Income							
<$10,000*	0.6	1.0	0.0	0.8	0.0	0.6	0.1
$10,000-$14,999	0.5	0.6	1.2	0.8	1.0	0.6	0.0
$15,000-$24,999*	0.8	1.3	1.2	1.0	0.5	1.0	0.1
$25,000-$34,999*	3.7	4.4	4.3	5.8	1.5	4.4	2.0
$35,000-$49,999*	8.5	9.6	8.6	12.0	15.1	8.6	4.6
$50,000-$74,999*	18.0	19.6	21.0	21.3	25.6	16.5	13.4
$75,000-$99,999*	20.6	21.4	24.1	22.7	23.1	20.9	17.5
>$100,000*	46.7	41.4	43.2	40.8	37.2	40.8	60.8

APPENDIX B

Table B1. Significant Differences Among Mode Choices by Question

Question	P value	P value measured
Trip Purpose		
Commute*	0.05	0.0
Recreation*	0.05	0.0
Work*	0.05	0.0
School*	0.05	0.0
Other*	0.05	0.0
Travel time*	0.05	0.0
Number of Vehicles Occupants		
1*	0.05	0.0
Motorcycle*	0.05	0.0
Took a bus*	0.05	0.0
2*	0.05	0.0
3*	0.05	0.0
4*	0.05	0.0
5 or more*	0.05	0.0
Heard of QuickRide before survey?*	0.05	0.0
How people first learned about QuickRide?		
TV*	0.05	0.0
Radio*	0.05	0.0
Mail*	0.05	0.0
Newspaper*	0.05	0.0

Family/Friend*	0.05	0.0
On the bus*	0.05	0.0
Don't Remember*	0.05	0.011
Other*	0.05	0.0
Total trips per week*	0.05	0.0
Travel Partner		
Co-worker*	0.05	0.0
Neighbor	0.05	0.484
Adult family member*	0.05	0.005
Slugging*	0.05	0.0
Children*	0.05	0.019
Other	0.05	0.442
Time to pick up and drop off passenger*	0.05	0.0
Age		
16-24	0.05	0.348
25-34*	0.05	0.0
35-44*	0.05	0.008
45-54*	0.05	0.0
55-64	0.05	0.531
65 and over*	0.05	0.0
Gender		
Female*	0.05	0.0
Male*	0.05	0.0
Household Type		
Single Adult*	0.05	0.0

Unrelated adults*	0.05	0.0
Married (no children)*	0.05	0.0
Married with children*	0.05	0.0
Single Parent family*	0.05	0.0
Other*	0.05	0.012
How many people living in household?*	0.05	0.002
Number of motor vehicles?*	0.05	0.013
Person's occupation		
Professional/Managerial*		0.001
Technical	0.05	0.071
Sales*	0.05	0.0
Administration/Clerical*	0.05	0.0
Manufacturing*	0.05	0.006
Stay at home parent*	0.05	0.0
Unemployed*	0.05	0.0
Other	0.05	0.277
Education		
Less than high school	0.05	0.701
High school graduate*	0.05	0.002
Some college/vocational*	0.05	0.0
College Graduate*	0.05	0.0
Postgraduate Degree*	0.05	0.0
Income		
<$10,000*	0.05	0.018

$10,000-$14,999	0.05	0.062
$15,000- $24,999*	0.05	0.026
$25,000-$34,999*	0.05	0.001
$35,000-$49,999*	0.05	0.0
$50,000- $74,999*	0.05	0.0
$75,000- $99,999*	0.05	0.035
>$100,000*	0.05	0.0

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Upon completion of his Bachelors, Carlos will begin his Master of Mechanical Engineering.

READING TIME AND COMPREHENSION ANALYSIS OF SIMULATED DYNAMIC MESSAGE SIGN MESSAGES

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SUMMARY

Dynamic message signs (DMSs) transmit valuable information to drivers such as traffic conditions, accident locations, and Amber Alerts. This research investigates how presenting simulated messages in different ways influences the message reading time and comprehension using the Texas Transportation Institute's (TTI's) Driving Environment Simulator. The following presentation methods were tested: flashing vs. static on one panel construction or incident messages, alternating line vs. no alternating line on two panel construction or incident messages, license plate number vs. no license plate number on Amber Alert messages, and telephone number vs. no telephone number on Amber Alert messages.

The research involved 24 subjects who reflect the demographic breakdown of licensed drivers in Texas. The analysis was accomplished by using the mean reading times and proportion of correct responses to determine how long subjects took to obtain the information on the sign and how much of the information subjects could remember, respectively. Several statistical tests were used to determine whether or not differences between sign pairs were significant.

The researcher found that flashing all or portions of a one panel message has no advantage over a static message. Using an alternating line on a two panel message gives no clear results, but testing more subjects could reveal a trend for these types of messages. Amber Alert messages that contain license plate or telephone numbers cause subjects to take longer to read the message and remember less of the information than messages of this type that do not contain numbers.

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INTRODUCTION

Dynamic message sign (DMS) technology has been available for use for several decades, but the full potential of these signs has not yet been reached. This type of sign is also referred to as a variable message sign (VMS) or a changeable message sign (CMS). Few standards exist to regulate what type of messages should be displayed; therefore, the messages can be confusing and misleading to passing motorists. DMSs are common along many major roadways in large cities around the country. One of the most beneficial features of these signs is their versatility. Using a laptop in the field or a computer located in traffic control center, the message on a DMS can be easily changed to provide a wide range of information to motorists such as traffic conditions, accident locations, and Amber Alerts. Current roadway information will give motorists the opportunity to adjust their travel plans if necessary to avoid an accident or construction to save time during their travel.

While DMSs are more flexible than conventional signs, this does not guarantee that they will be more effective. DMSs give transportation officials the opportunity to relay a limitless number of messages to the public. If the message presented on the roadway is too long or complex, passing motorists will not have enough time to read the entire message or will not understand the information given on the sign. On the other hand, if the sign is vague and uses abbreviations that the general public is not familiar with, the message will be ineffective. In both situations, the DMS fails to serve its purpose of keeping the public informed of roadway conditions. With continued research in this area, the messages on DMSs can give motorists enough information to be useful and understood without being overbearing.

The simulated DMSs used in this research will reflect the preferences for signs found in previous research. For example, using the actual days of the week instead of the calendar days is more effective when showing a time frame of when a future activity will take place (*1*). Other examples of sign preferences are using the word "EXIT" instead of "RAMP" to make a reference to a freeway exit, and using the roadway designation and number such as "I-10" or "US 290" instead of just the number to reference a roadway. By using sign messages that the public understands, the research will be more focused on the sign presentation instead of the sign content.

LITERATURE REVIEW

In 2000, Dudek and Ullman studied several aspects of dynamic message signs (DMSs) in a project for the Texas Department of Transportation (TxDOT) (*1*). The study took place in five cities across the state and involved 260 people, who reflected the age, gender and education level of licensed Texas drivers. Using a laptop computer, the subjects saw the simulated signs and answered questions about the content of each sign. The researchers found that flashing the entire message of a one frame message on a DMS does not have a significant impact on sign comprehension, but the flashing message does increase the amount of time a person needs to read the information. When only one line of a one frame message is flashed, subjects took about 20% longer to read the message, but the comprehension of the sign remained the same as the static message. Similar results were found when subjects were shown a 3 line DMS where 2 lines remained constant while one line alternated. Also, sign preferences were evenly split, and in some cases the preference depended on the order in which the signs were shown. When dealing with DMSs, it is important to be able to keep track for how much information is presented by a given message. No clear definitions exist for classifying units of information, but a unit is usually a single word or a series of words that passes a single idea to a driver. The following are all examples of one unit of information: "accident", "at I-10", and "use loop 410 W."

Simulated DMSs have also been used to look for differences in response time and message accuracy among different age groups as well as each gender. In 2001, Wang and Cao examined these differences by placing subjects in a driving simulator while displaying the DMSs. Of the 18 subjects that participated in the study, half were male, and 6 subjects fell into each of the following age categories: 20 to 40, 40 to

60, and greater than 60. Surprisingly, the oldest age group produced the lowest response times. Female subjects tended to read the signs a little quicker and remember the content more accurately than the male subjects. The results gave no significant correlation between the response time and message accuracy (*2*).

A study by McNees and Messer in the early 80's looked at how much information a person can handle on simulated urban freeway guide signs. Subjects were able to successfully interpret the signs and find the appropriate information when 1 to 15, 15 to 30, and 31 to 50 units of information were presented 100%, 51%, and 33% of the time, respectively. As expected, the accuracy of answers decreases as the amount of information presented to the subject increases; therefore, 16 units or less should be presented to drivers on overhead guide signs to be effective (*3*).

While a DMS can relay valuable information to drivers, some new technologies allow transportation officials to also present graphical information as well using Graphical Congestion Display Panels (GCDPs) to assist drivers along the roadway. Several countries around the world currently use GCDPs, and other countries are looking into this technology to help make their roads more efficient. The U. K. is one country interested in implementing this type of sign along its roadways, and Richards, McDonald, Fisher, and Brackstone have conducted research on the effectiveness of these signs. Using a steering wheel and pedals, subjects were instructed to control a vehicle in a simulated environment while a series of GCDPs were projected onto the screen. To determine how well subjects understood the signs, questions about the sign content were asked immediately after each sign was viewed and at the conclusion of test. Younger subjects could remember the information more accurately, but older subjects showed a better understanding of the sign content. No difference was found between genders in understanding the signs, but males did score higher on the accuracy. The varied viewing times of 4 and 6 seconds produced no significant differences in accuracy or understanding (*4*).

Surveys and focus groups have been used to gauge the public's view on DMSs across the United States. Motorists in Northern Virginia participated in one of these studies. Demographics played a very small role in how people feel about DMSs as long as the signs were beneficial to the public and easy to use. Over half of the participants in the study responded that DMSs often affect them while on the road, but only about 13% said these signs never changed the way they drive. Also, drivers preferred having times posted along with traffic updates to ensure the timeliness of current the information. Nearly every participant favored expanding the use of DMSs from freeways to arterial streets (*5*).

DMSs can also play a vital role in areas that are not traffic related, such as helping to recover kidnapped children through Amber Alerts. The Minnesota Department of Transportation is one group that has researched the functionality of these types of messages. Subjects were shown simulated DMSs while driving in a simulator and asked to recall the information. Only about 12% of the subjects remembered all of the vehicle details and the license plate number, but 50% could recall portions of this information. To increase the amount of information available to drivers, a radio station should be shown on the DMS instead of the license plate number. Also, the female subjects remembered more information and older drivers tended to slow down when shown the Amber Alert signs (*6*).

Many studies have been completed on DMSs using surveys and simulators, but other methods of research have also been used. One such method used by Levinson and Huo involved using loop detectors to obtain traffic flow and occupancy data to determine the influence of the DMS on traffic. The type of message shown on the DMS affected to what extent the driver's behavior changed. Accidents had the largest influence, and roadwork had the least impact. Congestion messages were between these two categories. Lower levels of traffic tended to make DMSs more beneficial to drivers. Although DMSs did not produce significant savings in travel time, the use of DMSs and ramp meters can lessen the total delay of traffic (*7*).

PROBLEM STATEMENT

This research examined how motorists responded to different presentations of DMSs by placing subjects in Texas Transportation Institute's (TTI's) Driving Environment Simulator and displaying a series of simulated DMS messages. Three types of signs were shown to the subjects: one-panel construction or incident messages, two-panel construction or incident messages, and Amber Alerts. The effect of flashing all or parts of a message were tested using the one-panel DMS messages, and the effect of alternating a single line of information was tested using the two-panel DMS messages. The Amber Alert messages were used to determine the influence of telephone numbers and license plate numbers on the effectiveness of the sign. Reading times and message comprehension were two important factors considered during the course of the research. By looking at the reading times, the amount of time it took subjects to obtain the information given by the sign for the different types of presentation can be seen. The message comprehension portion of the research indicated how much of the information the subject retained for the different types of presentation.

RESEARCH OBJECTIVES

The goals for this research were:

- Determine if reading times differed within the following simulated message groups: flashing vs. static, alternating line vs. no alternating line, license plate number vs. no license plate number, and telephone number vs. no telephone number.
- Determine if the level of message comprehension differed within the following simulated message groups: flashing vs. static, alternating line vs. no alternating line, license plate number vs. no license plate number, and telephone number vs. no telephone number.

DATA COLLECTION AND REDUCTION

The data for this research were collected using TTI's Driving Environment Simulator to provide a secondary task while the subject viewed the simulated DMS messages. Figure 1 shows the simulator setup.

Figure 1. Driving Environment Simulator

Subjects were asked to follow the yellow vehicle at a constant distance. To keep the subject's attention on the road, the lead vehicle changed speeds periodically. The subject was shown a simulated DMS message, and asked several questions about the sign's content. The simulated messages and the questions asked for each sign are shown in Table A1 in Appendix A.

Similar questions were asked for each sign, but the order was changed, so that subjects were forced to think about the information given on the sign as opposed to just blindly memorizing the information. The signs viewed in the comprehension portion of the research were displayed for 8.4 seconds each, and the subject determined how long the sign was visible during the reading time portion of the research. Also, the comprehension data were only used for the portion of the research where the subject saw each sign for 8.4 seconds. The subjects used in this research were representative of the population of Texas based on people with a current Texas driver's license. This research was a part of a Federal Highway Administration (FHWA) project consisting of 128 subjects that divided the subjects into groups based on age, gender and level of education. Each demographic group was then distributed equally into 4 demographically equal subgroups. Table 1 shows that the demographic breakdown for this research closely approximated the demographics for the state of Texas. The data used in the research were collected from June 3, 2004 until July 23, 2004, and a total of 24 subjects were used in the research.

Table 1. Research and Texas Demographics

Demographic Group		Sample Breakdown		Texas Demographic Percentage
		No. of Subjects	Sample Percentage	
Gender	**Male**	13	54	49[1]
	Female	11	46	51[1]
Age	**18-24**	4	17	14[1]
	25-39	7	29	32[1]
	40-54	8	33	30[1]
	55-64	2	8	12[1]
	>64	3	13	12[1]
Education	**No High School Diploma**	3	13	24[2]
	High School Diploma	8	33	25[2]
	Some College	5	21	27[2]
	College Degree	8	33	24[2]

1. U.S. Department of Transportation – Federal Highway Administration Statistics 2001.
2. U.S. Census Bureau, Census 2000.

Once the data were collected, it was placed in a Microsoft Excel spreadsheet to make accessing the information easier. Table 2 shows a portion of this database for one subject. In the spreadsheet, the data

for each subject was entered in its own worksheet, but the data for each sign needed to be compiled before the data analysis could take place. To accomplish this task each of the 10 signs was given an individual analysis page. The volume of data and the need to have the most recent data available made it impractical to simply copy and paste each piece of information to its desired destination. Macros, which are programs that are written using Microsoft Visual Basic to accomplish repetitive tasks in Excel, were used to efficiently bring the latest data into the analysis worksheets with a few simple keystrokes.

Table 2. Data Entry Example

Sign 18 (M2 Flash)								
				Reading Time (s)	5.9526			
	Correct	Substantially correct	Wrong		Response	1st word	2nd word	3rd word
	1			Where is the traffic problem located?	Tidwell	Y		
	1			What is the traffic problem?	freeway blocked	Y	Y	
		1		What are you to do?	use another routes	Y	N	Y

DATA ANALYSIS

After the data were sorted, several statistical tests were performed to analyze the data. Based on the small sample size (less than 30 subjects), a paired t-test with a significance level of 0.05 was chosen to analyze the reading time data. The following equations were used in this process:

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \qquad t = \frac{X_1 - X_2}{\sqrt{s_p^2(\frac{1}{n_1} + \frac{1}{n_2})}}$$

Where:

s_p^2= the pooled estimate of the population variance,
s_1^2 = the variance of the first message presentation,
s_2^2 = the variance of the second message presentation,
n_1 = the number of subjects in the first message presentation,
n_2 = the number of subjects in the second message presentation,
X_1 = the mean of the first message presentation,
X_2 = the mean of the second message presentation, and
t = test statistic.

The calculated test statistic, t, was compared to a critical value of t to determine if the reading times for a sign pair was significantly different (*8*).

The responses to the comprehension questions given by the subjects were categorized into three levels of correctness: 100% correct, substantially correct, and wrong. A substantially correct answer was one in which the subject failed to recall the exact words shown in the message, but still recalled the basic idea behind the sign. For example, one line of the simulated message read "use other routes", but the subject gave the response "use another road". Clearly the subject understood the message; therefore, this response was counted as substantially correct. The overall correctness of a sign was limited by the lowest level of correctness of the individual questions. For example, if a subject got one of the questions wrong then the entire message was considered wrong. In the analysis, 100% and substantially correct answers were grouped together, and counted as correct.

Initially, the researcher intended to use a test of proportions to determine whether or not the differences found in the message comprehension portion of the research were significant. Due to the small sample size this method could only be used if the data closely approximated a normal distribution. To determine the normality of the data, the researcher created a graph of the expected proportion using the binomial distribution for each message. After reviewing each graph, the researcher concluded that the test of proportions could not be used in this situation because the data were not close enough to being normal. On the other hand, the data could be analyzed using a confidence interval for a population proportion based on the binomial distribution (*9*). The confidence interval gave the range of values for which the actual percentage of the population who could correctly remember the information on the sign with a confidence level of 95% based on the collected data. A difference in message comprehension for a particular was determined to be significant if the two confidence intervals did not overlap.

RESULTS

Flashing vs. Static

The first group of simulated messages shown to subjects intended to determine if flashing all or portions of a one panel incident or construction message influenced reading times and message comprehension. Signs M1 and M2 flashed the entire message, while signs M3 and M4 flashed only the top line of the message. See Table A1 in Appendix A for the simulated messages used during this research. Figure 2 compares the mean reading times for these four signs. With the exception of sign M4, almost no difference existed between the reading time for the flashing and static messages for each sign. Even though the flashing M4 message took subjects around 2 seconds longer to read than the static message, the statistical analysis showed that this difference was not significant.

Figure 3 shows the proportion of subjects who could correctly recall the information given on each sign for the flashing and static messages. It also shows the 95% confidence interval for each message. For example, 87% of the subjects remembered the information presented on the static M1 message, and the percentage of the population who would do the same is between 59 and 98% according to the confidence interval. In some cases the confidence interval is rather large. The confidence interval for the static M4 sign ranges from 30 to 90%. The large variation is caused by the low sample size. Of the 24 subjects tested, only 9 saw this sign during the comprehension portion of the research. As the sample size increases, the statistical test will become stronger and the confidence interval will shrink. Although some variation existed in the comprehension data for the different presentations, none of these differences were found to be significant. For the difference to be significant, the confidence interval for the flashing message cannot overlap with the confidence interval for the static message. Subjects were also asked which message they preferred. For signs M1, M3, and M4, subjects showed a slight but not significant preference for the static message as shown in Figure A1 in Appendix A.

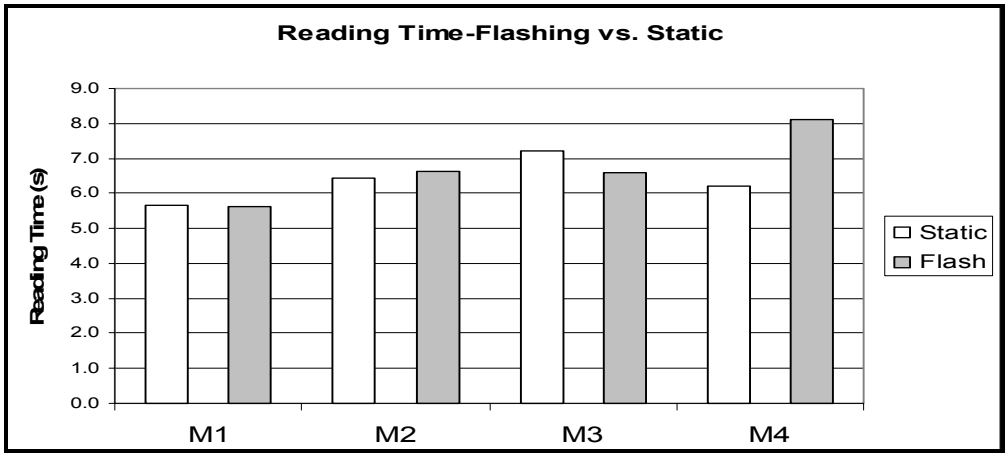

Figure 2. Reading Time-Flashing vs. Static

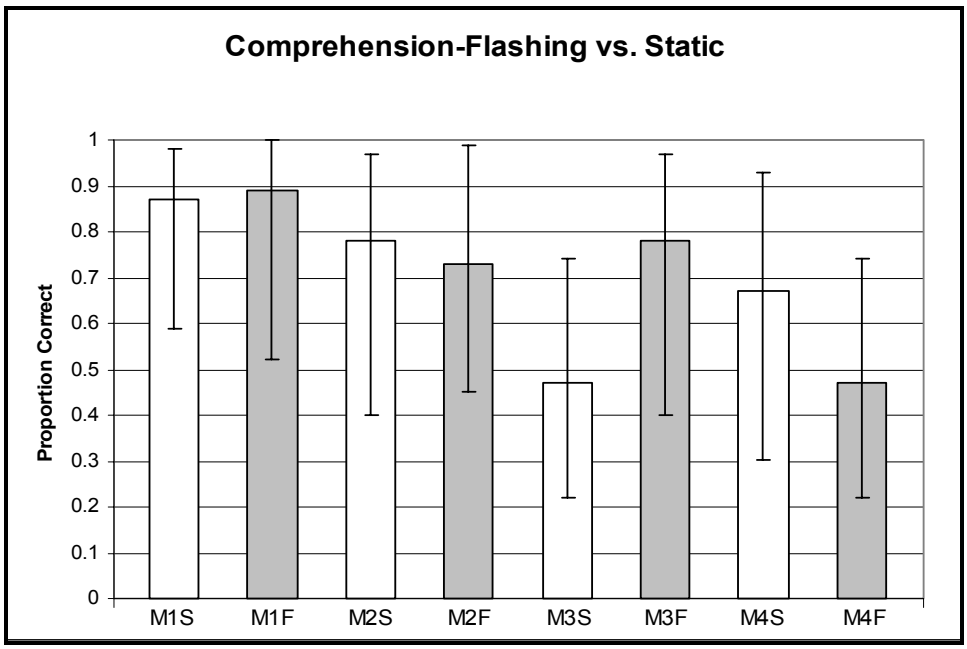

Figure 3. Comprehension-Flashing vs. Static

Alternating Line vs. No Alternating Line

Another group of simulated messages viewed by subjects involved alternating a line of information on a two panel construction or incident message. One type of presentation kept the same first two lines of information on each panel, but alternated the third line between the panels. The other type of message presented two different lines of information on each panel. See Appendix A for examples of signs M5 and M6 that were shown during this portion of the research. Figure 4 shows the mean reading times for the messages with and without the alternating line. Subjects took about 4 seconds longer to read the M5 sign when it included the alternating line, but the statistical analysis showed that this difference was not significant, and the M6 sign showed almost no difference in reading times.

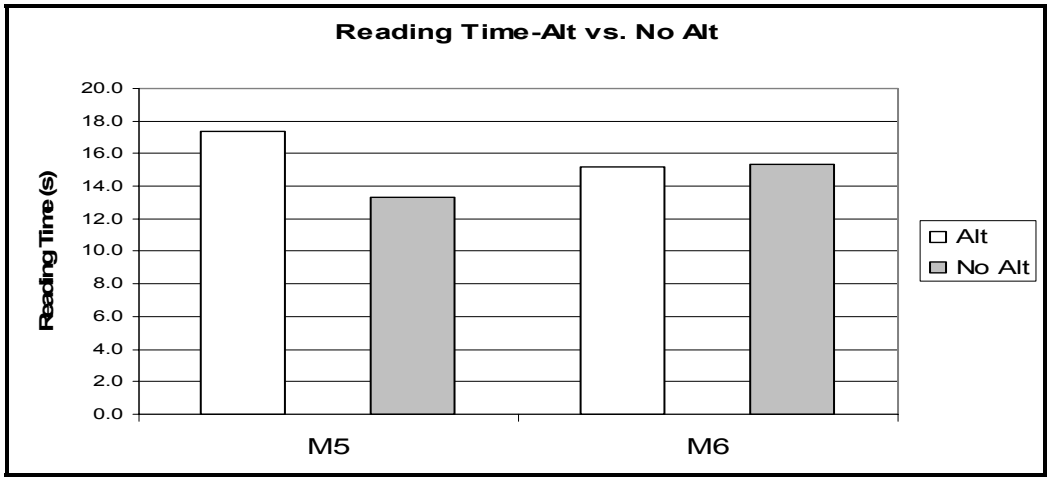

Figure 4. Reading Time-Alternating Line vs. No Alternating Line

Figure 5 shows the proportion of the subjects who correctly recalled the information from the messages with and without the alternating line of information. The M5 sign demonstrated that a significantly higher proportion of people can remember the information when the sign includes the alternating line. On the other hand, the M6 sign showed the exact opposite trend, but the difference in this case was not significant. One reason for the variation in the data was the small sample size. As more subjects are tested, it is expected that the data will more closely approximate the normal distribution, and perhaps the comprehension data for this group of messages will become clearer. Also, subjects might have found these messages confusing because the information was spread across two panels. As seen in Figure A2 in Appendix A, subjects showed no distinct preference for either presentation type of this message.

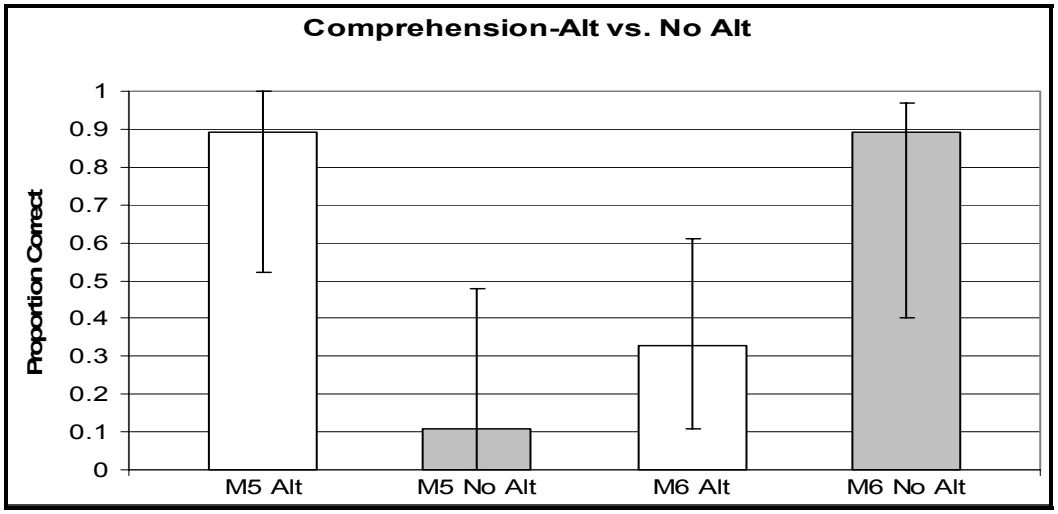

Figure 5. Comprehension-Alternating Line vs. No Alternating Line

License Plate Number vs. No License Plate Number

One type of Amber Alert message used in this research consisted of showing a license plate number or "tune to radio" for a subject to get information. See Appendix A examples of signs M7 and M8 that were included in this portion of the research. Figure 6 shows the mean reading times for the simulated messages with and without license plate numbers. In both cases, subjects took longer to read the

messages that included license plate numbers. The introduction of numbers into the message increased the units of information contained in the sign, and also increased the complexity of the message. Although both signs showed an increase in reading time for the message with the license plate number, the difference was only significant for sign M8.

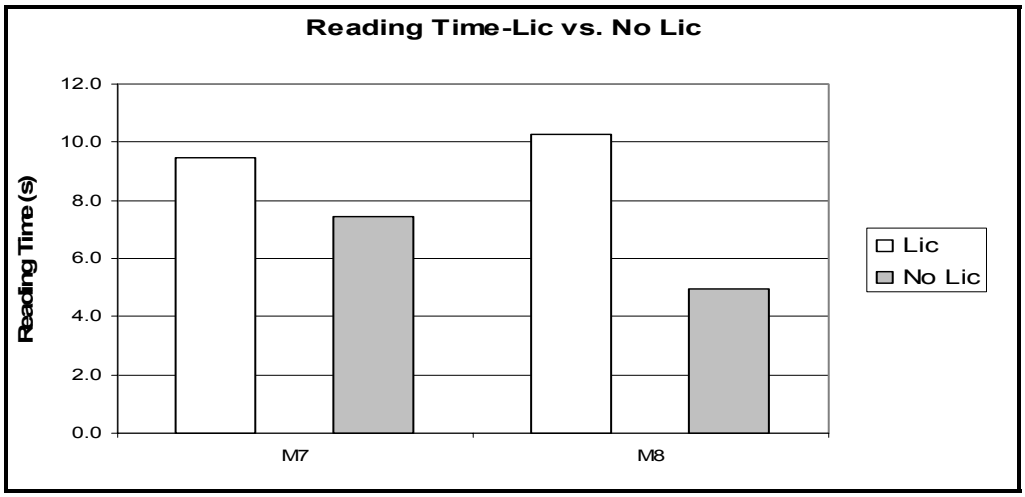

Figure 6. Reading Time-License Plate Number vs. No License Plate Number

Figure 7 shows the proportion of subjects who correctly recalled the information from the messages with and without license plate numbers. The proportion of subjects who got the information in the message correct increased when the license plate number was removed from the sign, but this difference was only significant for sign M8. The use of numbers in message made the subjects take longer to read the message, and they could remember less of the information. Figure A3 in Appendix A showed that subjects preferred the messages without the license plate number, but this difference was not enough to be considered significant.

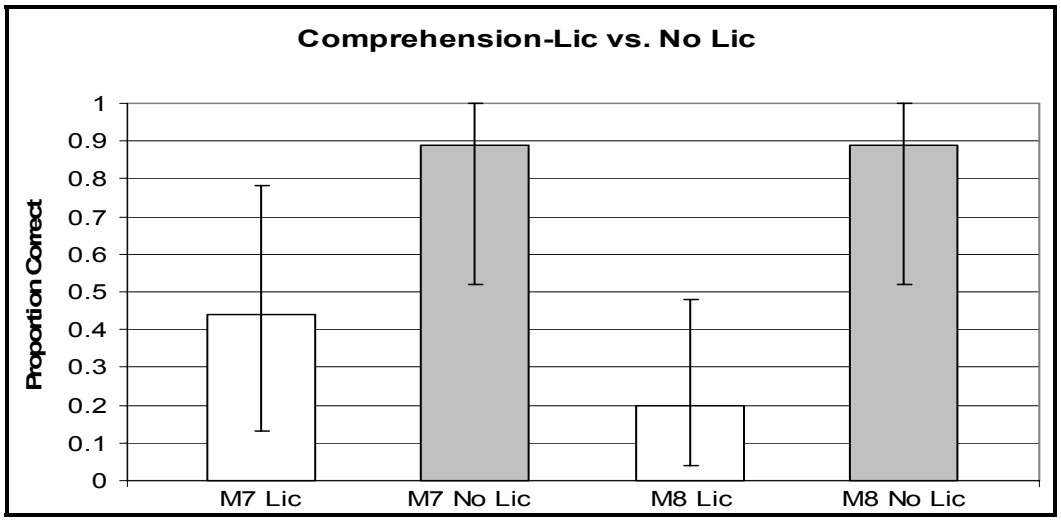

Figure 7. Comprehension-License Plate Number vs. No License Plate Number

Telephone Number vs. No Telephone Number

Another Amber Alert message that was tested either gave subjects a telephone number to call for information or instructed them to "tune to radio". See Appendix A for examples of signs M9 and M10 that illustrate the messages used in this portion of the research. Figure 8 shows the mean reading times for the messages with and without telephone numbers. For both signs, the reading times were higher for the messages that contained the telephone number, but the difference was only significant for sign M10. As was the case for the license plate number, the reading times increased when the subject was presented with more units of information.

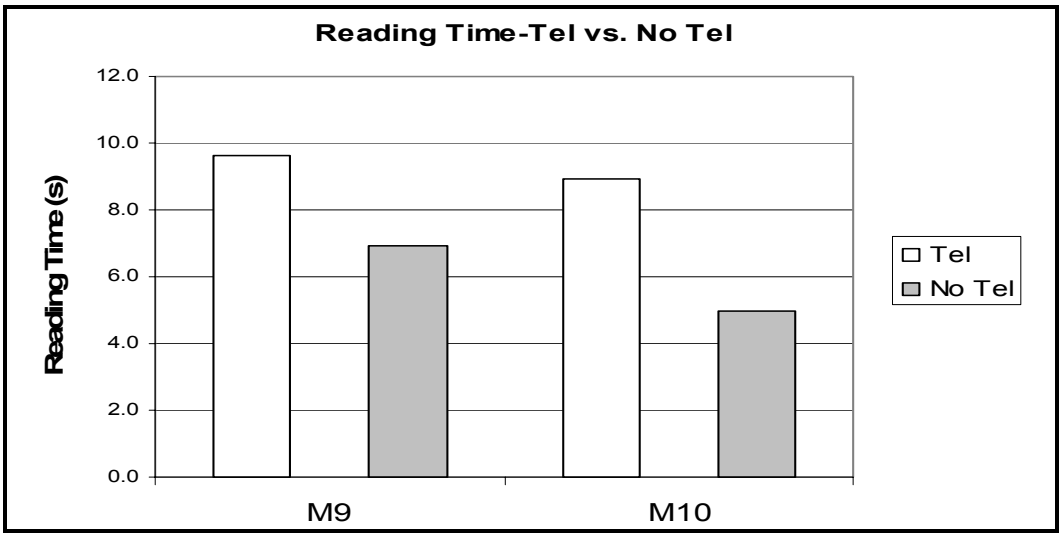

Figure 8. Reading Time-Telephone Number vs. No Telephone Number

Figure 9 shows the proportion of the subjects who correctly remembered the information from the messages with and without telephone numbers. When the telephone number was absent from the message, the proportion of subjects correctly recalling the sign increased, but this difference was only significant for sign M10. As seen in Figure A4 in Appendix A, subjects showed a preference for the messages without telephone numbers, but the differences were not significant.

Reading Time vs. Percentage Correct

One point of interest in this research was to determine if reading time had any influence on message comprehension. To investigate this matter, the researcher created several graphs with proportion of correct answers vs. reading time for each message. Figure 10 shows the graph for the flashing and static messages (M1, M2, M3, M4). At first glance, a general trend can be noticed. As the reading times increase, the proportion of correct responses tends to decrease. In some cases such as signs M2 and M4, the static message was understood more often, but the opposite was true for signs M1 and M3. Based on the statistical analysis used for this research, these differences were not significant. Only small differences exist in both reading times and message comprehension for static and flashing messages, but a general trend still emerged.

Figure 11 shows the graph for the messages with and without an alternating line. Unlike the flashing messages, this group showed no clear relationship between message comprehension and reading time.

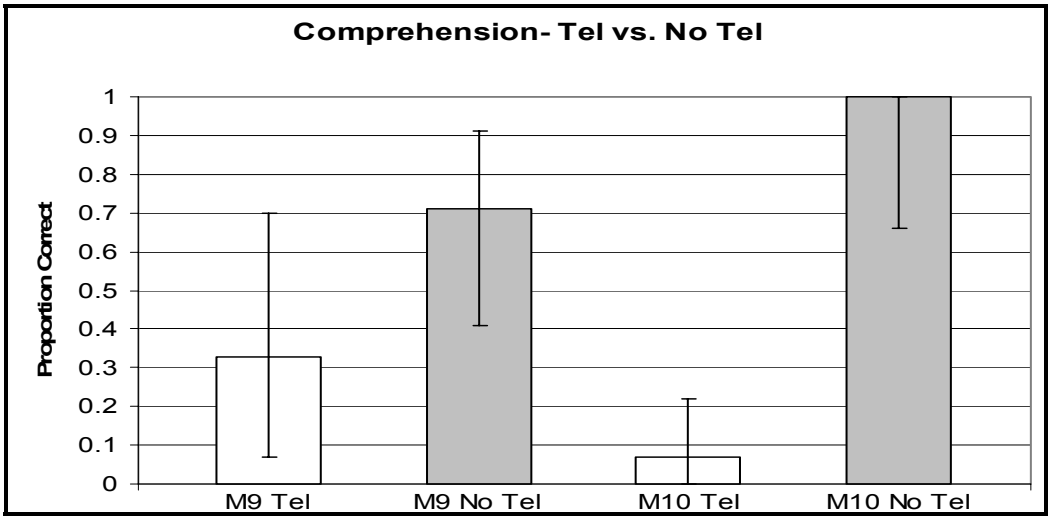

Figure 9. Comprehension-Telephone Number vs. No Telephone Number

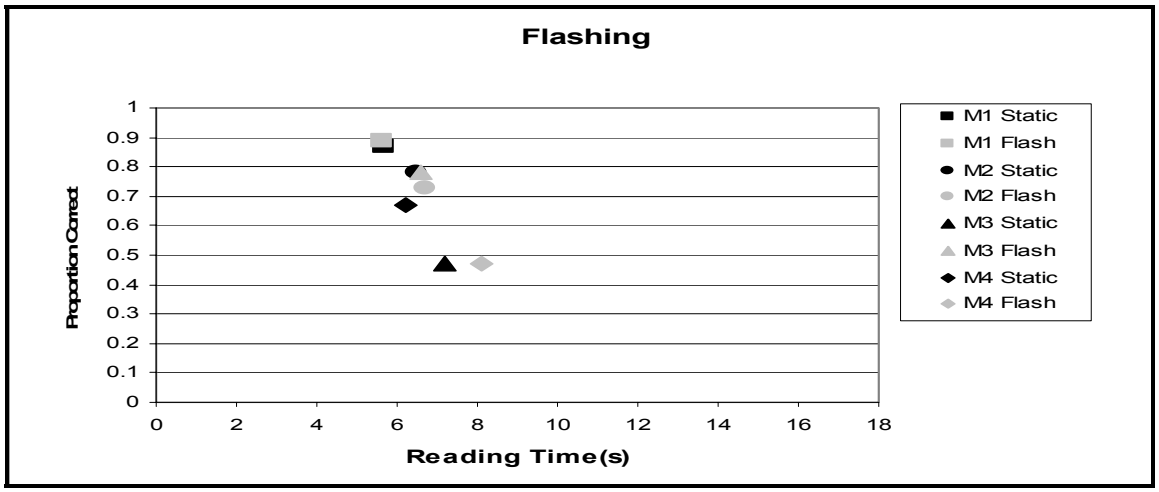

Figure 10. Flashing-Proportion Correct vs. Reading Time

The M5 message containing the alternating line took longer to read and subjects remembered the information more often than for the message without the alternating line. For sign M6, both versions of the message took similar times to read, but the message without the alternating line produced a higher proportion of correct responses. Several possibilities could explain this variation in the data. First, only 24 of 128 subjects for the FHWA project were used in this research. Due to the small sample size, the data failed to approximate the normal distribution, but running more subjects could lessen the randomness of the data and reveal a trend for the two panel messages. Also, the two panel messages contained four units of information as opposed to the three units shown on the one panel messages. This added complexity could have caused subjects to be uncomfortable with these types of messages.

Figure 12 shows the graph for the Amber Alert Messages. These messages followed the same trend as the flashing messages where an increase in reading time led to a lower proportion of correct responses. The graph also revealed two distinct clusters. Messages without a license plate or phone numbers were located at the top left of the graph, while the messages that contained a number were to the bottom right of the graph. As expected, the messages with numbers should be more difficult for subjects to understand

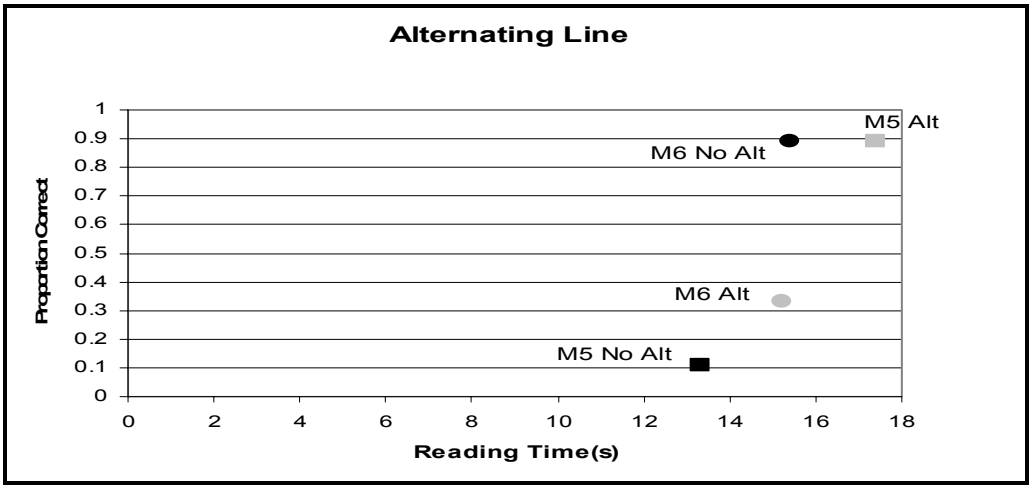

Figure 11. Alternating Line-Proportion Correct vs. Reading Time

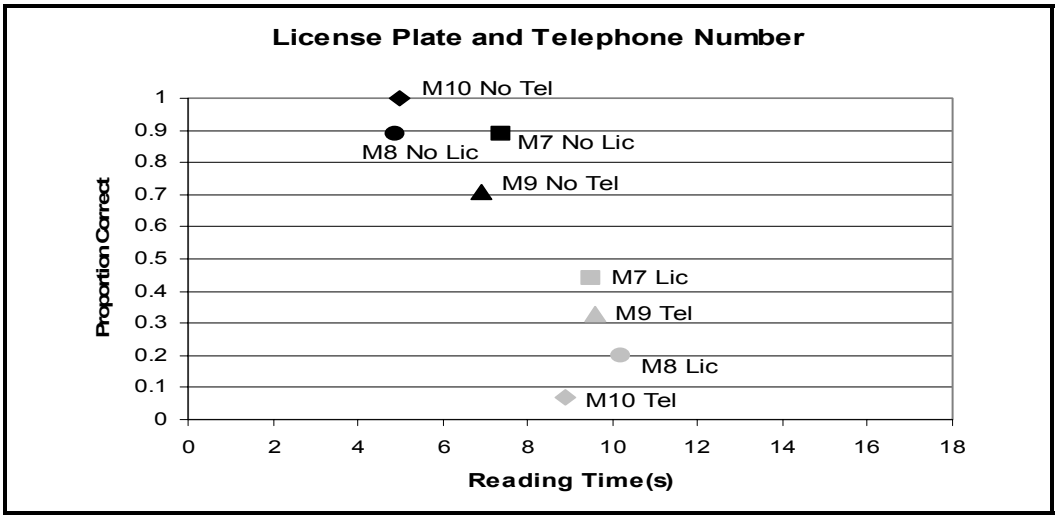

Figure 12. License Plate and Telephone Number

because the messages contain more units of information to remember. This graph also showed how extreme a difference needed to be considered significant. Signs M8 and M10 revealed significant differences in both reading times and message comprehension, and each message is located at the outer edges of the range.

CONCLUSIONS AND RECOMMENDATIONS

Dynamic message sign messages are a good way to relay information to motorists about traffic conditions, construction, and missing children, but these messages should be well thought out or otherwise they will not be useful. The researcher found that flashing all or parts of a one panel construction or incident message had no significant effect on either reading time or message comprehension. As for the two panel construction or incident message, the research gave no conclusive information. The reading time data for these messages produced no significant differences. The lack of a distinct relationship between message comprehension and the use of the alternating line could be explained by the small sample size. Also, the subjects could have been confused by the complexity of the

two panel messages or simply not be familiar with these types of messages. Using the simulated Amber Alert messages, the researcher found that including numbers in messages increased reading times and decreased the proportion of correct answers. A license plate and telephone number presented two and three units, respectively, of additional information in the message. On the other hand, when these numbers were replaced with "tune to radio" the subject only dealt with one unit of information. Clearly, as the complexity of messages increased i.e. more units of information, the subjects took longer to obtain the information, but could remember less of it.

Since flashing the message of a one panel construction or incident message should no significant benefit over a static message, the static message could be used in these cases. The static message will lessen the chance that motorists will be confused by the presentation of the message. One drawback to the conducted research was the small sample size of 24 subjects. The collected data failed to approximate a normal distribution; therefore, less powerful statistical tests than the test of proportions and z-test had to be used. In the case of this research, a large difference was necessary to be considered significant. As the sample size increases, smaller differences might show more significance between messages. After more subjects have been tested, the data might reveal trends for the messages with the alternating line.

Although not a part of this research, future research should investigate alternative ways of presenting telephone numbers on Amber Alert messages. First, replace the last 4 digits of the telephone number with an acronym such as "KIDS" or "HELP". Motorists could have an easier time remembering a single word as opposed to four digits. Also, use numbers in the first three digits that are common to the area where the DMS is located to try to increase message retention.

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APPENDIX A

Table A1. Simulated Messages and Questions (Bold Indicates a Flashing Message)

M1		M2	
Flash	Static	Flash	Static
MAJOR ACCIDENT **AT LITTLE YORK** **3 LANES CLOSED**	MAJOR ACCIDENT AT LITTLE YORK 3 LANES CLOSED	**FREEWAY BLOCKED** **AT TIDWELL** **USE OTHER ROUTES**	FREEWAY BLOCKED AT TIDWELL USE OTHER ROUTES
1. What is the traffic problem?		1. Where is the traffic problem located?	
2. What is told about the lanes?		2. What is the traffic problem?	
3. Where is the traffic problem located?		3. What are you to do?	

M3		M4	
Flash Line	Static Line	Flash Line	Static Line
FREEWAY CLOSED AT COLLEGE ST FOLLOW DETOUR	FREEWAY CLOSED AT COLLEGE ST FOLLOW DETOUR	**TRUCK ACCIDENT** AT AIRPORT RD USE SERVICE ROAD	TRUCK ACCIDENT AT AIRPORT RD USE SERVICE ROAD
1. What are you to do?		1. Where is the traffic problem located?	
2. Where is the traffic problem located?		2. What is the traffic problem?	
3. What is the traffic problem?		3. What are you to do?	

M5		M6	
Alternating Line	No Alternating Line	Alternating Line	No Alternating Line
CONSTRUCTION AT BROADWAY RD **ALL LANES CLOSED** CONSTRUCTION AT BROADWAY RD **USE OTHER ROUTES**	CONSTRUCTION AT BROADWAY RD ALL LANES CLOSED USE OTHER ROUTES	MAJOR ACCIDENT AT WAYSIDE RD **ALL LANES BLOCKED** MAJOR ACCIDENT AT WAYSIDE RD **USE OTHER ROUTES**	MAJOR ACCIDENT AT WAYSIDE RD ALL LANES BLOCKED USE OTHER ROUTES
1. How many lanes are closed?		1. What are you told to do?	
2. What are you told to do?		2. What is the traffic problem?	
3. What is the traffic problem?		3. How many lanes are blocked?	
4. Where is the traffic problem located?		4. Where is the traffic problem located?	

M7		M8	
License Plate No.	No License Plate No.	License Plate No.	No License Plate No.
KIDNAPPED CHILD BLUE CHEVROLET LIC 825 493	KIDNAPPED CHILD BLUE CHEVROLET TUNE TO RADIO	MISSING CHILD GREEN OLDSMOBILE LIC 739 452	MISSING CHILD GREEN OLDSMOBILE TUNE TO RADIO
1. Did the message tell you what to look for?		1. What type of situation has occurred?	
2. Did the message tell you where to get information?		2. Did the message tell you where to get information?	
3. What type of situation occurred?		3. Did the message tell you what to look for?	

M9		M10	
Telephone No.	No Telephone No.	Telephone No.	No Telephone No.
KIDNAPPED CHILD SILVER LINCOLN CALL 800 268 3200	KIDNAPPED CHILD SILVER LINCOLN TUNE TO RADIO	MISSING CHILD YELLOW TOYOTA CALL 888 769 5000	MISSING CHILD YELLOW TOYOTA TUNE TO RADIO
1. Did the message tell you where to get information?		1. What type of situation occurred?	
2. Did the message tell you what to look for?		2. Did the message tell you what to look for?	
3. What type of situation occurred?		3. Did the message tell you where to get information?	

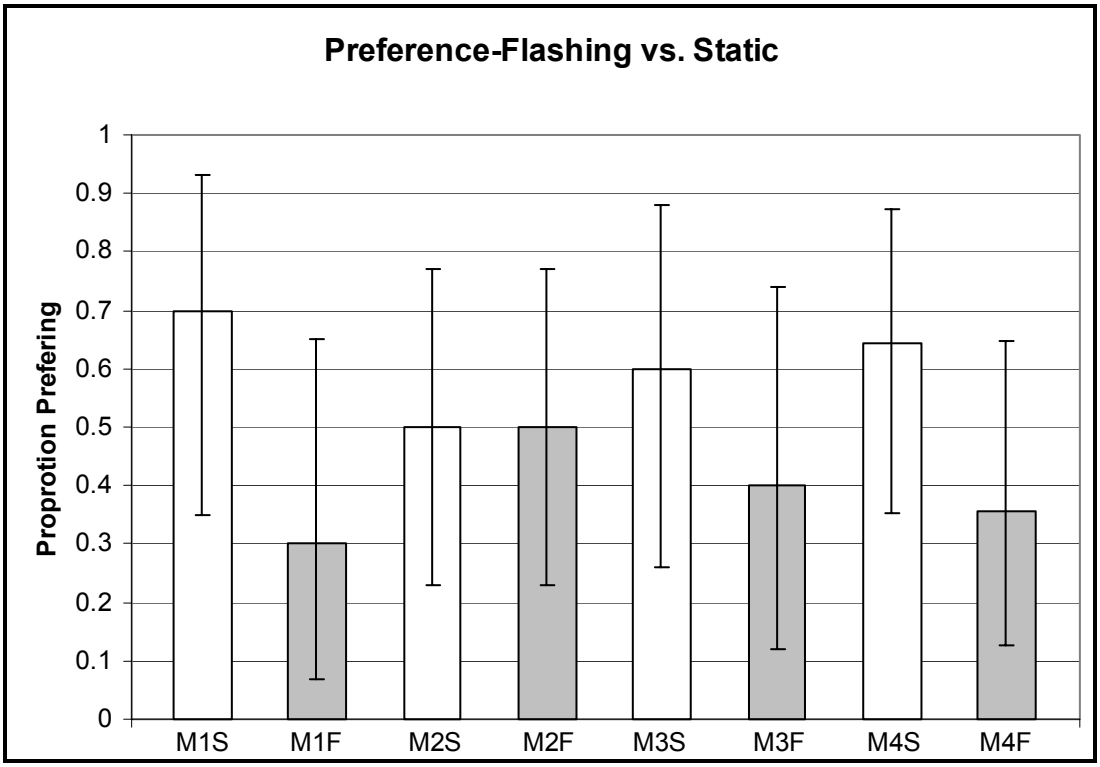

Figure A1. Preference-Flashing vs. Static

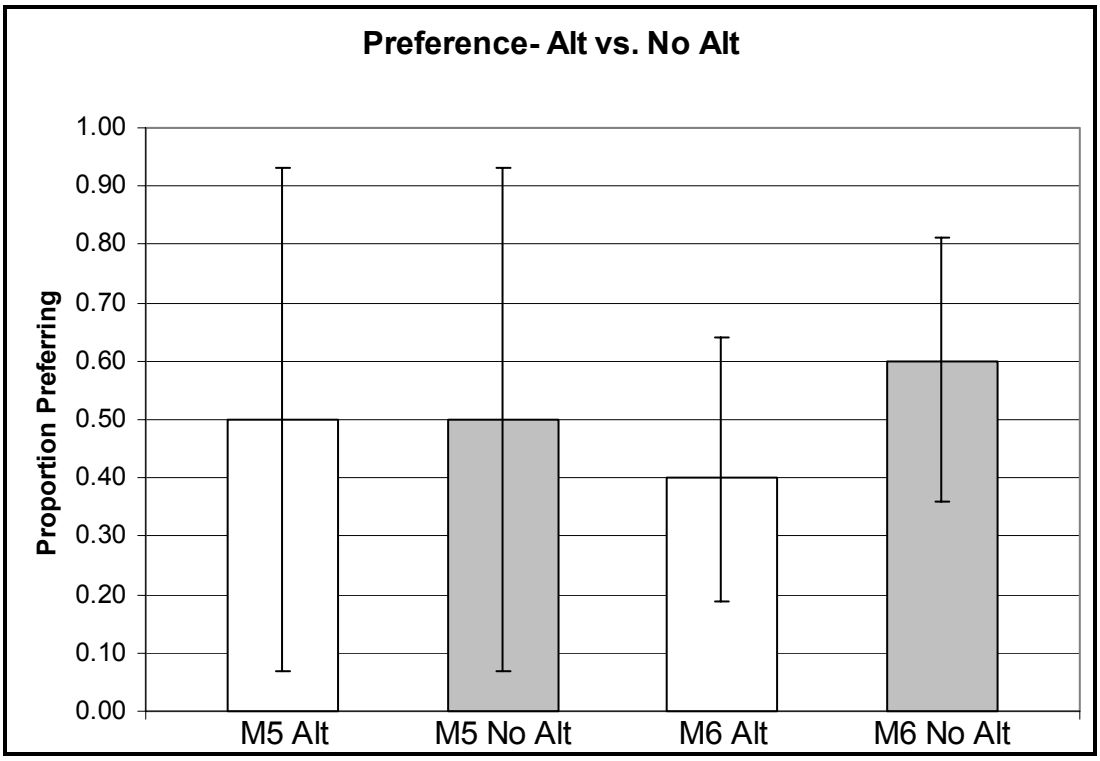

Figure A2. Preference-Alternating Line vs. No Alternating Line

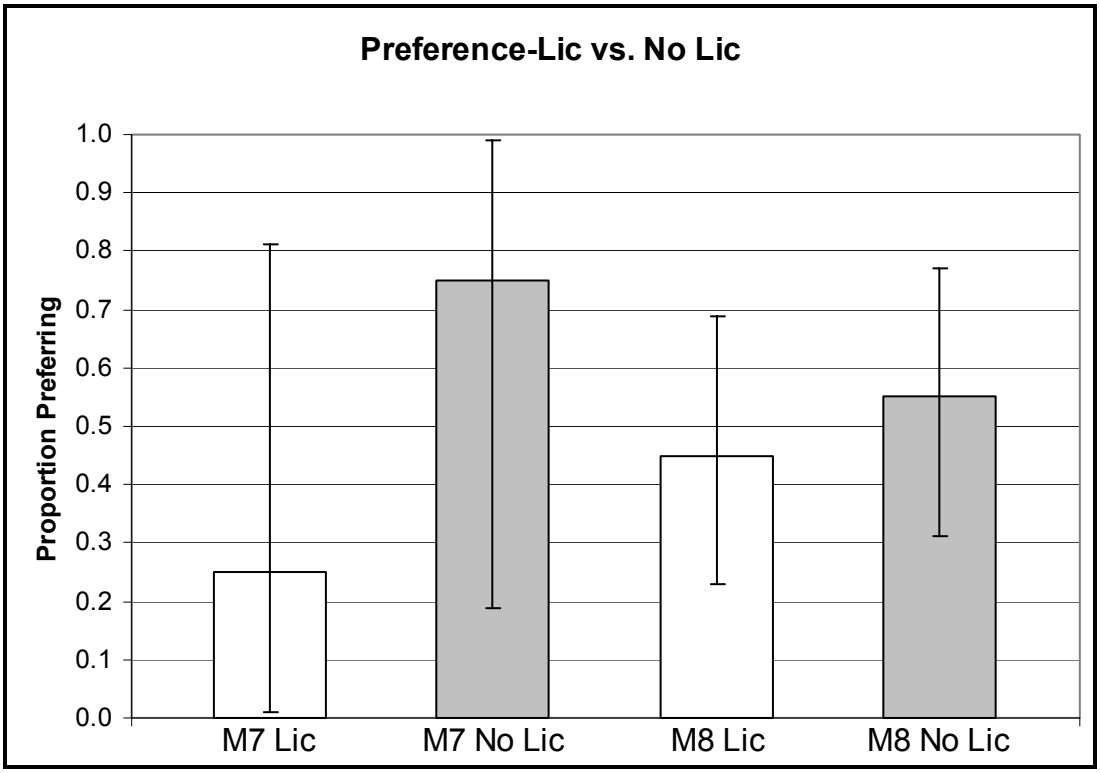

Figure A3. Preference-License Plate Number vs. No License Plate Number

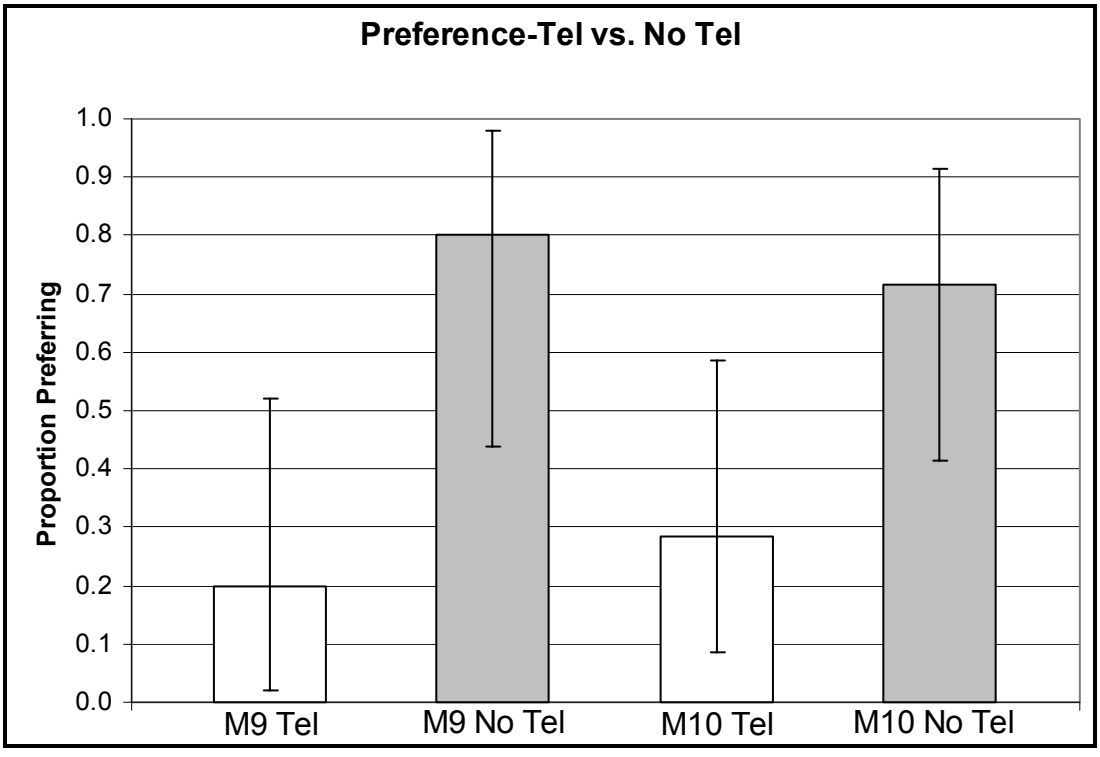

Figure A4. Preference-Telephone Number vs. No Telephone Number

APPENDIX B

Table B1: Comprehension and Preference Data

	Comprehension			Preference		
		Confidence Interval			Confidence Interval	
Simulated Message	**Proportion Correct**	**Lower Bound**	**Upper Bound**	**Proportion Preferring**	**Lower Bound**	**Upper Bound**
M1 Static	0.87	0.60	0.98	0.70	0.35	0.93
M1 Flash	0.89	0.52	1.00	0.30	0.07	0.65
M2 Static	0.78	0.40	0.97	0.50	0.23	0.77
M2 Flash	0.73	0.45	0.99	0.50	0.23	0.77
M3 Static	0.47	0.21	0.73	0.60	0.26	0.88
M3 Flash	0.78	0.40	0.97	0.40	0.12	0.74
M4 Static	0.67	0.30	0.93	0.64	0.35	0.87
M4 Flash	0.47	0.21	0.73	0.36	0.13	0.65
M5 Alt	0.89	0.52	1.00	0.50	0.07	0.93
M5 No Alt	0.11	0	0.48	0.50	0.07	0.93
M6 Alt	0.33	0.12	0.62	0.40	0.19	0.64
M6 No Alt	0.11	0.40	0.97	0.60	0.36	0.81
M7 Lic	0.44	0.14	0.79	0.25	0.01	0.81
M7 No Lic	0.89	0.52	1.00	0.75	0.19	0.99
M8 Lic	0.20	0.04	0.48	0.45	0.23	0.69
M8 No Lic	0.89	0.52	1.00	0.55	0.32	0.77
M9 Tel	0.33	0.08	0.7	0.20	0.02	0.52
M9 No Tel	0.71	0.42	0.92	0.80	0.44	0.98
M10 Tel	0.07	0	0.22	0.29	0.08	0.58
M10 No Tel	1.00	0.66	1.00	0.71	0.42	0.92

Table B2. Reading Time Data

Reading Time							
Critical t = 2.08							
Simulated Message	Mean Time (s)	Standard Deviation (s)	t	Simulated Message	Mean Time (s)	Standard Deviation (s)	t
M1 Static	5.7	1.67		M6 Alt	15.2	9.83	-0.06
M1 Flash	5.6	2.22	0.07	M6 No Alt	15.4	5.88	
M2 Static	6.5	2.66		M7 Lic	9.5	4.92	
M2 Flash	6.7	2.28	-0.18	M7 No Lic	7.4	4.03	1.03
M3 Static	7.2	2.72		M8 Lic	10.2	5.68	
M3 Flash	6.6	2.89	0.51	M8 No Lic	4.9	1.94	3.25
M4 Static	6.2	2.44		M9 Tel	9.6	4.06	
M4 Flash	8.1	5.13	-1.19	M9 No Tel	6.9	3.67	1.63
M5 Alt	17.4	7.01		M10 Tel	8.9	3.35	
M5 No Alt	13.3	6.99	1.35	M10 No Tel	5	1.66	3.76

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VALIDATION OF VIDEO-BASED SPEED MEASUREMENTS

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SUMMARY

The installation of centerline rumble strips (CLRSs) on two-lane highways has been contemplated by the Texas Department of Transportation (TxDOT). They have asked the Texas Transportation Institute (TTI) to analyze the operational effects of CLRSs on the passing maneuvers. To do this TTI used a mobile video-based system to collect passing maneuver data, which requires the speeds of vehicles to be estimated from the video data. This paper evaluates the methods of estimating speed measurements from the mobile video-based data collection system.

To obtain a set of data with known speeds, mock passing maneuvers were conducted at the Riverside Campus of Texas A&M University. The passing vehicle speed and the opposing vehicle speed were the two speeds that were being estimated from the video. Three different methods were used to estimate the speed of the passing vehicle and four different methods were used to estimate the speeds of the opposing vehicle. These estimated speeds were then compared to the known speeds that the vehicles were traveling during the mock passing maneuvers.

The results of the three methods used to estimate passing vehicle speeds were consistent, in that the estimated mean speeds of all methods were within ± 1.5 mph of the known speed. At least 90 percent of the estimated speeds were within the ± 2.5 mph of the known speeds. However one method in particular resulted in the least amount of error and from a data reduction point-of-view requires the least amount of data and time in order to estimate a speed.

For the opposing pass data, the results are very scattered. One method shows that it is not statistically different from the known speeds. At a tolerance of ± 10 mph the percentages range from 10 percent to 60 percent. This provides evidence that the method for estimating the speeds of opposing vehicles do not have a desirable level of precision and future research should be conducted to investigate additional methods.

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INTRODUCTION

One of the Texas Transportation Institute's (TTI's) current projects involves centerline rumble strips (CLRSs). These CLRSs are milled in the same fashion as the rumble strips placed in the shoulders of many of Texas's highways. They differ from shoulder rumble strips (SRSs) in that they are not as deep and have pavement marking painted over them. Their purpose is to create noise and vibrations when a vehicle's tires crosses over them. The CLRSs notify the driver when they are leaving the designated driving lane. They are a safety feature that alerts drivers that may be unaware that they may have shifted into the opposing traffic lane. This could be caused by drowsiness, inattentiveness or fatigue (*1*).

The highways of Texas tend to be relatively flat and straight. The CLRSs would appear to be an ideal safety enhancement at locations where crossover-related crashes are noted as being a problem. However, because of the straight and flat nature of many Texas highways, they happen to coincide with marked passing zones.

There are concerns that motorist would see a broken centerline indicating that passing is allowed and possibly have an unexpected or erratic reaction when they hear and feel the CLRSs as they begin their passing maneuver. The Texas Department of Transportation (TxDOT) is concerned that there is a possibility to, inadvertently, send conflicting messages to the motorist. TTI research (sponsored by TxDOT) is analyzing passing maneuvers before and after the installation of CLRSs. An example of a typical passing maneuver is located in Figure 1.

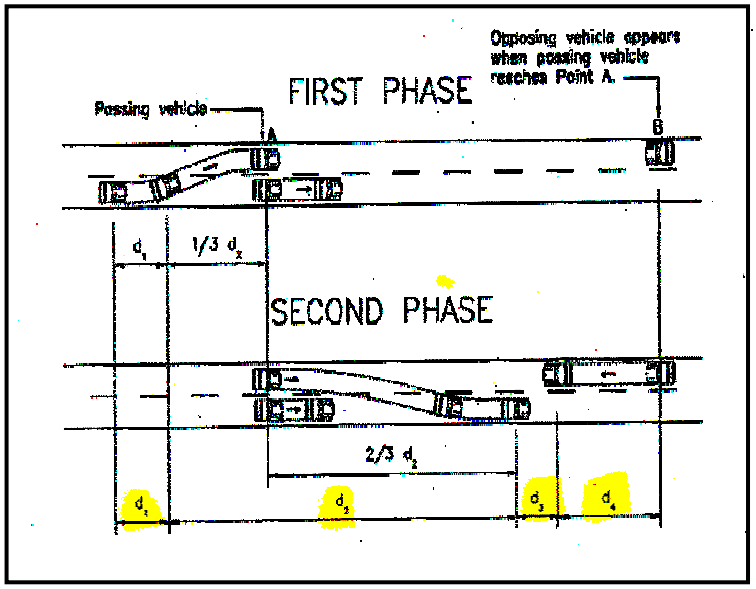
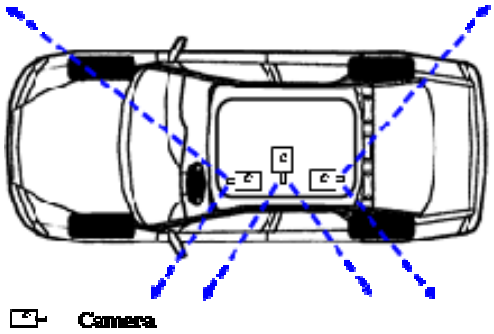


Figure 1. Distance for Two-Lane Highways (*0*)

A data acquisition system was designed and built to gather passing maneuver data in the field using a video-based system. This system was based on one of the earliest passing maneuver studies using a 16-mm camera in an observation box resembling a tool shed in the back of a pick-up truck (*2*).

A depiction of the video-based system used in the more recent experiment is given in Picture A of Figure 2. The Diagram B shows the three cameras that provided rear, side, and front views of passing maneuvers. These cameras were concealed in a streamlined cargo carrier. The images were recorded to a single VCR in a quad screen format (See Picture C). The fourth camera view represented in Picture C was of a distance measuring instrument (DMI) located inside the data-recording vehicle (DRV), indicated in picture A.

A: Picture of Video-Based System



B: Diagram of Video-Based System

Rear view **Side view**

Front view **DMI**

C: Picture of Monitor Display

Figure 2. Video-Based Data Collection System

Problem Statement

There are a number of methods that could be used to estimate vehicle speeds from video-based data collection. The purpose of this project was to identify and evaluate methods of estimating speeds from a mobile video-based data-collection system. The video data collection system has been used to analyze different methods of estimating speeds from a mobile data collection system.

A validation of the speed estimation method has never been completed, and therefore is needed. There are two separate elements that are being assessed: 1) the passing vehicle's speed and 2) the opposing vehicle's speed.

EXPERIMENTAL PLAN

The general hypothesis that was tested in this study was that the estimated speeds of passing vehicles generated from video data are not significantly different from the true vehicle speeds. The null hypothesis (H0) is that the difference in the actual speed and the estimated speeds from each method will be zero. The alternative hypothesis (H1) is that the difference between the two is not equal to zero.

The researchers have collected speed data at the Texas A&M University (TAMU) Riverside Campus. The speeds of each vehicle in the testing were constant and known. Three different methods of estimating speed were applied to the video passing vehicle data. The opposing vehicle data were subject to four different methods in order to obtain their speed. The true speeds were used to test the accuracy of the speeds estimated from the video data. A flowchart is provided in Figure 3 to give better understanding of this process. It shows the steps that were laid out to collect and reduce the control data. The latter sections will explain each speed estimation method and are explained in detail in the methodology.

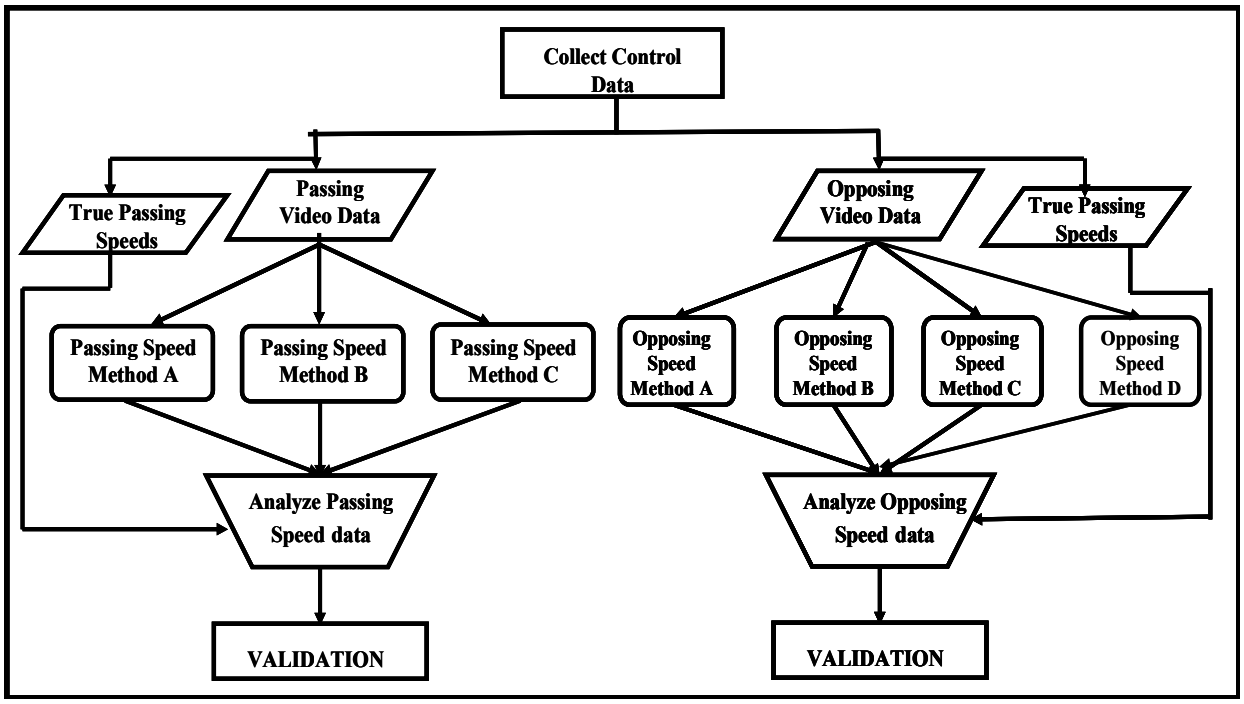


Figure 3. Data Collection/ Reduction Flow Chart

METHODOLOGY

Estimating Speeds from Video

In the passing maneuver scenario (See Figure 4), the lane positions are labeled on the tops of each vehicle. This depicts the positions that vehicles drive through as they pass another vehicle. They begin at lane position 1 where the vehicles are completely centered in their lane and proceed until the vehicles are completely in the opposing lane of travel. Lane positions 2 and 4 were indicated when the left and right tire, respectively, were on the centerline. Lane Position 3 was designated when the right and left tires straddled the centerline. When the vehicle is completely centered in the opposing lane of travel it is in lane position 5. These lane positions were used to identify what stage of the pass the vehicle was in at a particular instant.

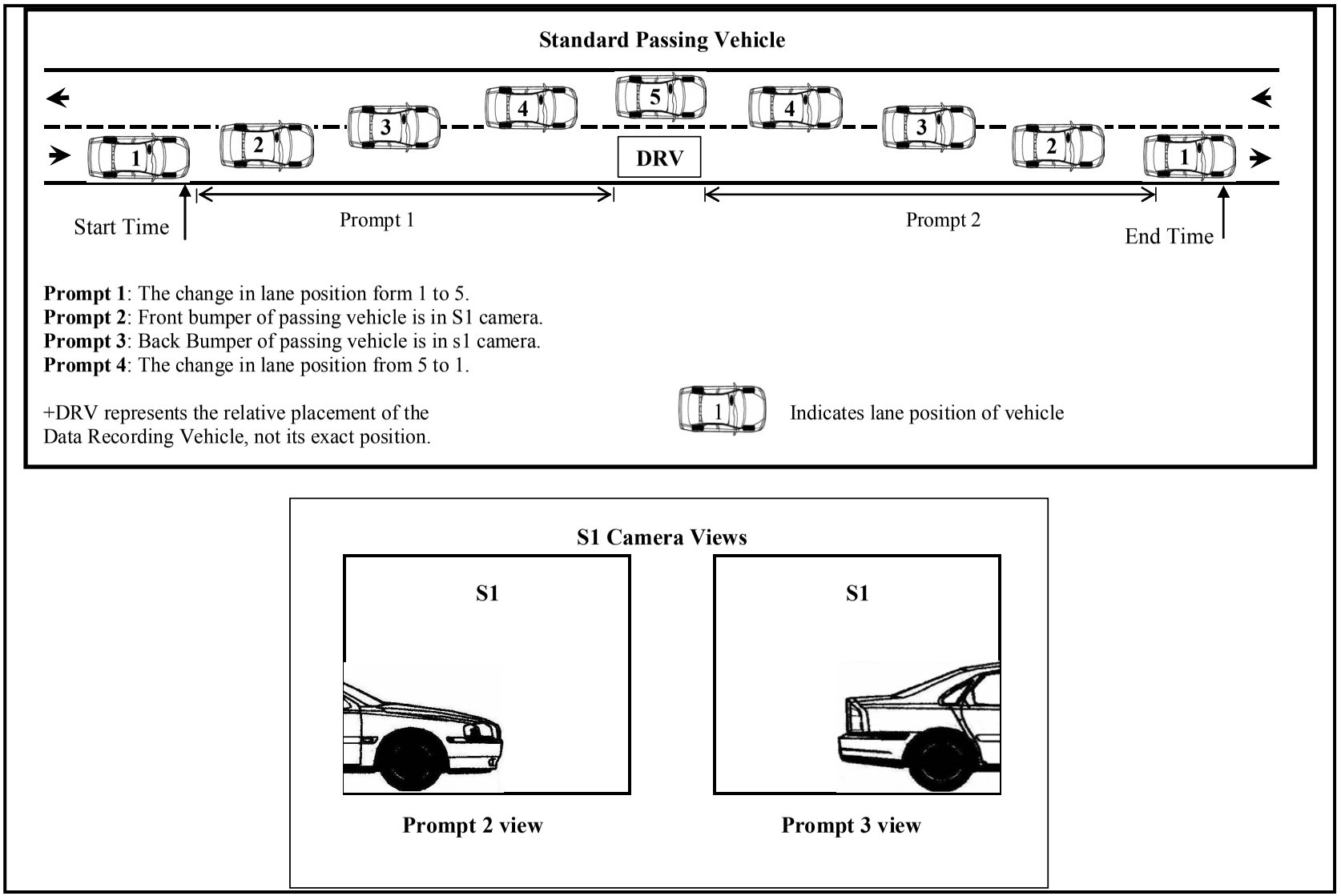


Figure 4. Passing Vehicle Maneuver

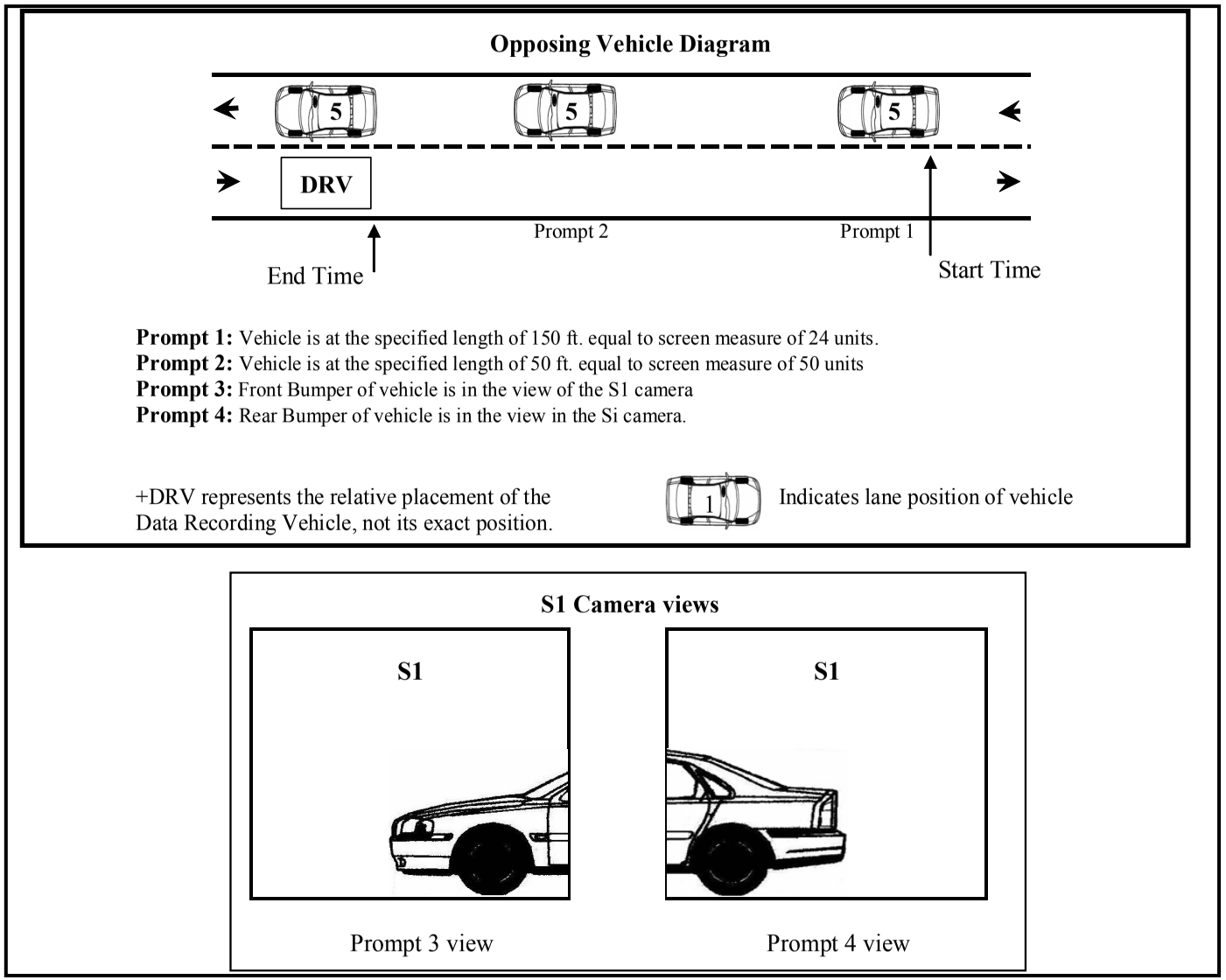


Figure 5. Opposing Pass Scenario

For the standard passing scenario prompts were established to indicate when a particular action was taking place and, subsequently, when to collect data. Prompt 1 was the change in lane positions to the opposing lane of travel, from 1 to 5. In this prompt data were taken each time the passing vehicle changed lane positions. Prompt 2 was the instant that the front bumper of the passing vehicle was in the center of the S1 camera, side view. Similarly, prompt 3 was the instant that the back bumper of the passing vehicle was in the center of the S1 camera. Data were taken in prompt 4 every time the passing vehicle changed lane positions back into the original lane of travel, from 5 to 1.

In the case of the opposing vehicle (See Figure 5) the steps were the same but the details were different and three different methods for estimating speed were used. The lane positions for these tests were the same but the prompts are redefined. In this scenario the opposing vehicle was always in the opposing lane of travel, lane position 5.

The prompts were still indications of when to transcribe information from the tape, but they became more place markers than descriptions of actions. Prompt 1 was the first point that was recorded. The data were recorded when the opposing vehicle was approximately 150 feet in front of the DRV, in the F1 camera. Prompt 2 was the second distance that was needed when the opposing vehicle was approximately 50 feet in front of the DRV. Prompt 3 were when the front bumper of the opposing vehicle was approximately in the center of the S1 camera and prompt 4, when the back bumper was approximately in the center of the S1 camera.

Data Collection

All of the data collected for this study were collected at the TAMU Riverside Campus, where there is a sufficient amount of distance on the runways to perform the passing maneuvers in a safe and realistic manner. Measures were taken so that the control data that was collected were an accurate replication of the data in the field.

In order to acquire speed data in a safe manner for both a passing vehicle and a vehicle traveling in the opposite direction, two separate data collection efforts were completed. Both efforts were conducted ten times at two speeds related to typical highway operating speeds.

In order to know the exact speeds of each vehicle and to ensure their accurate repeatability, the cruise control settings in the vehicles were used. The desired speeds were set on each vehicle and the resume function was used to return to that speed in each run. Before any testing occurred, the resume accuracy was tested with a Lidar System, with an accuracy of ± 1 mph (*3*). The cruise control was set and the Lidar System was used to measure the speed of the vehicle after it reached the desired speed. After the vehicle came to a complete stop, the resume was used to return to the same speed and then the speed was measured again. These steps were repeated ten times for each of the trials at each speed. All ten of the measurements registered the same reading.

For the first passing vehicle speed test, the DRV was traveling at 55 mph and the passing vehicle at 69 mph. The speeds of the second passing vehicle test were 65 mph and 74 mph, respectively. It should be stated that the goal speeds of these tests were 55 mph and 70 mph for the first test and 65 mph and 75 mph for the second test. The actual speeds varied because of the manual setting on the cruise control and were also within the accuracy of the Lidar readings.

For the first opposing vehicle test, both vehicles were traveling at 55 mph (towards each other but in adjacent lanes). For the second opposing vehicle speed test both vehicles were traveling at 70 mph.

Data Reduction

The information that was collected from the tapes included such things as: speed of DRV, direction of travel, location, date, start and end times, vehicle number, and vehicle type/make/model. For each data point the time (hr/min/sec), DRV speed, prompt number, camera view, DMI reading, screen reading and lane positions were recorded. Prompts were the criteria where the video data was stopped and data were recorded. The prompts for each scenario are different and they are defined within each section.

Before any video data could be reduced a scale had to be made for the screen reading system. This scale was in units of $1/50^{th}$ of an inch. By securing this scale to the screen, where all the data were reviewed, a screen reading could be obtained. These scales were placed in the rear camera view and the front camera view. A separate tape was made of the DRV driving away from and approaching a building at Riverside Campus. The DMI distance was used to relate screen readings with actual distance that the DRV traveled. A full three runs were reduced and compiled into a spreadsheet to provide a trend line that was used to estimate the gap distance between the passing vehicle and the DRV. For quality control purposes, the same researcher that reduced the data from the field for the original TTI research also reduced the control data. This ensured that measurements that were read from the monitor were taken in the same manner and in reference to the same objects.

This research looks at three different ways to estimate the speed of this passing vehicle from the video data. The lane positions and prompts allowed the researchers to identify the specific places where speeds were estimated. All speed calculations are based on the relationship of a change in distance with respect to a change in time.

Method A used the average of three different speeds estimated from four different points within the pass. These points were last prompt 1, prompt 2, prompt 3 and the first prompt 4. At each of these points the estimation was based on the information collected at that point and the point just before. All the lane positions were 5 in this method. Method B just used the speed estimated at one points, prompt 3. It also used the datum from the previous point as well as the current datum to obtain the speed calculation at that point. Method C estimated the speed using two points over a larger distance than the other methods. The first data point in the interval was prompt 1, lane position 2 and the second point was prompt 2. This method was not an average of the speeds estimated at each point, as before in method A. Method C only used the information taken from these two points and the relationship of the change in distance over the change in time from the first point to the second.

A different set of prompts was used for the opposing pass maneuver (See Figure 5). Opposing method A estimated the speed using the information from prompts 1 and 2. Method B used prompts 2 and 3 to estimate speed. Similarly, method C used the data from prompts 3 and 4 to estimate the speed of the opposing vehicle. Only the prompts 1 and 3 were used to estimate speed in method D. All speeds were estimated using the relationship of a change in distance with respect to a change in time.

Analysis Approach

Once all of the control data were collected the various techniques of estimating speeds were implemented. Actual vehicle speeds as measured w/ Lidar were compared to the estimated values of the different methods. The methods were not compared to each other.

A paired t-test was used to estimate a 95 percent confidence interval from the mean of each of the differences. This interval was formed using the equation below and a standard t-table.

Confidence Interval:

$$\bar{d} - \frac{t_{\alpha/2,n-1} s_D}{\sqrt{n}} \leq \mu_d \geq \bar{d} + \frac{t_{\alpha/2,n-1} s_D}{\sqrt{n}}$$

Where:

n = sample size
d = mean of the differences of Actual – Experimental
$t_{\alpha/2,n-1}$ = upper α/2 percentile point of the t - distribution with n-1 degrees of freedom
s_D = standard deviation of the differences
μ= μ1 - μ2 (Actual – Experimental)

H_0 = μd = 0 (The value of zero lies within the confidence interval)
H_1 = μd ≠ 0 (The value of zero does not lie within the confidence interval)

The general null hypothesis (H_0) was that the difference between the actual speeds and the estimated speeds (μ_d) is zero. The alternative hypothesis (H_1) was that the difference (μ_d) is not equal to zero. If the actual was indeed equal to the estimated speed, then it would be logical for the mean of the differences to be zero. According to the definition of the paired t-test, if the desired value lies within the interval, at the 95 percent level of confidence it can be said that the data do not give any reason to reject the null hypothesis, but they also do not give enough evidence to accept the null hypothesis. Although, if the desired value does not lay in the confidence interval it does give enough evidence to reject the null hypothesis, so therefore the alternative hypothesis is accepted (*4*).

RESULTS

By analyzing the known speeds from the scenarios conducted at Riverside the researchers were able to make a comparison between the actual speeds and the estimated speeds of these vehicles.

The results of both passing scenarios were clearly defined by the confidence interval. If the value of zero is in the confidence interval then the null hypothesis could not be rejected. First the descriptive statistics were completed to provide the information to perform the paired t-test. The results were graphically reported so placement and range of the interval could be seen easily.

Passing Vehicle Speeds

The results of the passing vehicle analysis are located in Table 1. The method with the least amount of mean speed error used to estimate the passing vehicle speed was method B. However, all mean values of each method that were used to estimate speeds for the passing data were statistically within ± 1 mph. With method B, at both speed tests, the interval included zero (See Figures 6 & 7). This meant that there was not enough evidence to conclude that method B was significantly different from the actual speeds. The researchers are comfortable with a precision of ± 2.5 mph.

The results of method C were mixed. The interval that took place at a higher speed has a larger interval, so it includes zero. Although, the interval for the test at lower speeds did not include the zero. From this test the researchers can say that the actual speeds are significantly different from the estimated speeds. The standard deviations and ranges of the method C data were considerably smaller than method B. Subsequently, method C is more precise than B, but method B is more accurate.

Method A is the only method that, in both speed trials, zero is not included in either confidence interval. This information allowed the dismissal of this method because it confidently states that the speeds

Table 1. Results of Standard Passing Speeds

Descriptive Statistics (Actual – Experimental)					
DRV Speed (mph)	**Passing Speed (mph)**	**Statistics (mph)**	**Method**		
			A	**B**	**C**
55	69	Mean	-1.0	0.1	1.0
		Standard Deviation	0.5	2.0	0.4
		Range	1.8	6.9	1.1
65	74	Mean	-0.7	-1.2	0.4
		Standard Deviation	0.8	2.5	1.0
		Range	3.1	8.3	2.5

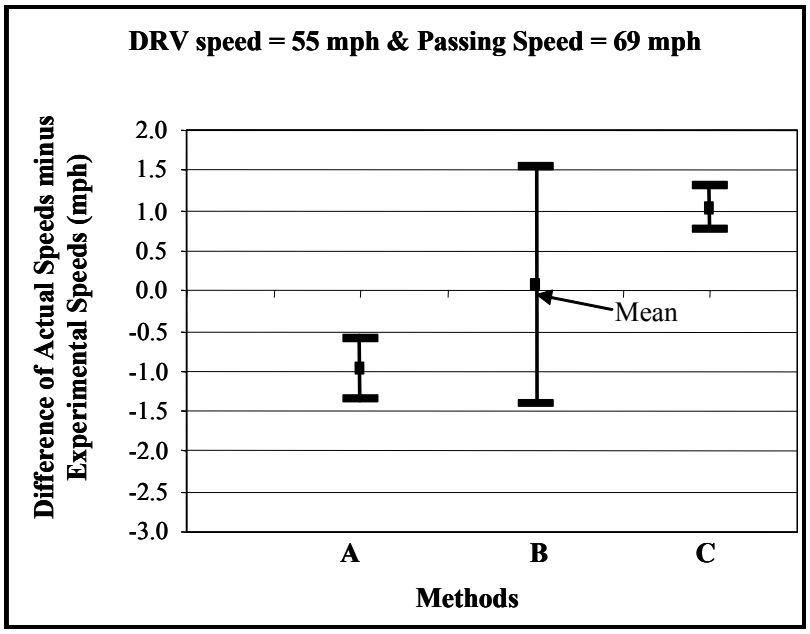


Figure 6. 95% Confidence Intervals of Lower Speed Passing Data

estimated from method A were significantly different from the speeds of the actual speeds. Method A has relatively good precision, but poor accuracy.

Opposing Vehicle Speeds

The opposing vehicle pass results were not as precise as the standard passing vehicle results. Table 2 shows the results of the opposing vehicle pass speeds. The most notable result from Table 2 is the spread of the estimated speeds. The standard deviations of these methods were much higher in these tests than in the standard passing tests.

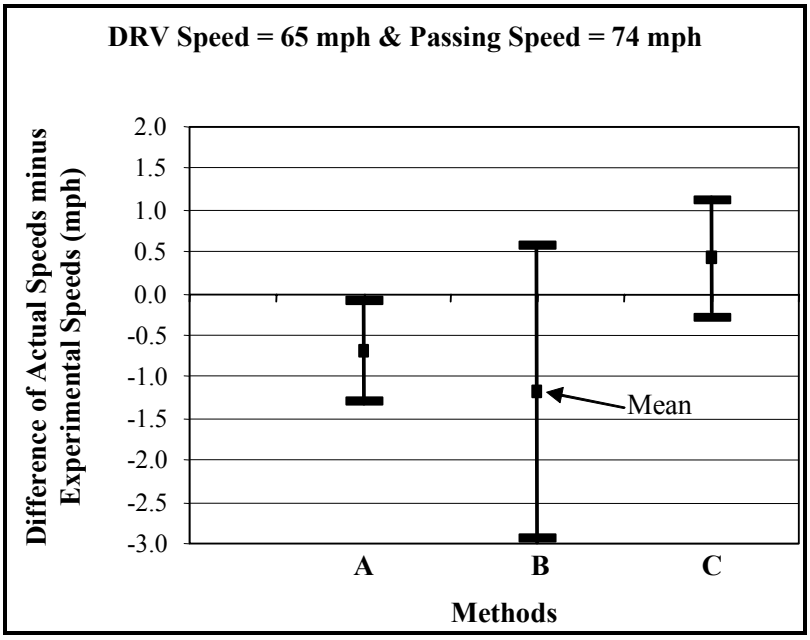


Figure 7. 95% Confidence Intervals of Higher Speed Passing Data

Table 2. Results of Opposing Speeds

Descriptive Statistics (Actual – Experimental)						
DRV Speed (mph)	**Opposing Speed (mph)**	**Statistics (mph)**	**Method**			
			A	**B**	**C**	**D**
55	55	Mean	1.7	-17.9	-25.9	-5.2
		Standard Deviation	10.7	10.6	38.2	10.0
		Range	29.6	36.3	126.7	32.7
70	70	Mean	-0.8	-46.7	14.5	-23.8
		Standard Deviation	17.2	38.1	26.7	15.8
		Range	49.5	116.6	60.3	47.4

Method A's interval contains zero in both speed tests. There was not enough evidence from this data to reject the null hypothesis that the speeds are equal. The mean of this method, for both speed tests, was the closest to zero of all of the methods. The confidence interval for this method was also more centered on zero than any of the other methods (See Figures 8 & 9). If a recommendation was to be made for the opposing passing data, these factors lead to the choice of method A, because it is the most accurate.

The confidence intervals for method C also included zero. This, just like method A, means that the null hypothesis can not be rejected. Although, by looking at the results further, the observation was made that the range in the lower speed test was 126.7 mph and in the higher speed test it was 60.3 mph (See Table

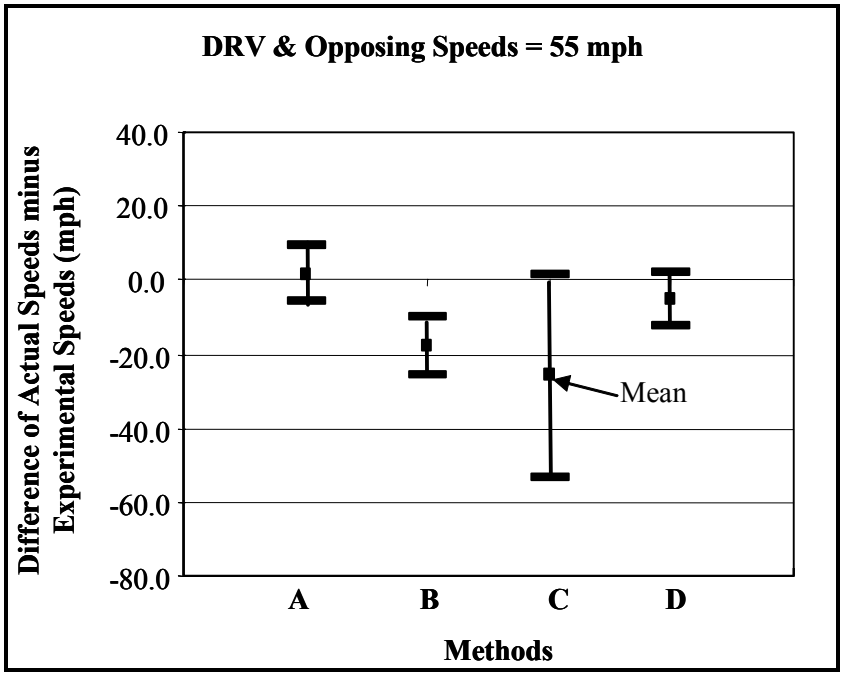


Figure 8. 95% Confidence Interval of Lower Speed Passing Data

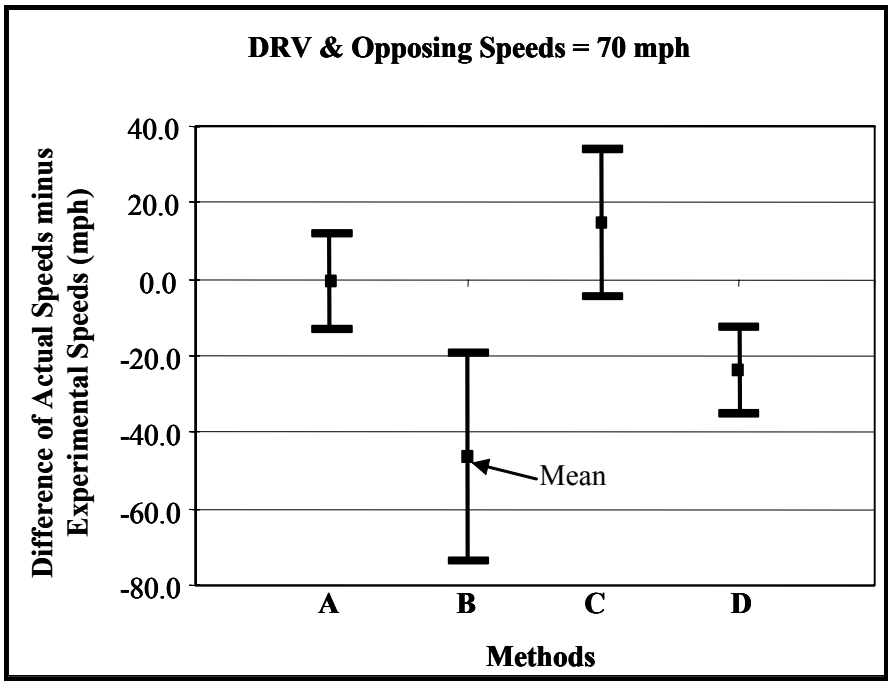


Figure 9. 95% Confidence Interval of Higher Speed Passing Data

2). The intervals that were created in both tests were not centered on zero, either. One interval was shifted in the negative direction and the second interval was shifted in the positive direction, showing that method C is not accurate. All these factors together made method C unacceptable.

One of the confidence intervals for method D included zero and the other does not. From this information alone the researcher could eliminate this method. The interval for the higher speeds was shifted more negatively than the other method. The ranges of the two speed test were relatively close to each other.

Method B had intervals that in both speed tests did not include zero. Both intervals were shifted in the negative direction. The data for the 70 mph tests had a wide spread, with a range of 116.6 mph. These speeds were not consistent and, from the confidence intervals, were significantly different from the actual speeds.

CONCLUSIONS

The data received for the passing speeds were much more reliable than the opposing data (See Table 3 & 4). If implemented into future research, all methods would give results with a relative accuracy. The decision of which method to use in future should rely upon the results presented in this paper and the amount of work needed to estimate speeds from video. Not only was method B found to have the least amount of error, but it also is the quickest method to use to estimate passing vehicle speeds.

Table 3. Percent Measurements of Passing Data within Range of Known Speed

DRV Speed (mph)	Passing Speed (mph)	Tolerance (mph)	Method		
			A	B	C
55	69	±0.5	10%	30%	10%
		±1.5	90%	90%	90%
		±2.5	100%	90%	100%
65	74	±0.5	30%	60%	20%
		±1.5	90%	80%	90%
		±2.5	90%	90%	100%

The opposing vehicle speed estimates the measurements were considerably less accurate than the passing vehicle speed estimations. The most accurate method can provide 60 percent relative accuracy at a tolerance of ± 10 mph (See Table 4).

The inaccuracies in the opposing vehicle speed estimates seemed to be attributed mainly to the DMI. Because the vehicles were traveling in the same direction in the passing vehicle speed estimates, the speed difference was only 10 or 15 mph and the change in the display of the DMI was updated relatively quickly. In the case of the opposing vehicle speed estimates, the relative speed difference was 110 mph or 140 mph. The DMI display did not update the distance as quickly as the camera frames updated the image of the vehicle. This resulted in a distance update once for about every three camera frames. When opposing vehicle speeds were collected, there were approximately three frames to view the passing vehicle. When measurements were taken in the S1 camera, the distance measurements that corresponded with the images were not as accurate as they needed to be to collect acceptable data. Many of the calculations that were made used the distances from the DMI. The accuracy of the DMI is a limitation of the video-based system.

Table 4. Percent Measurements of Opposing Data within Range of Known Speed

DRV Speed (mph)	Opposing Speed (mph)	Statistics (mph)	Method			
			A	B	C	D
55	55	±2.5	10%	0%	0%	0%
		±5.0	30%	20%	10%	20%
		±10.0	60%	20%	50%	50%
70	70	±2.5	0%	0%	0%	10%
		±5.0	20%	10%	10%	20%
		±10.0	40%	10%	20%	20%

The results from the passing vehicle speed estimates are reliable, and method B is the recommended method to use for calculations. Each of the methods produced speeds more accurate than the speeds of the opposing pass data. No method is recommended for the opposing pass data because of the limitations with the DMI.

RECOMMENDATIONS

The objectives of this paper were to evaluate the methods of estimating speed from a mobile video-based data-collection system. Based on the findings the following recommendations are made:

- Use method B for estimating speeds for passing vehicles, and
- No method is recommended for estimating the speed of an opposing vehicle. Additional research needs to be conducted to refine the process for estimating the opposing vehicle speed.

Researchers used off-the-shelf equipment to collect the data for this paper. For improved speed estimates the researchers recommend:

- More advanced DMI that updates faster than 1.30 of a second,
- Estimating speed with camera frames instead of DMI distances. Speed measurements can be collected by the same relationship of distance and time with the known DRV speed, length of the vehicle and number of frames, and
- Account for the curve of the camera lens by using angle geometry. A right triangle can be formed between the DRV and the passing vehicle and then used to solve for the missing direct length between the DRV and the passing vehicle.

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APPENDIX A

Table A1. Passing Vehicle Data

Control Data Summary Passing Scenario								
			Average Speed of Passing Vehicle			Passing Differences		
Veh. #	DRV Speed	Actual Speed of Passing Vehicle	Method A (2, 3 & 4)	Method B (3)	Method C (1 & 2)	Method A (2, 3 & 4)	Method B (3)	Method C (1 & 2)
	(mph)	*(mph)*	*(mph)*	*(mph)*	*(mph)*	*(mph)*	*(mph)*	*(mph)*
1	55	69	70.33	70.07	68.08	-0.33	-0.07	1.92
2	55	69	70.42	69.86	67.80	-1.42	-0.86	1.20
3	55	69	68.76	68.55	68.34	1.24	1.45	1.66
4	55	69	70.13	63.43	67.88	-2.13	4.57	0.12
5	55	69	69.86	68.90	67.57	0.14	1.10	2.43
6	55	69	69.72	69.77	67.44	-1.72	-1.77	0.56
7	55	69	70.43	70.29	67.59	-2.43	-2.29	0.41
8	55	69	69.63	68.55	68.30	-1.63	-0.55	-0.30
9	55	69	69.94	70.29	68.15	-1.94	-2.29	-0.15
10	55	69	70.58	69.66	68.55	-0.58	0.34	1.45
11	65	74	74.71	74.29	73.61	-1.71	-1.29	-0.61
12	65	74	74.76	74.80	73.34	-1.76	-1.80	-0.34
13	65	74	76.67	81.84	74.15	-2.67	-7.84	-0.15
14	65	74	74.62	74.29	72.95	0.38	0.71	2.05
15	65	74	73.86	74.21	73.24	0.14	-0.21	0.76
16	65	74	75.20	76.23	73.25	-1.20	-2.23	0.75
17	65	74	74.59	74.54	72.60	-0.59	-0.54	1.40
18	65	74	73.59	73.55	73.25	-0.59	-0.55	-0.25
19	65	74	74.72	74.37	76.14	-0.72	-0.37	-2.14
20	65	74	74.18	73.69	73.35	-1.18	-0.69	-0.35

Table A2. Opposing Vehicle Data

Control Data Summary Opposing Scenario								
Veh. #	DRV Speed	Actual Speed of Passing Vehicle	Average Speed of Opposing Vehicle			Opposing Differences		
			Method A (2, 3 & 4)	Method B (3)	Method C (1 & 2)	Method A (2, 3 & 4)	Method B (3)	Method C (1 & 2)
	(mph)	*(mph)*	*(mph)*	*(mph)*	*(mph)*	*(mph)*	*(mph)*	*(mph)*
1	55	69	70.33	70.07	68.08	-0.33	-0.07	1.92
2	55	69	70.42	69.86	67.80	-1.42	-0.86	1.20
3	55	69	68.76	68.55	68.34	1.24	1.45	1.66
4	55	69	70.13	63.43	67.88	-2.13	4.57	0.12
5	55	69	69.86	68.90	67.57	0.14	1.10	2.43
6	55	69	69.72	69.77	67.44	-1.72	-1.77	0.56
7	55	69	70.43	70.29	67.59	-2.43	-2.29	0.41
8	55	69	69.63	68.55	68.30	-1.63	-0.55	-0.30
9	55	69	69.94	70.29	68.15	-1.94	-2.29	-0.15
10	55	69	70.58	69.66	68.55	-0.58	0.34	1.45
11	65	74	74.71	74.29	73.61	-1.71	-1.29	-0.61
12	65	74	74.76	74.80	73.34	-1.76	-1.80	-0.34
13	65	74	76.67	81.84	74.15	-2.67	-7.84	-0.15
14	65	74	74.62	74.29	72.95	0.38	0.71	2.05
15	65	74	73.86	74.21	73.24	0.14	-0.21	0.76
16	65	74	75.20	76.23	73.25	-1.20	-2.23	0.75
17	65	74	74.59	74.54	72.60	-0.59	-0.54	1.40
18	65	74	73.59	73.55	73.25	-0.59	-0.55	-0.25
19	65	74	74.72	74.37	76.14	-0.72	-0.37	-2.14
20	65	74	74.18	73.69	73.35	-1.18	-0.69	-0.35

PATRICIA JOHNSON

Patricia Johnson is currently attending Texas A&M University and she plans to graduate with a Bachelor of Science degree in Civil Engineering in May of 2006. Patricia is a member of the student chapter of American Society of Civil Engineers. She has also worked part-time for Texas Transportation Institute (TTI) since June of 2003. Patricia plans to continue to work for TTI through the next school year and seek an internship for the summer of 2005. After graduation, she hopes to work for 1 to 3 years and then attend graduate school at Texas A&M University.

DEVELOPING WORKSITE CRITERIA FOR "FLOATING" SPEED ZONE RESEARCH

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SUMMARY

A "floating" speed zone is basically a lowered speed limit that "floats" or moves with workers and machinery as they work on a roadway construction project. The idea is to have the driver brake only in the vicinity of workers and equipment, while maintaining the posted speed limit in other sections of the roadway. Research is currently underway at the Texas Transportation Institute to determine the validity of the idea.

The objective of this project was to develop criteria a roadway under construction should have before data collection should commence. This project consisted of several steps ultimately leading to the discovery of several key criteria that a site needs to meet. A literature review, survey analysis, field work, and computer work were all performed this summer. Some of the major products of this research project include: job site criteria to be met, a criteria checklist to be used in the field, and a work zone characteristics sheet to discuss job sites in detail.

Some of the major criteria a work site needs to have in order for successful data collection include:

- Roadway length greater than 8 miles,
- Good driver visibility,
- The road should be relatively straight,
- The shoulders should be of good quality and width,
- There needs to be a posted work zone speed limit,
- The machinery and workers should work and move in small sections relative to the length of the roadway under construction, and
- Conditions other than the speed limit should not be controlling driver speeds.

This research is a small portion of a larger project currently underway at the Texas Transportation Institute for the Texas Department of Transportation. The findings in this report will provide information and useful suggestions for the data collection phase of the project coming this fall.

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INTRODUCTION

Safety in construction zones is an important issue that has been concerning transportation engineers for years. Some of the facts on accidents in construction zones are staggering. According to the Texas Department of Public Safety, 9523 crashes occurred in work zones in the state of Texas in 2002. These crashes resulted in 143 fatalities and 9899 injuries. Speed was cited as a contributing factor in approximately 42 percent of these crashes (*1*). Speed limit compliance studies performed at highway construction work zones in Georgia showed that although drivers reduce their speeds in the vicinity of active work zones, these speeds are significantly higher than the posted speed limits (*2*) Speeding in work zones puts numerous people in unnecessary danger. Drivers in both directions along with the construction workers on the site are all at risk when the speed limit is not being obeyed.

We have all been driving and seen signs with a message similar to 'ROAD WORK NEXT 20 MILES, SPEED LIMIT 50 MPH'. In some cases, though construction is only being performed on small sections of the roadway at a time, the construction zone speed limit is posted for all 20 miles. A "floating" speed zone can move with the machinery and workers as they work. The ultimate goal is to determine if driver compliance with the speed limit will be increased if they only have to slow down to 50 MPH for a small section of the construction zone.

This project attempts to establish guidelines for which a construction zone should meet before "floating" speed limit tests should be performed. The Texas Department of Transportation (TxDOT) has already approved for the Texas Transportation Institute (TTI) to analyze the effectiveness of a "floating" speed zone in construction areas. This project will only help and expedite the research during the fall of 2004.

SCOPE OF THE PROJECT

This project was managed in several stages. They include:

- Literature review (TxDOT survey included),
- Site identification,
- Brainstorming certain criteria and techniques,
- Developing a draft of a work site characteristics sheet,
- Field work and observations,
- Developing a final draft of work zone characteristics sheet,
- Developing a checklist of criteria for sites, and
- Conclusion and making recommendations for future research.

LITERATURE REVIEW

This portion of the research helped provide background information about the project. As the topic is relatively new, technical information and material directly related to the project was difficult to find. There was extensive information found on current practices and safety in the field, though. Some of the most interesting things found in this search included the realization that law enforcement has such a major role in speed zone compliance and that this project needed to consider many factors before the data collection phase. These factors included: work type, duration, roadway length, the location of CMS and advance warning, and the conditions of the roadway and the surrounding area. Studies on various other methods to increase driver compliance revealed that work needed to be done to isolate the "floating" speed zone so it would be the only tool working to improve compliance.

TxDOT Survey of Current Practices

A web-based survey was conducted by TTI in December 2003 to gather information pertaining to the improvement of driver compliance in work zones. The survey, figures, and results that follow all come from TTI, specifically the Technical Memo mentioned in the references *(3)*.

Though both in-state and out-of-state surveys were distributed, for the purposes of this research, only the in-state survey will be examined. Potential participants in the survey were sent an email asking them to complete the survey on-line.

Figure 1 shows the email requesting participation in the survey sent to the district engineer in each of the 25 TxDOT districts.

Happy Holidays,

The Texas Transportation Institute is conducting a research project for TxDOT on **Driver Compliance with Work Zone Speed Limits** for which we would like to get input from the districts about their current practices. This survey is part of a research project to identify and evaluate methods to increase compliance with work zone speed limits. The survey's primary objective is to assess the current state-of-the-practice of establishing and enforcing speed limits, and using various speed control devices and strategies to improve speed limit compliance in work zones.

The intended recipient of this survey is someone who has knowledge of your practices for setting work zone speed limits and the devices used to indicate such speed limits. Feel free to forward this e-mail to area engineers and others that might also be responsible for work zone speed limits.

The survey is located at http://san-antonio.tamu.edu/4707/survey.asp. There are 12 questions in the survey. Please contact Marcus Brewer if you have any questions (979-845-2640 or m-brewer@tamu.edu). We hope that the on-line format of the survey minimizes the effort needed for you or your staff to respond. We hope that you can find an opportunity to complete this survey or that you will ask one or more of your staff to complete the survey. We would like to have responses by January 23, 2004, if at all possible. Thank you in advance for your cooperation and please feel free to contact us if you have any questions.

Figure 1. Initial Contact E-mail for TxDOT Survey *(3)*

The survey sent had 12 questions, three of which had multiple parts. The main points of the survey were to find comments on procedures and thoughts on setting WZSLs, devices and methods used to enhance driver compliance within the work zone, and current practices used by the respective district with regard to law enforcement. All distributions are based on a sample size of 16 unless otherwise stated.

Question 1: How do you determine the appropriate work zone speed limits on your projects?

As shown in Figure 2, close to 90% of the respondents adjust the speed limit in construction zones, but there was much deviation between the groups doing this. The most common answer given was

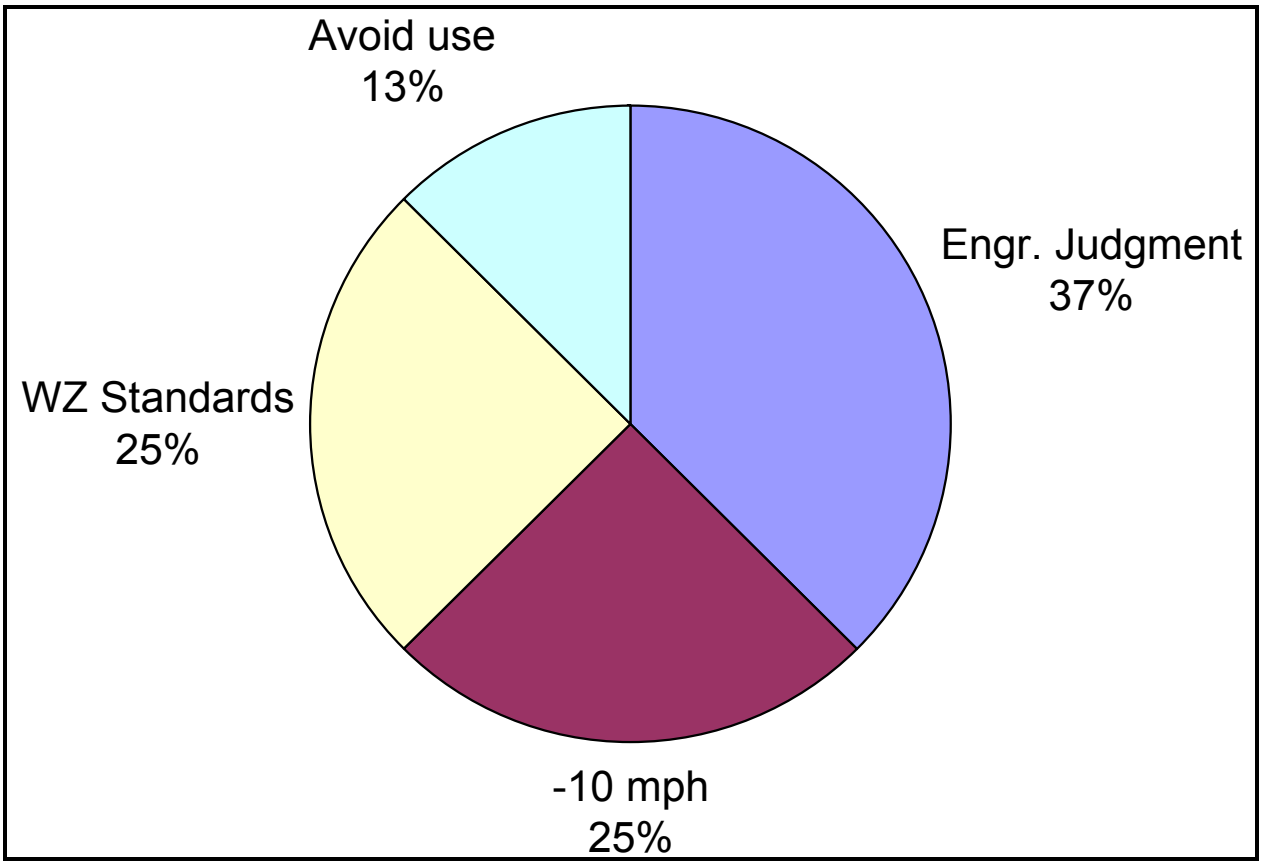

Figure 2. Answers to TxDOT Survey Question 1 *(3)*

"engineering judgment" while there were other answers given that included avoiding the use of work zone speed limits altogether.

Question 2: Do you post and remove the work zone speed limit according to the status of the actual work being performed? (For example, on a work zone 10 miles in length, do you post the work zone speed limit for all 10 miles for the entire duration of the project, or do you move the extents of the speed limit to cover the portion of the work zone where work is taking place?)

The responses to this question provided some positive feedback for the purposes of this research project. The major result that came from this question was that 9 of the 16 respondents stated that they prefer to move the WZSL with the work being performed. It was mentioned, however, that in many cases that it was the contractor's responsibility to move the signs and sometimes the contractor might leave the WZSL signs up over the entire work zone.

Figure 3 shows the results from this question. Four survey participants provided no response to this question and two revealed they post the WZSL over the entire project for the duration of the road work.

Question 8: Which of the following strategies do you use for speed control and/or improved compliance, and how effective are they?

Participants were able to select as many of the five strategies as they wished in the first part of Question 8. For each strategy selected, they were then asked to describe how effective they believed the strategy

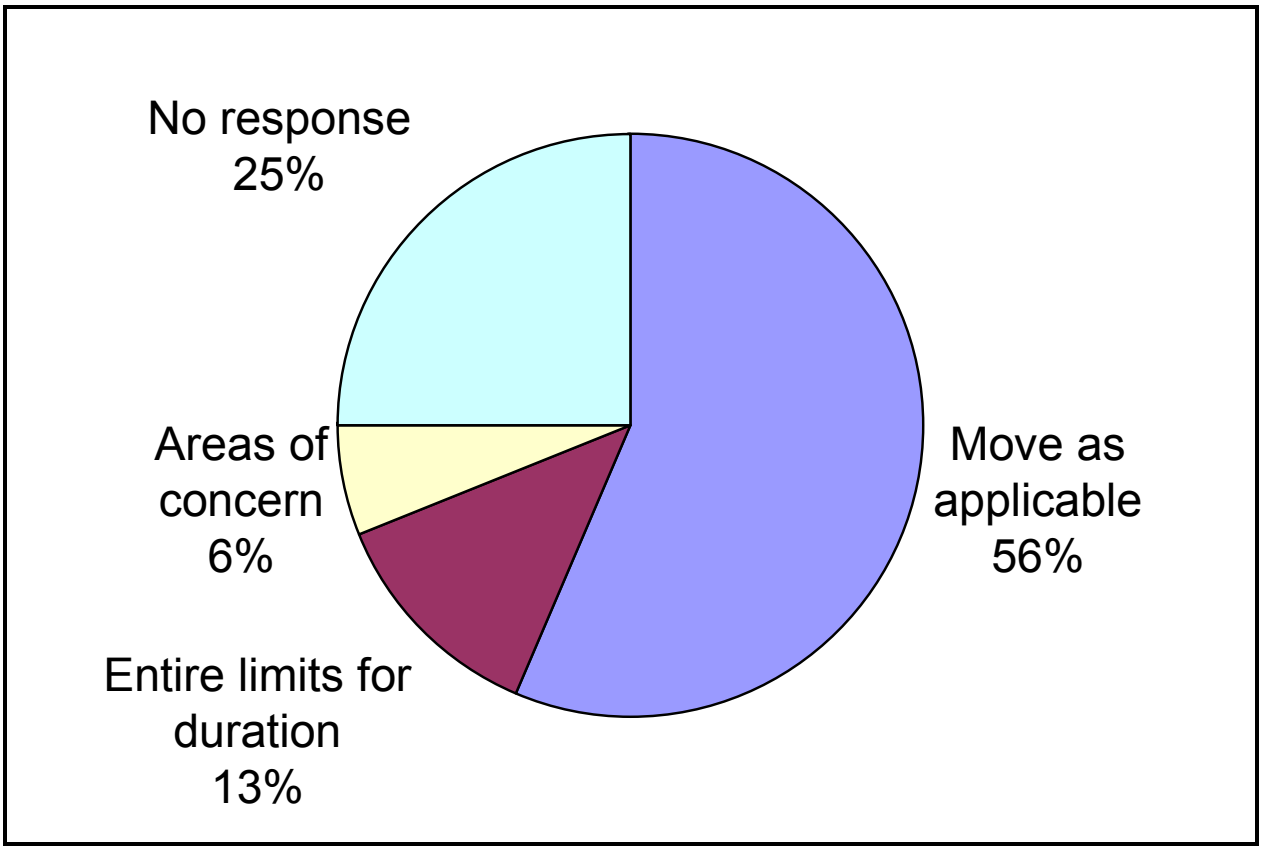

Figure 3. Answers to TxDOT Survey Question 2 *(3)*

was. However, some participants provided their opinion on the effectiveness of some strategies even if they did not indicate they had used them. There are two distributions for the second part of Question 8, one for strategy users and one for all responses. Question formatting for Question 8 is shown in Table 1 and the answer distributions are shown in Table 2.

The following list contains the comments submitted by four of the respondents after answering Question 8. They are listed in no particular order *(1)*.

- PCMS are normally placed at 1 mile in advance of the work zone speed reduction area and are very effective, usually the driver has slowed to the work zone speed limit at the PCMS or well in advance of the actual work zone.
- Our area is rural in nature. Highways such as US 75 carry a lot of traffic and they resist slowing down because it is mostly an open rural highway. It is very difficult to get motorists to adhere to the speed reductions unless there are law enforcement vehicles on project.
- Different strategies are more effective depending upon local conditions. Engineering judgment needed to select method most effective for conditions.
- Until traffic became accustomed to the trailers they were effective.

Table 1. Options Given on Question 8 *(3)*

	Have used this strategy?	Strategy was effective? (if used)		
Lane Narrowing	☐	☐ Yes	☐ Partially	☐ No
Longer Speed Zone Transitions	☐	☐ Yes	☐ Partially	☐ No
Flagging (as a Speed Control Method)	☐	☐ Yes	☐ Partially	☐ No
PCMS (as a Speed Control Method)	☐	☐ Yes	☐ Partially	☐ No
Rumble Strips	☐	☐ Yes	☐ Partially	☐ No

Table 2. Answers to TxDOT Survey Question 8 *(3)*

Question 8a (n = 16)
"Which of the following strategies do you use for speed control and/or improved compliance?"

	Responses	Percent
PCMS	10	63%
Flagging	6	38%
Lane Narrowing	4	25%
Longer Speed Zone Transitions	1	6%
Rumble Strips	1	6%
None of the Above	4	25%

Question 8b -- Users Only (n = variable)
"Was the strategy effective?"

		Yes		Partially		No	
	n	Responses	Percent	Responses	Percent	Responses	Percent
PCMS	10	4	40%	5	50%	1	10%
Flagging	6	2	33%	4	67%	0	0%
Lane Narrowing	4	2	50%	2	50%	0	0%
Longer Speed Zone Transitions	1	0	0%	1	100%	0	0%
Rumble Strips	1	0	0%	0	0%	1	100%

Question 8b -- All Responses (n = 16)
"Was the strategy effective?"

	Yes		Partially		No	
	Responses	Percent	Responses	Percent	Responses	Percent
PCMS	6	38%	5	31%	1	6%
Flagging	3	19%	4	25%	1	6%
Lane Narrowing	2	13%	3	19%	2	13%
Longer Speed Zone Transitions	1	6%	1	6%	2	13%
Rumble Strips	1	6%	0	0%	3	19%

Question 9: What other methods of influencing work zone speeds have you used? Did you find them effective?

Half of the participants stated that they used enforcement to influence work zone speeds. The wide variety of other responses can be seen in Figure 4.

The responses to the web-based survey produced some interesting results. Some of the most promising statistics to the purposes of this research project include the fact that close to 90% of the district engineers in Texas lower the speed limit in work zones and 56% already move the reduced speed limit as applicable. Another important result of the survey to be considered is the fact that 50% believe that enforcement is the single greatest tool to increase driver compliance with speed limits in work zones. This point further suggests that the "floating" speed zone research needs to be conducted in areas where enforcement is not present as it may skew the data severely. Portable changeable message signs (PCMS), flagging, and narrow lanes were all said to be somewhat effective in the survey responses. This also provides incentive to avoid construction zones with PCMS, flaggers, and narrow lanes. The presence of these may also skew the results produced in the research testing the effectiveness of the "floating" speed zones.

SITE IDENTIFICATION

Upon completion of the literature review, it came time to find work zones in surrounding areas to pursue for field studies and the development of the work zone criteria checklist. The TxDOT website offers great tools to search for and analyze current construction projects within the state. There are two links that were used to find information on current projects.

Information on project letting details was found at: http://www.dot.state.tx.us/business/schedule.htm.

Current construction reports were found at:
http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/recap/recap.htm.

Data is updated on TxDOT's website at the beginning of every month. This is important because the percentage of the job complete given on the website will not be accurate if the site is used at the end of the month. This is because construction has been occurring all month long and more of the job has been completed.

A sample posting of letting details for a project is shown in Figure 5.

The two tools available on TxDOT's website must be used together in order to receive accurate information that is up to date. The second tool available is the construction report. This document is also updated at the beginning of every month. A sample is shown in Figure 6.

After completing a search through these two sources, an Excel file housing all of the relevant information to the search was created. This file provided vital information quickly and easily.

An Excel file that was created to reference current construction jobs is shown in Figure 7.

BRAINSTORMING CERTAIN CRITERIA AND TECHNIQUES

The idea of a "floating" speed zone makes sense. Drivers can slow down for only small sections of a roadway under construction and drive the posted speed limit in the rest of the zone where machinery and

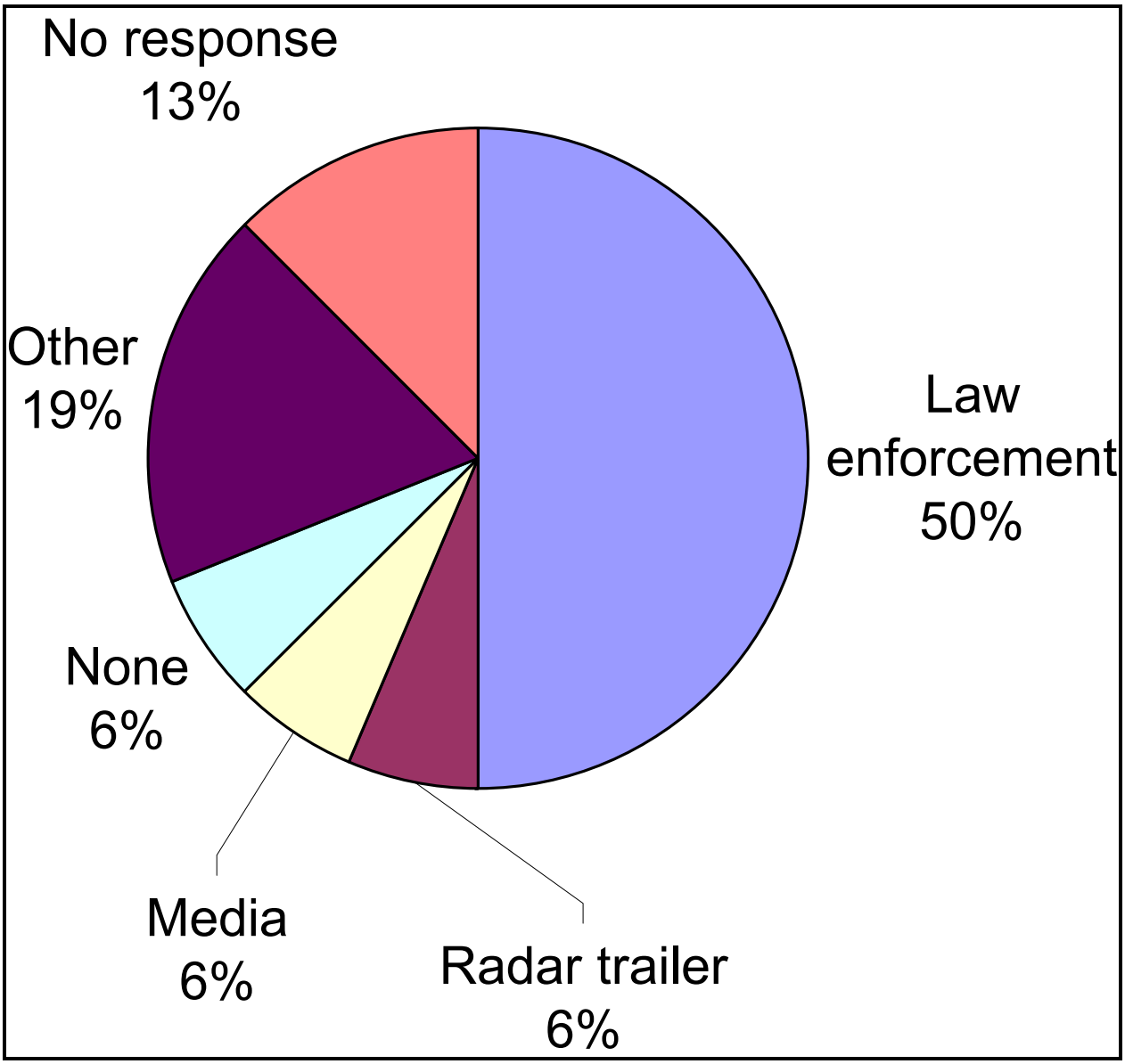

Figure 4. Answers to TxDOT Survey Question 9 *(3)*

workers are not located. But turning this idea into actual scenarios that produce results in the field is a quite a challenge.

A lot of thought was given during the early stages of this project to develop some basic criteria that a job site should meet before any research should be conducted to test the implementation of a "floating" speed zone. Preliminary thought and brainstorming resulted in a conclusion that roadways needed to be long (greater than about 8 miles), relatively straight (no sharp curves), and the construction work and machinery should be working only in a small section of the roadway at a time relative to length of the work zone. The kinds of work conducive to a moving crew working on small sections at a time include new construction and restoration jobs. The addition of a lane, for example, would involve a crew that progresses steadily forward and operates in a small area relative to the length of the roadway. Overlays

Last Update: Monday, July 5, 2004

Brazos County (FY 2004)

CCSJ: 0475-02-047

District:	Bryan	**Let Date:**	Nov-03
Highway:	OSR	**Let Status:**	Actual
Project ID:	CPM 475-2-47	**CSJ:**	0475-02-047
Description:	Seal coat consisting of a one course surface treatment	**Handling Code:**	N/A
Limits From:	FM 46	**Fund Cat.:**	1
Limits To:	The Navasota River Bridge	**Estimate:**	$257,384
Length:	10.2 Miles	**Actual:**	$199,170

Figure 5. Sample posting of letting details

and minor patch jobs on existing roadways may also meet the criteria of having a crew that moves steadily together.

Brainstorming produced some ideas for the project and helped to develop some thoughts on what kinds of construction jobs would produce sites to perform the research on. But like with many research projects, only so much can be done behind a computer. It was determined that some field observations needed to be taken at various sites to get a better feel for characterizing work sites.

DEVELOPMENT OF A DRAFT OF WORK SITE CHARACTERISTICS SHEET

Before any observations could be taken in the field, a characteristics sheet needed to be developed. This sheet was very rough in that conditions in the field were only visualized and then adjustments were made to the sheet. Thought was given to include all necessary criteria for a work zone on the characteristics sheet. Information about the job location, duration, weather, time of day, type of work being performed, various road data, room to sketch the site, room for field notes, and reminders for site identification were included on the sheet. But there is no substitute for actually getting out into the field and making observations. The sheet was taken to four work sites in the state and used to collect data. Notes and ideas were also collected throughout the day. The worksheet is shown in Figures 8 and 9.

Monthly State Let Construction Report
For Bryan District As Of Jun 9, 2004
Page 2 Of 3

Contract Identification and Information		Length	Contract Amount	Total Estimate To Date	% Complete
County	Freestone	3.67 mi	$557,011.10	$529,673.90	99.0
Highway	IH 45				
From	On WFR from 0.1 mile North of Kirvin				
To	0.3 mile North of FM 833				
CSJ	0675-01-044				
Proj ID	IM 45-2(118)				
Work Type	Grading, structures, base and surface				
Work Order	29-Oct-2003				
Work Began	15-Dec-2003				
Work Completed	99.0%				
Time Computed	15-Dec-2003				
Contract Working Days	80				
Addl Days Granted	6				
Working Days Charged	81				
Percent Time Used	94				
Contractor(s)					
BIG CREEK CONSTRUCTION, LTD.					
Subcontractor(s) for CSJ: 0675-01-044					
American Remediation Options, Inc. (1.25%)					
Statewide Guardrail Service (1.21%)					
United Rentals Highway Technologies (Austin) (6.33%)					
S & S Trucking (3.37%)					
Contract #	9033025				
	Totals	3.67 mi	$557,011.10	$529,673.90	99.0

Figure 6. Construction report

Possible Work Zones for Data Collection - Bryan District

County	Length (mi)	Highway	From	To	Percent Complete	Description
Leon	14.9	FM 831	FM 542	FM 1511	16.4	Restoration of existing road consisting of grading
Robertson	10.8	SH 6	SH 14	Sandy Creek	20.7	Seal coat consisting of a one course surface treatment

Possible Work Zones for Data Collection - Houston District

County	Length (mi)	Highway	From	To	Percent Complete	Description
Fort Bend	26.7	SH 6	US 90 A	FM 361	3.5	Base repair, planing, thin bonded friction course
Fort Bend	13	FM 762	3 mi S of FM 2759	FM 1462	25.9	Base repair, planing, ACP overlay
Harris	13.9	IH 10	Maxey	Magnolia	28.8	Clean and seal joints and pavement repair
Galveston	16.5	IH 45	Harris C/L	S SH 6	60.3	Full depth concrete repair, clean and seal joints and fill

Possible Work Zones for Data Collection - Austin District

County	Length (mi)	Highway	From	To	Percent Complete	Description
Caldwell	13.3	US 183	FM 20	6.7 mi S of FM 20	10.4	Overlay
Caldwell	23.1	US 183	FM 20	US 90	48	Sealcoat and level up

Figure 7. Excel file used to describe work zones

FIELD WORK AND OBSERVATIONS

Construction projects in surrounding districts were identified using the procedure mentioned earlier. An extensive search was performed on TxDOT's two major work zone websites and all relevant information was pooled together in an Excel file. Four active job sites were identified as good candidates for data collection. These jobs were under construction in the Bryan and Houston districts.

Significant additions to the development of the site characteristics sheet were made at each site. The following is a summary of what each site contributed to the project.

Work Zone Site Characteristics Sheet

-Criteria to determine if a "floating" speed zone test could be implemented-

JOB # _____

State		City		Site No	
Date	Time of Data Collection	Light	Weather	Comments	
County and District					
Type of Work Being Performed:					
Road(s) Under Construction:	Major Road		Minor Road/feature		
Beginning Feature/Milepoint					
Ending Feature/Milepoint				**Regular**	**WZ**
Direction (NB/SB/EB/WB)			Shoulder Width & Type		
Posted Speed Limit			Total Pavement Width		
WZSL			Median Width & Type		
Area Type (UC, UM, SR, SC)					
Number of Lanes					
Lane Width	OUTSIDE INSIDE	OUTSIDE INSIDE			
Length of Workzone					
Length of Active Work / Machinery					
Multiple Crews in Multiple Places (Y/N)					
Discuss the Nature of the Roadway (Straight, Slightly Curved, etc.) – Advisory Speeds?					
Location of CMS					
- Beacon/Flags					
- Innovative					
- Advance Warning					
Enforcement Present (Y/N)					

Figure 8. Work Zone Site Characteristics Sheet, Page One

Area Type:

- Urban mixed-use/light retail and residential (UM)
- Urban commercial (UC)
- Suburban residential or recreational (SR)
- Suburban commercial (SC)

FIELD CHECKLIST

- o Complete form
- o Draw sketch
- o Take SEVERAL digital pictures.
- o Write comments

COMMENTS:

_____

_____

_____

_____

_____

_____

SKETCH:

Figure 9. Work Zone Site Characteristics Sheet, Page 2

[Project #1]

This project was a restoration and grading job occurring in Flo, TX – Leon County. Important results from this site included:

- Emphasizing the importance of driver visibility for speed zone research,
- The road needs to be relatively straight,
- Road conditions cannot govern driver speeds for accurate research, and
- The characteristics sheet needed to have mention of the surface characteristics of the roadway.

[Project #2]

This project was a surface treatment job occurring in Calvert, TX – Robertson County. Important results from this site included:

- The realization that data needs to be collected towards the beginning of the month because that is when TxDOT's construction data is the most accurate, and
- Jobs more conducive to "floating" speed zone research may need to be more in depth than a surface treatment. Perhaps construction or reconstruction may be better suited for the research.

[Project #3]

This project included an ACP overlay and planning of an existing roadway in Crabb, TX – Fort Bend County. Important results from this site included:

- Make sure that the job construction mileage given in TxDOT's information is not a compilation of small segments of roadway, but rather a single segment of road, and
- Important note needs to be taken on the quality of the road shoulders.

[Project #4]

This project included the planing and addition of a thin-bonded friction course to an existing roadway in Sugarland, TX – Fort Bend County. Important results from this site included:

- The roadway used for research needs to be in rural areas where traffic flow is not interrupted by traffic signals, and
- Weather can become very important in driver compliance, so data needs to be collected on days where rain and other such conditions aren't playing a role in driver speeds.

DEVELOPMENT OF A FINAL SITE CHARACTERISTICS WORKSHEET

The field work performed and notes taken produced several important changes to the characteristics sheet. The Site Characteristics Worksheet shown in Figures 10 and 11 is the final draft and is the one that will be used on job sites in the fall of 2004 when work zones are being identified.

DEVELOPING A CHECKLIST OF CRITERIA FOR SITES

Throughout this project, certain criteria emerged as musts for a site to be recommended for "floating" speed zone research. The final draft of the of the work site characteristics became rather in-depth and would take extensive time in the field to complete. It was determined that a site needed to meet certain base-line criteria before it should ever be examined close enough to complete the characteristics worksheet. Twelve different criteria were established and put into checklist form (seen below). The checklist shown in Figure 12 was designed to provide a quick, easy, and effective means of checking a jobsite in the field to determine if it should be examined further with the Site Characteristics Worksheet.

CONCLUSION

If driver compliance with speed limits in construction zones goes up, crashes and fatalities in these zones will go down. As part of a larger project for the Texas Department of Transportation, this project helped to develop criteria for a work zone site to be effective for research of the "floating" speed zone.

The idea of a "floating" speed zone is a new idea in the world of transportation engineering. Therefore, the research project to come will be somewhat of a pioneering venture. Support from the Texas Transportation Institute and the TxDOT are both vital to the success of the project. Work zones in nearby areas will be identified and examined. Using techniques presented in this report, a determination of whether or not to use the site will be made. A work zone meeting the criteria given in this report has a good chance of producing results in the data collection phase of this project.

Hopefully, this research project will contribute significantly to future research in the area of work zone safety. Characteristic sheets, checklists, and criteria developed in this project will all be used this fall during the data collection phase of the TxDOT project and hopefully, they will continue to be used in the future for other projects.

Texas Transportation Institute

Site Characteristics Worksheet

Project 0-4707

State:	City:	Site No:
County:	District:	Date:
Time of Collection:	Light:	Weather:

Type of Work Being Performed:		
Road(s) Under Construction:		
Beginning Feature (Milepoint):		Ending Feature (Milepoint):
Length of Workzone:		Length of Active Work/Machinery:
Multiple Crews in Multiple Places (Y/N): (If yes, at what spacing?)		
Area Type:		

Direction (NB/SB/EB/WB):		
Posted Speed Limit:		
WZSL:		
Surface Conditions of Roadway:		
Number of Lanes:		
Lane Width:		
Shoulder Width & Type:		
Total Pavement Width:		
Median Width & Type:		

Discuss the Nature of the Roadway: (Straight, Slightly Curved, etc.) Include Advisory Speed Limits	
Location of CMS	
Beacons/Flags	
Innovative	
Advance Warning	
Enforcement Present (Y/N)	

Figure 10. Site Characteristics Worksheet, Page 1

SKETCH:

COMMENTS:

FIELD CHECKLIST:

- ✓ Complete the front side of the form
- ✓ Draw a sketch of the construction zone
- ✓ Include comments about the roadway and various conditions not covered in the form
- ✓ Take several digital pictures

Figure 11. Site Characteristics Worksheet, Page 2

Work Zone Criteria Checklist - Job #4707

Date:	Roadway:	Time of Day:
County:	City:	% of Job Completed:
District:	State:	Expected Completion Date:

	YES	NO
Does the construction crew/machinery move with the work?		
Is the roadway under construction longer than 8 miles?		
Is there a posted Work Zone Speed Limit?		
Is there good driver visibility on the road?		
Is the roadway straight for the most part?		
Is there enforcement present?		
Are there multiple crews in multiple places?		
Is the road under construction in a rural area?		
Is a flagger being used to move traffic around the work?		
Are CMS, beacons, or flags being used on the roadway?		
Are lane widths or surface conditions controlling speeds?		
Is there a shoulder on the roadway?		

Field Notes:

Does this job site make a good candidate for "floating" speed zone research?
Why or why not?

Figure 12. Work Zone Criteria Checklist

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1. Texas Department of Public Safety Crash Data CD-ROM, 2000.

2. Daniel, J., M. Clements, and J. Dawkins. *Evaluation of Enhanced Traffic Control of Construction Zones*. Georgia Department of Transportation Project 9403, Georgia Institute of Technology, Atlanta, 1995.

3. Brewer, M., and M. Jacobson. *Development of Measures for Motivating Drivers to Comply with Speed Limits in Work Zones*. Technical Memorandums 4707-1 to 4707-4, submitted to Texas Department of Transportation, Texas Transportation Institute, College Station, Texas, Spring 2004.

DANIEL KRIER

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A COMPARISON OF ERRATIC TRAFFIC BEHAVIOR AT CONGESTED DAYTIME AND NIGHTTIME WORK ZONES

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SUMMARY

Highways in big cities such as San Antonio, Dallas, and Houston experience significant high traffic volumes. As a result of travel lane closures due to either work zones or traffic incidents, there can be excessive traffic congestion. The implementation of nighttime work zones has increased in order to avoid situations when traffic volumes are highest. Although working at night does typically result in less traffic congestion than would have occurred if the work had been done during the day, there is a concern about the relative safety risks of nighttime work activities for both workers and drivers. In particular, it is hypothesized that erratic traffic behaviors may be more frequent at nighttime work zones, especially when queues are still created. The increase in erratic behaviors at nighttime might occur because of factors such as less visibility, less worker and driver alertness and higher traffic speeds.

This paper describes a study of nighttime and daytime erratic traffic behaviors at work zone lane closures on high-volume freeways. Three types of erratic behaviors were identified and compared by work zone location. Two nighttime work zones were evaluated where traffic queues did not form, and one daytime work zone was monitored where a traffic queue did occur. Because of a nighttime work zone where a traffic queue formed was not identified for evaluation during the conduct of this study, researchers obtained videotape data of queue formation at two recurrent congestion locations in Dallas under both daytime and nighttime viewing conditions. The analysis indicated that, for the recurrent congestion queue locations, the nighttime average erratic behavior rate was 28 percent higher than the daytime average erratic behavior rate. Comparison of the work zone data indicated that the daytime work zone where a traffic queue formed experienced a much higher erratic behavior rate compared to nighttime work zone without a queue creation.

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INTRODUCTION

The constant use of roads for an efficient transportation system has increased due to population development needs. The cost of congestion has continued to rise, as recently estimated by the Texas Transportation Institute (*1*). In addition, the continuous growth of traffic congestion presents a serious hazard; it can affect some important aspects such as productivity and competitiveness of the Nation's economy, environment, and quality of life for workers (*2*). As a result of their continuous use, maintenance and construction of highways and freeways has become more frequent. Both maintenance and construction activities can require long work periods depending on the amount and type of road damages. To avoid periods of heavy traffic during the day, the implementation of nighttime work in road maintenance and construction activities has increased dramatically over the last few years and will continue to grow out of necessity (*3*).

Nationally, several states are increasing nighttime work zone activities. For example, New Jersey has seen the implementation of nighttime work on maintenance and construction zones increase approximately 25 percent in the last five years *(2*). Another state that is experiencing increased nighttime work zone implementation is Texas in cities such as Dallas, San Antonio, and Houston because all have high traffic volumes on most facilities. These highways and freeways where work zones take place will cause tremendous congestion at any time of day. Consequently, there is significant public pressure to perform road work at night.

There are valid reasons for performing nighttime work. First, traffic volumes at night are usually lower than during the day. This factor helps to reduce traffic congestion and make traffic management easier. As a result of less traffic congestion, there is also a reduction of environmental pollution (*4*). Second, nighttime versus daytime work zones can reduce the economic impact caused when the road is under maintenance and/or construction activities. Third, less traffic means better access and control in the transportation of materials to the work zone, which can help increase productivity of work activities. Fourth, lower temperatures in summer at nighttime versus daytime can actually create a more pleasant working atmosphere for workers.

The above factors notwithstanding, the decision to perform work at night is most often because of economic impact. This impact exists in terms of additional road use which increase costs for motorists (due to increased fuel consumption, vehicles wear, and value of time for the delays created) and the reduction in business productivity due to longer delivery times less reliable part deliveries, and so on. However, the decision is many times made without considering the potential impact upon safety, as very little objective data exist upon which to make such a consideration. Previous research has suggested that nighttime accidents during roadway construction were 37.4 percent greater than before construction. On the other hand, accidents during the daytime in the construction zone increased by only 24.4 percent. (*5*). However that study did not attempt to specifically compare the influence of actual night work activity upon accident risk. Certainly, other factors such as narrower lanes, elimination of shoulders and entrance ramp acceleration lanes could all have created more difficult driving for motorist at night and led to the more significant increase in accidents.

Nighttime work zones can create several types of potential safety problems. First and most obvious, nighttime brings a reduction of visibility for both drivers and workers. This loss of visibility affects the detection of work at a distance and conspicuity of traffic control devices (*1*). Such a loss in visibility at night can be particularly critical for drivers who need greater visibility to have adequate time to react to the unexpected situation such as traffic queues that nighttime work activity presents. Second, some studies showed that there are a higher percentage of drivers under the influence of alcohol and drugs at night than during the day. Both of these substances influence driver alertness. (*4*). Third, due to the low traffic volume, drivers can travel at higher speeds at night than during the day, which reduces the amount

of time that a driver has to react once detecting a potential hazard such as the presence of a work zone (*4*). This characteristic can be particularly problematic when the work zone creates an upstream queue.

In conclusion, nighttime work zones can create safety concerns for workers and drivers. Unfortunately, few studies provide useful information about how risky nighttime work activities are compared to daytime work zones. Without objective measures of the relative difference in risk, it is difficult to consider safety concerns in the decision whether or not to work at night. To address this lack of objective measures, the research project described in this paper was undertaken to understand how the rate of erratic traffic behavior compare at congested areas during both daytime and nighttime periods, especially when a traffic queue is present.

HYPOTHESIS

Nighttime and daytime conditions can be a changeable factor in erratic traffic behaviors at congested work zones. In addition, it is possible that nighttime work zones with a queue formation are unsafe for the reason that erratic traffic behaviors can have a higher frequency rate at nighttime than daytime. Some erratic traffic behaviors, which are caused at the upstream end of congested zones, are near misses, hard braking, and collisions. The increase of those behaviors at nighttime work zones creates dangerous conditions for both workers and drivers.

There are some factors, which can increase erratic traffic behavior frequency at nighttime work areas. First, there is the perception that traffic moving through work zones at night traveling at higher speeds (*3*). Second, the visibility of drivers may be less because of the dark environment. (*1*) Third, the traffic queue formation may adversely impact the safety of work zones at nighttime. And finally, some studies show that there are more tired and drunk drivers at nighttime than daytime.

OBJECTIVES

This research project had two objectives.

- To perform a study of nighttime and daytime work zones where congestion is present. This study is focused on identifying and quantifying erratic traffic behaviors at the upstream end of traffic queues.
- To obtain and compare the frequency rates of erratic traffic behaviors that occurs in daytime and nighttime work zones.

PROCEDURE

A series of steps were followed for a successful achievement of the objectives for this project. The steps are described below and were followed in a chronological sequence.

Identification of Study Sites

Researchers queried personnel from various TxDOT districts to identify suitable study sites. The initial goal was to find four active nighttime work zones and four daytime work zones for accurate comparison of erratic behavior rates. Emphasis was placed on locating active work zones where traffic queues were likely to form, as researchers believed that the boundary between high-speed approaching traffic and slow-speed traffic moving through the queue was the primary condition that would create erratic traffic behaviors.

Two nighttime work zones were located in Dallas and San Antonio Districts. Unfortunately, neither work zone created significant congestion and queuing. Consequently, it was not possible to assess the effect of nighttime work zones that create an unexpected traffic queue upon the rate of erratic traffic behaviors. Researchers were not able to find other nighttime work zones within the available study duration. In addition to the two nighttime work zone study sites, researches identified a useful active daytime work zone with a queue formation in Waco District when they were traveling from Dallas to San Antonio with purposes of collecting data from those places. Since nighttime traffic queue conditions due to work zone activity could not be located, researchers decided to use two recurrent congestions bottlenecks on Dallas highways for analysis purposes in this study. Videotape data of the upstream end of the traffic queue at these bottlenecks had previously been collected on a different research study. Researches obtained videotape data of recurrent congestion bottlenecks that occurred during both nighttime and daytime viewing conditions.

Obviously, each site studied has its own set of road characteristics that can also influence traffic behaviors (in addition to the presence of a traffic queue). To the extent possible, researchers attempted to identify the differences that existed between study sites that may have also affected behaviors. Those characteristics include the following:

- Time,
- Lanes closed,
- Number of lanes, and
- Rural vs. urban environment.

Experimental Plan

The main work activity in the data collection of both the work zone lane closures (field studies) and the analysis of recurrent congestion bottlenecks (videotape analyses) was to observe the erratic traffic behaviors, count traffic volume using a clipboard counter and document the work zone characteristics with the use of a digital video camera and distance-measuring instrument (DMI). In favor of a good organization of data, three different forms where used to collect all the information needed. Data collection forms can be viewed in Appendix C.

Three important facts were collected:

- Erratic traffic behaviors,
- Traffic volume for every fifteen minutes, and
- Road characteristics.

The description of the erratic maneuver categories identified is as follows:

- **Near Miss** – when a vehicle either changes lanes drastically or goes to the shoulder to avoid almost hitting the vehicles in front of it which are in the queue.
- **Hard Braking** – when excessive pitch of a vehicle or close spacing between it and the vehicles ahead of it after stop (listen for locking up of tires) was observed.
- **Collision** - any accident that involves work vehicles or workers, or between two vehicles at the upstream end of the queue (no such accidents were actually observed in any of the studies).

Data Collection

Two different methods were followed for collecting data, depending on whether the site was a work zone activity (i.e., a field study) or a site where recurrent congestion was evaluated (videotape analysis). A summary of the data collection sites is shown in Figure 1.

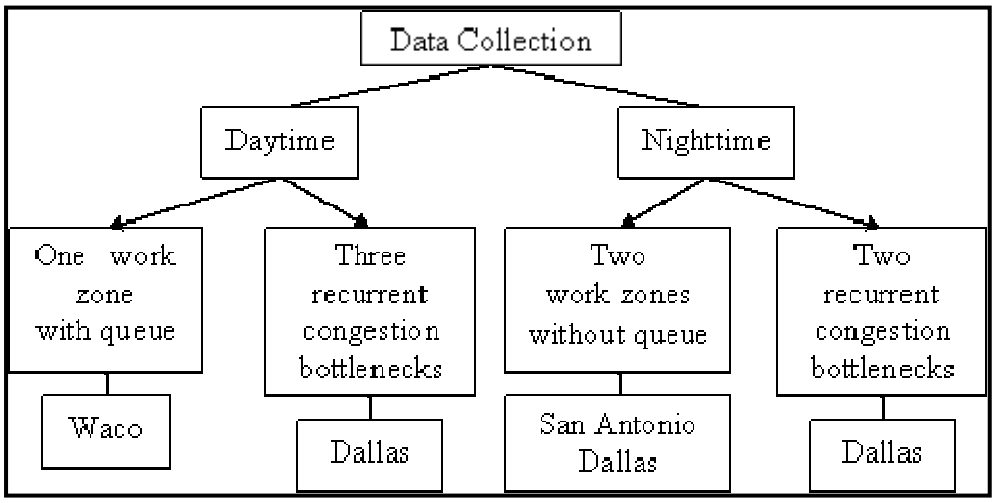

Figure 1. Data Collection Locations

Recurrent Congestion Bottleneck Sites

Three daytime and two nighttime recurrent congestion bottlenecks were used in this study. The site where daytime data were obtained was located on US 75 and nighttime site where located in I 35 both of them in Dallas, TX. Each time period was six hours long, from 2:00 p.m. to 8:00 p.m. Eight videotapes of each group (daytime and nighttime) were checked for pertinent data; however, only three of them were useful for daytime and two for nighttime. The main characteristic of interest was the formation of a traffic queue within the available view on the videotape. One of the difficulties in observing erratic behaviors is that the camera does not move continuously to show the upstream end of the queue as it increases or decreases along the roadway section. After selecting the useful videos, each one was watched three times total.

The first time helped to identify the exact time when the traffic queue starts. In almost all the videos, traffic congestion time duration was about 2 hours long. During the second pass through the video, researchers collected traffic volumes in fifteen minute periods. And finally, erratic behaviors were observed during the third pass through the videotape. The duration to view the video was longer this third time in order to record erratic behavior category, time, and description.

Active Work Zones Sites

The active work zone data collection process was more complicated as it involved actual field studies rather than use of previously-recorded videotape data. The field studies required the collaboration of 6

data collection personnel at the three different locations. Three vehicles were also used for data collection; two people were in each one. Each team was located at a specific point along the roadway to observe the formation/dissipation of the queue. The researchers adjusted their location as necessary as the queue grew or shrank in order to continue observing the end of the queue. For the organization and uniformity of the collected data, the information was documented on three different data forms (see Appendix C).

Figure 2 illustrates the method used to collect active work zone data.

- Car A was located close to the lane closure so that researchers could observe and collect the erratic behaviors at the upstream end of the queue.
- Car B was located behind car A and researchers in this car collected the traffic volume.

- Researchers in car C collected road characteristics of the site, and occasionally drove through the queue as the green path shows in Figure2 to obtain information on work activity and traffic control device location.

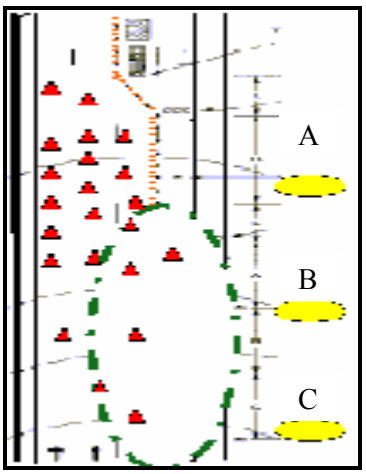

Figure 2. Active Work Zone Data Collection Method

Analysis

The analysis of the data was conducted by determining the total traffic volume observed for each field study or videotape that was evaluated. Second, the total erratic behavior frequency was summed across each behavior category (near miss, hard braking, and collision) and divided by the total traffic volume for that site. This process thus yielded the erratic traffic behavior rate which is the number of erratic behaviors per 1000 approaching vehicles per site, and is shown in Figure 3. In addition, another calculation was solved such as traffic volume average for each site. After that those calculations, daytime and nighttime erratic behavior rates were compared. For more information about total traffic volumes and erratic behaviors for each site see Appendix A.

RESULTS

The main analyses for this research project were the following interest areas:

- Erratic behavior rate for daytime recurrent congestion bottlenecks,
- Erratic behavior rate for nighttime recurrent congestion bottleneck.,
- Erratic behavior rate for nighttime work zones (uncongested, no queuing), and
- Erratic behavior rate for daytime work zones (congested, queuing present).

Daytime Traffic Behavior Rates

There are some different characteristics between the three daytime recurrent congestion bottlenecks and the active daytime work zone sites that influence their erratic behaviors rates. First, I35-W is a four-lane freeway; on the other hand, US75 is 10-lane highway. Second, the traffic volume average for US75 is 1950 vehicles every 15 minutes and I35-W has a traffic volume average of 350 vehicles every 15 minutes. An important factor contributing to the high erratic behavior rate at I35-W daytime work zone site is the location of the lane closure. It was located just beyond a hill, which consequently surprised many approaching motorists as they reached the upstream end of the traffic queue. Although there are road

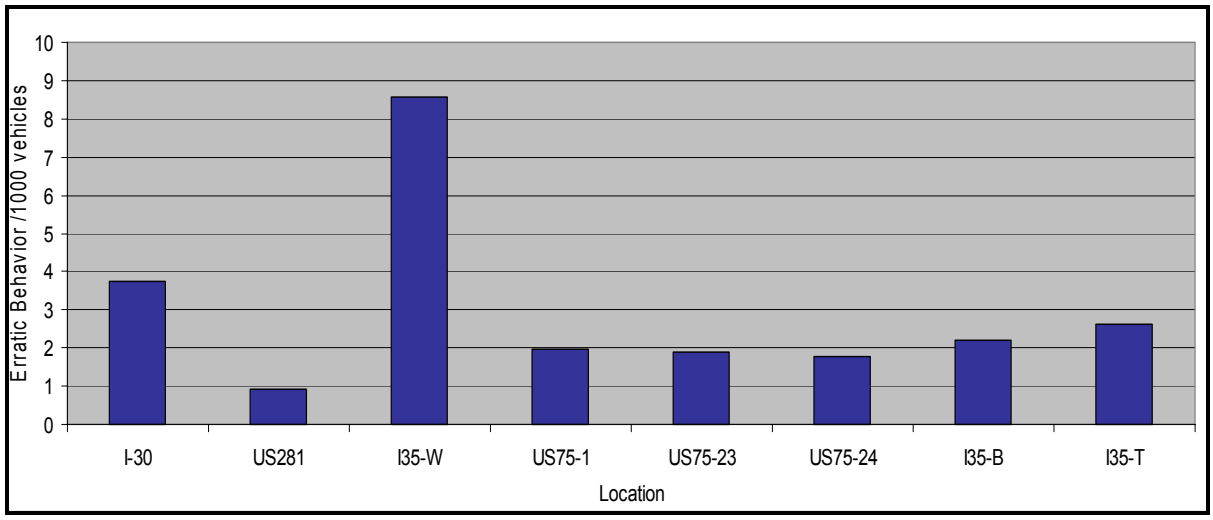

Figure 3. Erratic Behavior Rates

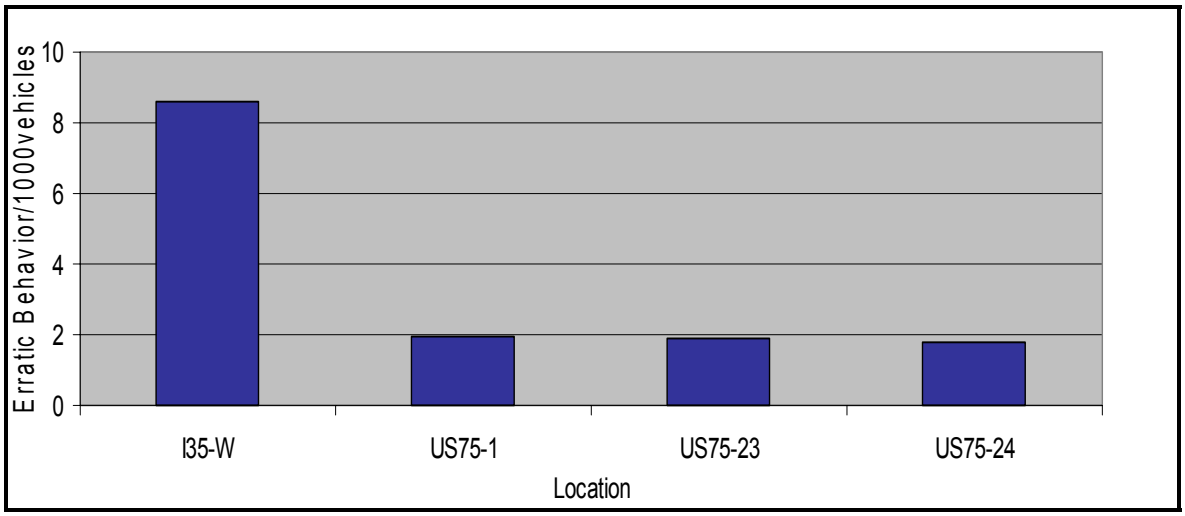

Figure 4. Daytime Erratic Behavior Rates

differences in the studies, it is believed that the lane closure location is the reason why the erratic behavior rate for I35-W is higher than the average rate of US75 at daytime. It is clear in Figure 4 that a good traffic behavior average rate for US75 is approximately two erratic maneuvers per 1000 vehicles based on the fact that the three different bottleneck studies have very similar erratic behavior rates.

Nighttime Traffic Behavior Rates

Nighttime data is evaluated for four different studies. They are divided in two groups because of their characteristics. The first group is for I-30 and US281, which were field data collection sites. Both roads were under either maintenance or construction activities. I-30 is a rural four-lane freeway located east of Dallas, TX. This site experienced a traffic volume of about 800 vehicles per hour during the time of the field study. US281 is a six-lane freeway, located in San Antonio, TX. This site experienced a traffic volume of about 1760 vehicles per hour. The second group was composed of two bottleneck locations on I-35 in Dallas, TX. These bottlenecks were from different dates and locations in a 10-lane freeway section. Both bottleneck locations had similar traffic volumes, averaging of 6860 vehicles per hour during the times of the study.

Note that the two first columns from Figure 5, which correspond to active work zones without traffic queue formation, have very dissimilar erratic behavior rates. The influencing factor in these two varying inaccurate erratic behavior rates could be the work zone characteristics. At the I-30 active work zone, the traffic was mostly big trucks with traveling at high speeds. It affected drastically the traffic flow and increased erratic behaviors. On the other hand, the procedure followed at the lane closure at US281 was very efficient and therefore traffic at no time formed a queue and the traffic control was carried out by police reducing traffic speed considerably. The two last columns are the bottlenecks locations, which display close results in terms of the erratic behavior rates.

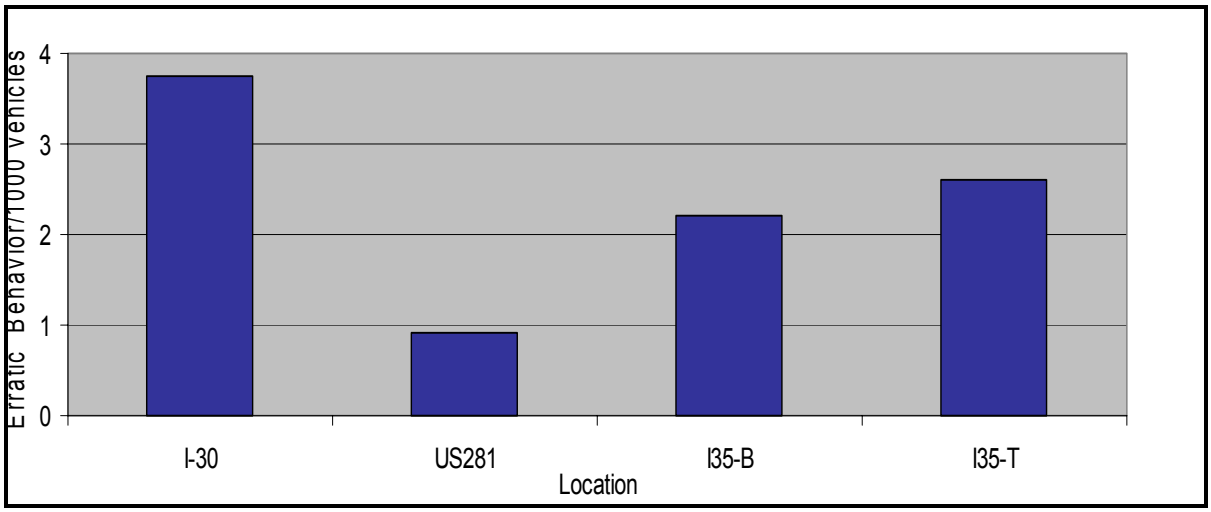

Figure 5. Nighttime Erratic Behavior Rates

Comparison of Daytime Vs. Nighttime Traffic Behavior Rates

Since a nighttime work zone location where a queue was present could not be found, only daytime and nighttime data from the bottleneck locations could be compared directly. The results of each location (US75-1, US75-23, US75-25) were combined and compared to the rate of the average of two nighttime bottleneck locations (I35-B and 135-T). The results of this analysis are presented in Figure 6. Overall, researchers estimated that the bottleneck locations experienced 1.88 erratic behaviors per 1000 approaching vehicles during daytime viewing conditions. Conversely, researchers estimated that the bottleneck locations at night experienced 2.41 erratic behaviors per 1000 approaching vehicles. In other words, the erratic behavior rate at the nighttime bottleneck locations was 28 percent higher than the day time bottleneck location.

Work Zones Erratic Behavior Rates

The data of the three work zone were taken in the field. It was noted that those sites did not have similar road characteristics between them. There was one daytime work zone a with traffic queue (I35-W) and two nighttime work zones without traffic queues (I-30 and US281). The I35-W daytime work zone was located in the Waco District. It was a four-lane rural road and had approximately a one-half mile lane closure. This site had a high erratic behavior rate of 8.6 because of its road characteristic set mentioned before.

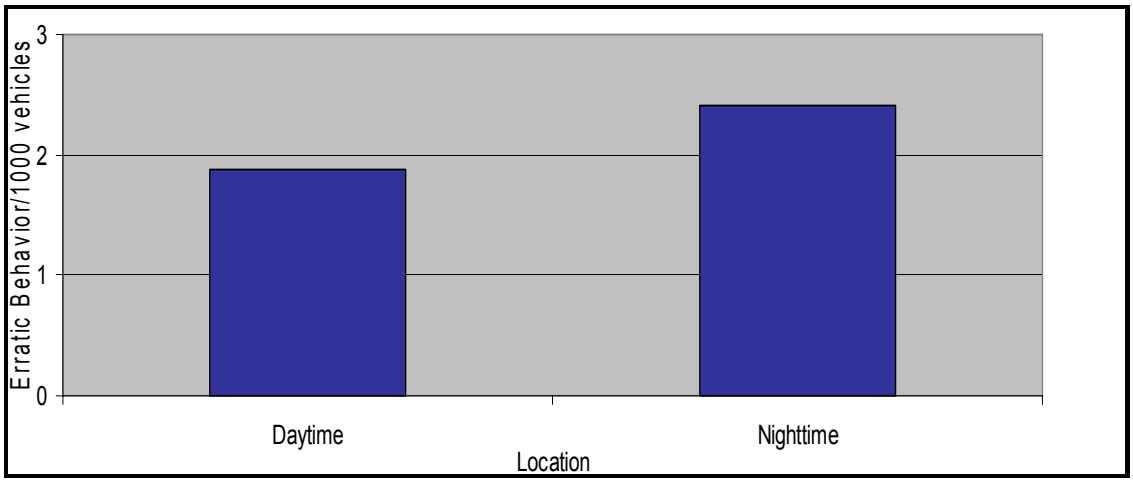

Figure 6. Daytime vs. Nighttime Erratic Behavior Rates

The I-30 nighttime work zone was located in the Dallas District. It is a four-lane suburban road and had an erratic traffic behavior rate of 3.8 as shown in Figure 7. During data collection, traffic was free-flowing and never formed a traffic queue. The US281 nighttime work zone was located in San Antonio on a six-lane freeway. The main reason why it had a lower erratic traffic behavior rate of 0.91 was due to a good lane closure set up method. Two of the inside lanes were closed, but not at the same time and the presence of police helped to reduce traffic speed at the work zone limits. In addition, the beginning of the lane closure was located at one exit ramp which helped to prevent traffic congestion. It is believed that the continuous use of dynamic message sign messages during daytime to inform motorist about the nighttime lane closure duration reduced traffic volume on the freeway. In conclusion, the main reason of the result variations is due to the traffic queue formation and their own road characteristics.

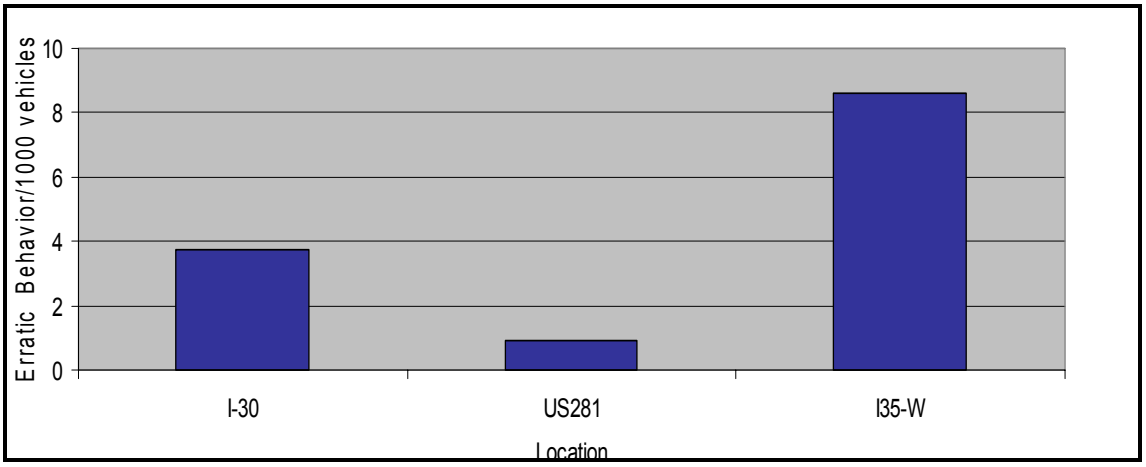

Figure 7. Work Zones Erratic Behavior Rates

CONCLUSION

After completing the analysis of the results from this project, it is obvious that site differences can considerably influence the erratic behavior rate for each site. Because of the diversity of the eight study locations, there are some interesting conclusions.

- The formation of a traffic queue at an active work zone increases erratic traffic behavior rates. For example, the I35-W daytime work zone with a traffic queue formation had the highest traffic behavior rate of 8.59. On the other hand, US281 nighttime work zone, which did not have any queue formation, has a 0.91 erratic behavior rate, which is the lowest one of all the locations. As a result, daytime work zone with traffic queue formation created a 287 percent higher erratic behavior rate than nighttime work zones without any queue formation (see Figure 9 in Appendix B).
- Night and day are another influencing factors for erratic behavior rates. Bottleneck locations were selected to make a better comparison between nighttime and daytime traffic behavior rates. The bottlenecks for daytime and nighttime groups have the similar characteristics such as road and locations. The daytime bottleneck group was formed for three studies and the nighttime group was formed by two studies. The results show that the average of the nighttime recurrent congestions had a 28 percentage higher erratic behavior rate than the daytime recurrent congestion average (see Figure 6 in Appendix B).
- The last comparable factor is traffic queue formation. The average of the daytime recurrent congestion bottlenecks, which was composed by three sites, was compared with the daytime active work zone with queue formation. These sites have different road characteristics, such as number of lanes and a lane closure. As a result, daytime work zone queue caused a 356 percent higher erratic behavior rate than daytime recurrent congestion (see Figure 8 on Appendix B).
- The road number of lanes is a variable reason in erratic behavior category frequency. Three of the studies are four-lane roads and the other sites are six or ten-lane roads. In the two-lane road the frequency of hard braking was higher than near-miss behavior. Due to the fewer number of available lanes on the two-lane road, the motorists may not have the opportunity to change lanes when they perceived the queue end. In some occasions, a number of drivers took the shoulder avoiding hitting cars in front of them which were forming the end of the traffic queue. On the other hand, on the ten-lane road motorists have more opportunity to change lanes before making a hard braking maneuver.
- Nighttime can be another factor in erratic behavior category frequency because of motorists' reduced visibility. At nighttime, motorists make more hard braking behaviors than at day. It is believed this is because motorists do not have enough visibility in their sides, they only can see without any problem at the front. When motorist perceive a traffic queue end the easier maneuver that they do due to reduced visibility is a hard braking to avoid hitting cars which form the end of the queue.

ACKNOWLEDGEMENTS

Now, it is the space to thank all the people that helped me during my research project process. The successful project result would have not been possible without the knowledge, and experience of these people. I would like to make a special mention of two people that were always available to help me and answer all my questions. They made this experience very exciting and significant in my life. They are my mentors Brooke and Gerald Ullman. I would like to thank the following people for their help in data collection and comments.

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- Brett Story,
- Melisa Finley,
- Dr. Conrad Dudek, and
- Steven Schrock

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APPENDIX A

Active Nighttime Work Zone Summary

Table A1. Road Characteristic Information

Date	7/6/2004
Time	8:00 AM
District	Dallas
Location	IH-30 West Rockwell TX. near 549
Weather	PC
Roadway Type	Freeway
Land Use	Rural
No. of Lanes Total	2

Table A2. Erratic Behavior

	Erratic	**Traffic**	**Behavior**
	Near miss	Hard braking	Collision
TOTAL	0	3	

Table A3. Traffic Volume

1-inside	**2**	**3**	**4**	**5**	
97	701	0	0	0	TOTAL OF EACH LANE
				798	TOTAL TRAFFIC
				1:00	TOTAL TIME

Table A4. Road Characteristic Information

Date	7/7/2004
Time	10:00pm
District	San Antonio
Location	US 281 NB Between J-Ment and I-410 exit
Weather	PC
Roadway Type	Fay
Land Use	Urban
No. of Lanes Total	6
No. of Lanes Closed	1 at 9:30pm and 2 at 10:00pm

Table A5. Erratic Behavior Rates

Time	**Erratic**	**Traffic**	**Behavior**
	Near miss	Hard braking	Collision
TOTAL	0	2	

Table A6. Traffic Volume

1-inside	**2**	**3**	**4**	**5**	
9:21 closed					
	10:00 closed				
39	543	1620	0	0	TOTAL OF EACH LANE
				2202	TOTAL TRAFFIC
				1:35	TOTAL TIME

Active Daytime Work Zone Summary

Table A7. Road Characteristic Information

Date	7/7/2004
Time	11:55 AM
District	Waco
Location	I-35 NB
Weather	PC
Roadway Type	Freeway
Land Use	Rural
No. of Lanes Total	4
Significant number of truck are using exit at Chatt Rd. to direct reduce conflicts at read to stop abruptly.	

Table A8. Erratic Behavior

Time	**Erratic**	**Traffic**	**Behavior**
	Near miss	Hard braking	Collision
TOTAL	8	13	0

Table A9. Traffic Volume

1-inside	2	3	4	5	
1118	1328	0	0	0	TOTAL OF EACH LANE
				2446	TOTAL TRAFFIC
				1:35	TOTAL TIME

Daytime Recurrent Congestion Bottleneck Summary

Table A10. Road Characteristic Information

Top VCR
4/23/2002
US 75 NB
Quad screen
2:30-8:30

Table A11. Erratic Behavior Rates

Time	**Erratic**	**Traffic**	**Behavior**
	Near miss	Hard braking	Collision
TOTAL	15	10	0

Table A12. Traffic Volume

1-inside	**2**	**3**	**4**	**5**	
3237	3231	3152	3256	2294	TOTAL OF EACH LANE
				15170	TOTAL TRAFFIC
				2:00	TOTAL TIME

Table A13. Road Characteristic Information

Top VCR
4/24/2002
US 75 NB
Quad screen
2:30-8:30

Table A14. Erratic Behavior Rates

Time	**Erratic**	**Traffic**	**Behavior**
	Near miss	Hard braking	Collision
TOTAL	9	16	0

Table A15. Traffic Volume

1-inside	**2**	**3**	**4**	**5**	
3843	3859	3836	3901	2678	TOTAL OF EACH LANE
				18117	TOTAL TRAFFIC
				2:15	TOTAL TIME

Table A16. Road Characteristic Information

Top VCR
5/1/2002
US 75 NB
Quad screen
2:30-8:30

Table A17. Erratic Behavior Rates

Time	**Erratic**	**Traffic**	**Behavior**
	Near miss	Hard braking	Collision
TOTAL	12	7	

Table A18. Traffic Volume

1-inside	**2**	**3**	**4**	**5**	
2010	2031	1992	2114	1592	TOTAL OF EACH LANE
				9739	TOTAL TRAFFIC
				1:15	TOTAL TIME

Nighttime Recurrent Congestion Bottleneck Summary

Table A19. Road Characteristic Information

VCR1	
Tuesday PM	Wednesday AM
10/27/1998	10/28/1998
IH 135	
Quad screen	

Table A20. Erratic Behavior Rates

Time	**Erratic**	**Traffic**	**Behavior**
	Near miss	Hard braking	Collision
TOTAL	2	21	

Table A21. Traffic Volume

1-inside	**2**	**3**	**4**	**5**	
1576	1995	2213	2268	2411	TOTAL OF EACH LANE
				10463	TOTAL TRAFFIC
				1:30	TOTAL TIME

Table A22. Road Characteristic Information

VCR1	
Tuesday PM	Wednesday AM
10/27/1998	10/28/1998
IH 135	
Quad screen	

Table A23. Erratic Behavior Rates

Time	**Erratic**	**Traffic**	**Behavior**
	Near miss	Hard braking	Collision
TOTAL	1	21	

Table A24. Traffic Volume

1-inside	**2**	**3**	**4**	**5**	
1366	1742	1648	1803	1874	TOTAL OF EACH LANE
				8433	TOTAL TRAFFIC
				1:35	TOTAL TIME

APPENDIX B

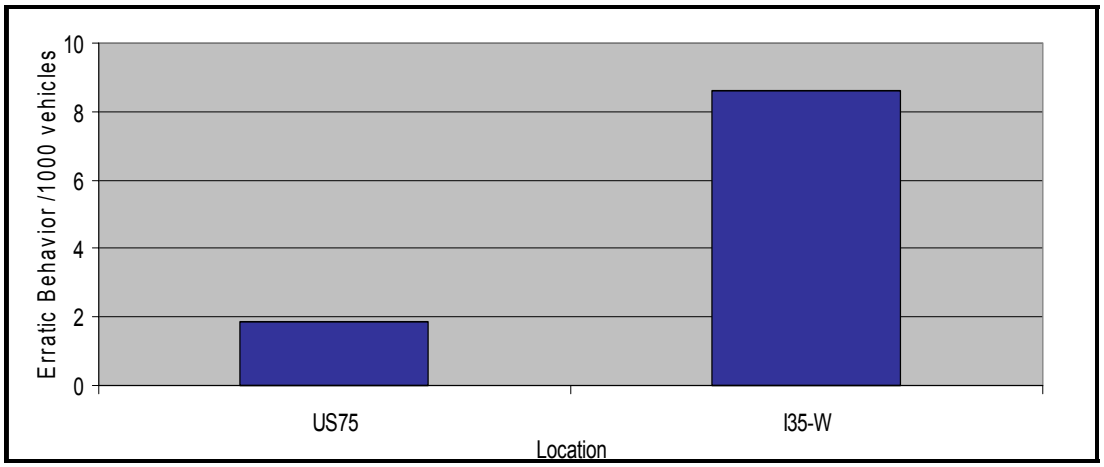

Figure B1. Daytime Bottleneck and Work Zone Erratic Behavior Rate

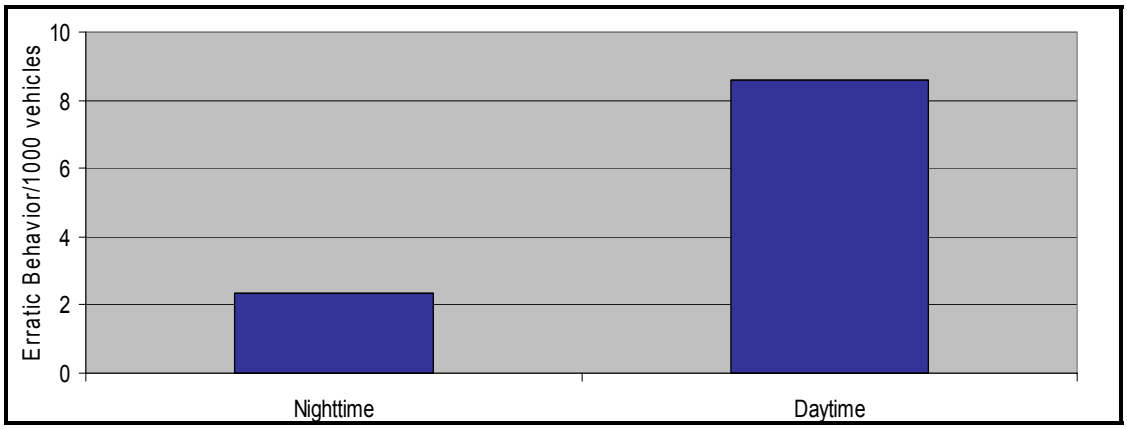

Figure B2. Work Zone Nighttime (no-queue) vs. Daytime (queue) Erratic Behavior Rate

APPENDIX C

Erratic Behavior Form

District:_____ Site #:_____
Recorder:_____
Weather:_____

ERRATIC MANEUVERS

Date:_____ Start Time:_____ End Time:_____
Location Data Collected:
Location Description:

Time	Type of Maneuver			Description
	Near Miss	**Hard Braking**	**Collision**	

Notes:

Traffic Volume Form

Project 0-4747 Summer 2004
District:_____ Site #:_____
Recorder:_____
Weather:_____

VOLUME COUNTS

Date:_____ Start Time:_____ End Time:_____
Location of Count:

Time		**Cumulative Volume**									
		1 - Inside		**2**		**3**		**4**		**5 - Outside**	
From	**To**	**PC**	**CV**	**PC**	**CV**	**PC**	**CV**	**PC**	**CV**	**PC**	**CV**

Comments:

Road Characteristics Form
Project 0-4747 Summer 2004
District:_____ Site#:_____
Recorder:_____ Weather:_____

FIELD OBSERVATIONS DATA COLLECTION FORM

Date:_____ Time:_____ District:_____ Site #:_____

Location: _____

Weather: _____

ROADWAY CHARACTERISTICS

Roadway Type:_____ Land Use: Urban Rural Suburban

No. of Lanes (total): _____ No. of Lanes (one direction):_____ Speed Limit:_____

Does the road have a median? *Yes* *No*

Description (e.g., raised, grass, two-left turn lane): _____

Does the road have an outside shoulder? *YesNo* *Est. of Width:* _____

Does the road have an inside shoulder? Yes No Est. of Width:_____

Description of Topography: _____
_____

Ramp: Entrance Exit Location: _____

Ramp: Entrance Exit Location: _____

Ramp: Entrance Exit Location: _____

Other Notes: _____
_____

WORK ZONE CHARACTERISTICS

Project Contact:_____ Phone Number: _____

Type of Work Zone: Construction Maintenance

Type of Operation (e.g., paving): _____

No. of Lanes Closed:_____ No. of Lanes Open: _____ Work Zone Speed Limit: _____

General Description of Start Location:_____

General Description of End Location: _____

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INTEROPERABILITY ISSUES REGARDING MANAGED LANES

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August 6, 2004

SUMMARY

Conducted in the summer of 2004, as part of the Undergraduate Fellows Program at Texas A&M University, this research examines the concept of interoperability as it applies to managed lanes. Interoperability can be addressed in many aspects of managed lanes, such as geometric design, operations, enforcement, and incident management. In the context of this research, interoperability exists on three levels – agency, facility, and equipment. Proper coordination at each of these levels is necessary to ensure that managed lane facilities are compatible with each other and with their adjacent infrastructure. Through an extensive literature review and an online survey of the profession, a matrix was developed that shows where interoperability concerns must be addressed, and how important those concerns are. This information will ultimately be incorporated into the Managed Lanes Manual being developed for the Texas Department of Transportation.

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INTRODUCTION

In the post-WWII era, the United States has been plagued with traffic congestion. In particular, metropolitan areas have had their freeways crippled by traffic. Because transportation arteries are the life lines of a metropolitan area, the ramifications of this problem are quite significant. Suburban sprawl, encouraged by government policies and city planning that promotes automobile dependent development, has intensified the problem. Additionally, unlike the culture of other industrialized nations, American culture glorifies life in the suburbs while simultaneously portraying life in city centers as being undesirable. Dependence on cheap gasoline has not only exacerbated this problem, it has encouraged a culture of automobile dependency. Now, in the beginning of the 21st century, it is evident that these problems will only continue to worsen unless something is done to mitigate them.

When faced with problems, transportation planners and engineers have been forced to devise solutions and adapt infrastructure to fit current and future needs. With limited resources and space to construct new infrastructure, innovative solutions are necessary to solve today's problems. One such idea that has been proposed is the concept of managed lanes. The Texas Department of Transportation (TxDOT) has adopted the following definition for a managed lane:

"A managed lane facility is one that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals" (*1*).

The theory behind managed lanes is to reserve certain freeway lanes and use a variety of operating strategies to move traffic more efficiently in those lanes (*1*). Managed lanes are often thought of as "freeway-within-a-freeway" facilities (*2*). An example of a managed lane is a high-occupancy vehicle (HOV) lane. By restricting the use of HOV lanes to vehicles with multiple occupants, people who choose to carpool are rewarded with a savings in travel time. Managed lanes offer a smart alternative to constructing more pavement.

PROBLEM STATEMENT

Interoperability is hard to define because it relates to many ideas on multiple levels. Depending on the context, interoperability can mean many different things. For example, in the computing world, interoperability often refers to software compatibility. While Apple's Mac OS is arguably superior to Microsoft's Windows operating system, it does not hold a large market share because it is not interoperable with the majority of computer systems. Similarly, while managed lanes have enormous potential, if they are not interoperable with current and future needs, and if they are not compatible with the rest of the transportation network, it is doubtful that they will be deployed extensively or effectively. This caveat is the impetus for this research.

This research investigates interoperability issues regarding managed lanes. With respect to managed lanes, there are three levels of interoperability – agency, facility, and equipment. At the agency level, coordination among various agencies should occur, and interoperability issues should be addressed from a governance perspective. The facility level refers to coordination that should occur between various managed lane facilities or between a managed lane facility and its adjacent infrastructure. The lowest level of interoperability is the equipment level. Here, interoperability of compatible data elements is necessary to ensure seamless communication between various devices. Both now and in the future, interoperability is critical in ensuring the smooth operation of managed lanes.

In order for managed lanes to be implemented efficiently and effectively, interoperability issues regarding all aspects of managed lanes should be thoroughly investigated. Additionally, issues should be addressed accordingly on the three previously defined levels. For instance, planning should be coordinated at the

agency level (see Figure 1) (*3*). This assignment strives to identify the pertinent issues that interoperability relates to, and to understand how relevant each area is. Ultimately, the lessons learned from this work will be incorporated into the Managed Lanes Manual for the State of Texas.

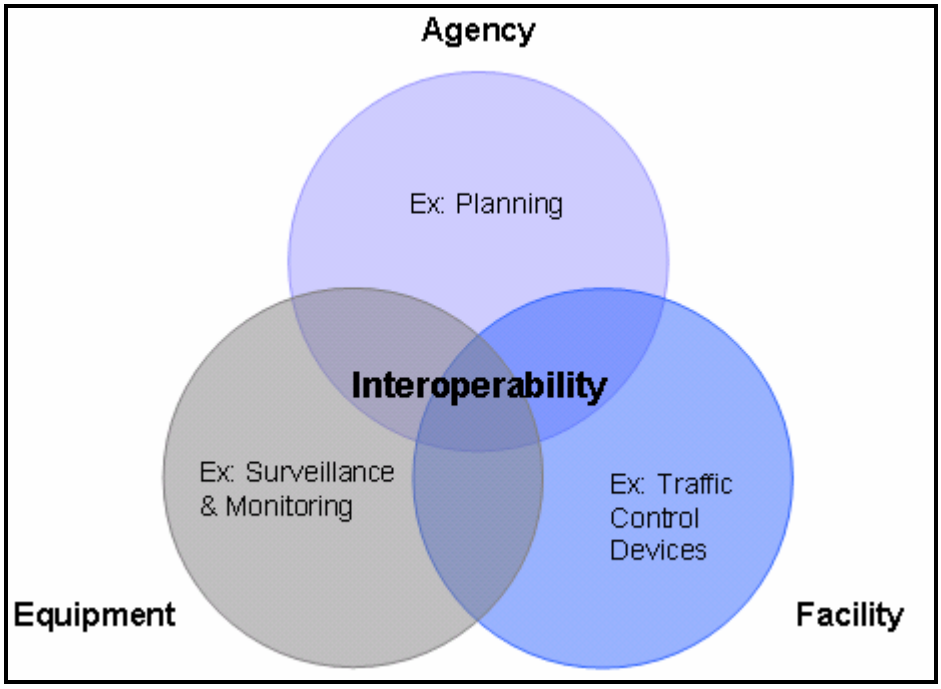

Figure 1. Interoperability

RESEARCH OBJECTIVES

The Managed Lanes Project is a multi-year project that is currently in its fourth year. Addressing interoperability concerns is one of the many tasks in this large undertaking. Therefore, given only ten weeks for this assignment, the goal of this portion of the project is to identify both the areas where interoperability is necessary, and the relevant issues that must be considered. Because interoperability is a concept that relates to multiple areas, this research will provide information that supplements the Managed Lanes Manual across many chapters. Ultimately, writing the Managed Lanes Manual will be the final culmination of work on the Managed Lanes Project. It is important to remember that this assignment will not focus on solving problems, but rather, its main thrust is to identify which problems and issues must be addressed.

RESEARCH METHODOLOGY

This assignment consists of twelve tasks divided into two parts – a literature review, and a survey of the profession. A graphic depicting the sequence of events is shown in Figure 2.

Step 1: Review Literature

The first step is a comprehensive review of the literature. Because the investigation of interoperability issues related to managed lanes is a relatively new concept, little has been published on it. Therefore, the bulk of the literature is comprised of articles that are either about interoperability in general, or about issues that pertain to interoperability – such as wireless communication devices. Thus, in order to

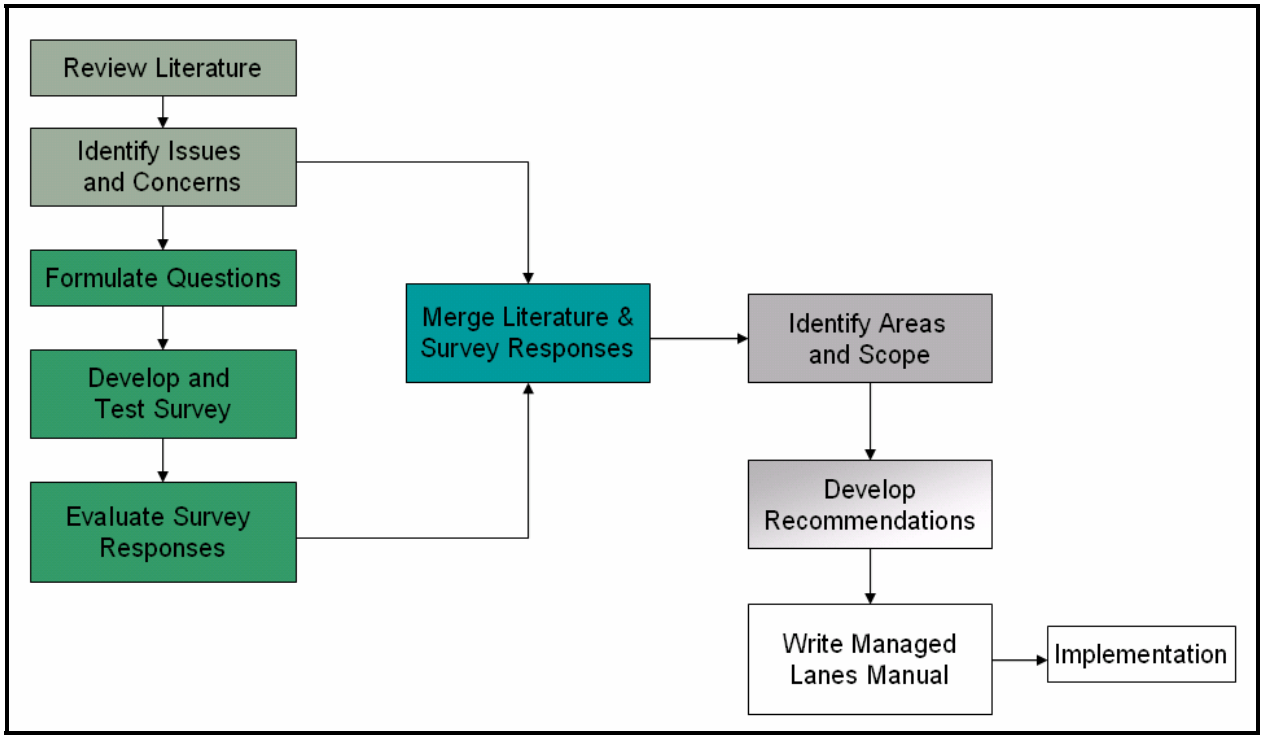

Figure 2. Procedure

investigate the literature properly, it was necessary to cast a broad net while searching. The following terms were used in the literature search:

- Interoperability,
- Interoperable,
- Inter-agency coordination,
- Agency coordination,
- Regional coordination,
- Corridor coordination,
- Inter-agency planning,
- Regional planning,
- Corridor planning,
- Data fusion,
- Data sharing,
- Managed Lanes,
- HOV,
- HOT, and
- Diamond Lanes.

With so many search terms, it should be no surprise that the amount of literature acquired was quite extensive.

Step 2: Identify Issues and Concerns

This step is concurrent with the first one, in that while reviewing the literature, pertinent issues regarding interoperability and managed lanes were recorded. Most issues regarding interoperability pertained to a specific issue, such as communications.

Step 3: Proposal Presentation and Report

This step is not shown in Figure 2, however, it was necessary to present a proposal of the research project as part of the Undergraduate Fellows Program. A short Microsoft PowerPoint presentation was used to introduce the research topic to other members of the Undergraduate Fellows Program. Additionally, a proposal report was submitted to offer a brief overview of this project. The proposal consisted of an explanation of the project's objectives, and a detailed plan of how those objectives would be achieved.

Step 4: Formulate Questions

After reviewing the literature, specific questions regarding interoperability issues were developed. These questions were written with the knowledge that they would be posed in an online survey. The questions probed two areas of interest – identification of major interoperability issues, and questions about interoperability as it pertains to specific technical issues.

Step 5: Develop and Test Survey

From the questions developed in step 4, an online survey was created. Mr. Bradley Hoover was asked to code the survey, and within a few days a prototype was available for testing. Testing the survey was conducted by verifying the output.

On July 14, 2004, a notice was sent out to about 300 transportation professionals on the Managed Lanes listserv. Subsequently, on July 20, 2004, the notice of the survey was included in the Transportation Communications Newsletter that goes out to approximately 5,000 people. Thus, it is estimated that this survey ultimately went out to about 5,300 people.

Step 6: Evaluate Survey Responses

As people responded to the survey, the database automatically logged responses into a Microsoft Excel file. Numeric and text responses were logged together, so separating them presented a challenge. In order to interpret the data, another Microsoft Excel file was created so that all of the analysis could be done quickly.

Step 7: Merge Literature and Survey Responses

This step involved synthesizing the information from both the literature and the survey responses. The literature and the survey are the two sources of information for this project. Much of the survey was motivated from information found in the literature, and some of the survey questions were used to fill in gaps of content that the literature did not address.

Step 8: Identify Areas and Scope

By this point, all of the relevant data for this project has been compiled. From the survey responses, pertinent areas and the scope of their importance were identified. Furthermore, important information about specific issues was combined with information found in the literature to develop recommendations.

Step 9: Develop Recommendations

This step involves acknowledging the issues that have been identified, and then developing recommendations. The majority of this project is not about solving problems – it is about identifying them. However, this step is where addressing the issues actually begins. Because the survey will be left up for several weeks after the Undergraduate Fellows Program is over, more responses are expected. As more responses come in, more recommendations may be developed. Recommendations were developed from statistical analysis of numeric survey results and the evaluation of text responses in conjunction with information obtained from the literature.

Step 10: Prepare Presentation and Final Report

This step is not shown in Figure 2, but a final presentation and a report of the findings of this project are also required as part of the Undergraduate Fellows Program. Like the proposal presentation, this presentation was conducted on Microsoft PowerPoint. The presentation explained the research methodology and offered some conclusions and recommendations. This written report is also a part of this step. It is hoped that this final report will prove to be useful in writing the Managed Lanes Manual. This report serves to explain the objectives, outline the methodology of this research, and offer some concluding recommendations. This is the last step that will be completed in this assignment.

Step 11: Write Managed Lanes Manual

This step will not be completed, or even started, during the ten weeks assigned for this research. However, it is simply shown in Figure 2 to note that writing the Managed Lanes Manual is one of the ultimate goals of the Managed Lanes Project. The research from this assignment will serve as a guide for which areas of the Managed Lanes Manual will need to address interoperability.

Step 12: Implementation

The final step in the Managed Lanes Project, and almost any other transportation related project, is to implement the findings into the real world. It is hoped that the Managed Lanes Project will have a positive impact in alleviating congestion and improving safety on the roadways of Texas and elsewhere.

Schedule

The schedule for this research is shown in Table 1.

RESULTS

Part I: Literature Review

A review of the literature was necessary to understand general concepts about interoperability and managed lanes. However, there is virtually no literature published on interoperability in the context of managed lanes. Because of this, reducing the literature to only the relevant articles was a very laborious task. However, there was really no substitute for the wealth of information that the literature provided. Some key points from the literature included the following:

- There are differences between incident management in a managed lanes facility and a non-managed lanes facility (*2*).
- The public does not seem to perceive tolling to be inequitable as long as there are other options (*4*).
- Various agencies should be able to communicate despite having different kinds of equipment (*5*).
- The existence of formal agreements among agencies is important (*6*).

Table 1. Project Schedule

Step	Activity	June 2 – June 4	June 7 – June 11	June 14 – June 18	June 21 – June 25	June 28 – July 2	July 5 – July 9	July 12 – July 16	July 19 – July 23	July 26 – July 30	August 2 – August 6	Not Completed
1	**Review Literature**	X	X	X								
2	**Identify Issues and Concerns**	X	X	X								
3	**Proposal Presentation and Report**		X	X								
4	**Formulate Questions**				X	X						
5	**Develop and Test Survey**					X	X	X				
6	**Evaluate Survey Responses**							X	X			
7	**Merge Literature and Survey Responses**							X	X	X		
8	**Identify Areas and Scope**								X	X		
9	**Develop Recommendations**									X		
10	**Prepare Presentation and Final Report**									X	X	
11	**Write Managed Lanes Manual**											X
12	**Implementation**											X

- Managed lanes should not be developed separately from each other or from other infrastructure (*7*).
- The decisions of one agency (or facility) will impact other agencies (or facilities) (*6*).
- Evaluations are necessary to properly identify benefits and rewards (*8*).
- Seasonal effects should be considered, since large volumes of traffic may require a different operational plan (*3*).
- Tolls collected on managed lanes are primarily used to manage demand, not to generate revenue (*4*).
- Plans should be scalable to accommodate agencies and facilities of different sizes (*7*).
- Due to privacy concerns, there is reluctance among government agencies to share certain information with the public (*9*).

- Interoperability requires both institutional agreements and common technological formats and standards (*10*).

The nine issues that are listed in Table 2 are areas where the literature indicated that interoperability may be necessary. Additionally, Table 2 shows the level(s) upon which each issue is important as indicated in the literature. This information was compiled from multiple sources during the literature review, but most of it was not explicitly stated. Thus, inferences were made to develop this table.

Table 2. Relevant Areas Identified From the Literature

	Agency	Facility	Equipment
Geometric Design	**X**	**X**	
Operations	**X**	**X**	**X**
Enforcement	**X**		
Communications		**X**	**X**
Traffic Control Devices		**X**	**X**
Planning	**X**		
Incident Management	**X**	**X**	
Legislation	**X**		
Evaluation	**X**		

Part II: Survey of the Profession

The purpose of developing a survey was to capture the knowledge and experience of the profession, highlight relevant issues, and identify areas that require additional investigation. This was necessary because the literature does not offer a comprehensive overview of interoperability with respect to managed lanes. In total, the survey consisted of 24 questions in the following eight sections (a full text of the survey can be found in Appendix A):

- Identification of Major Interoperability Issues,
- Geometric Design,
- Operations,
- Enforcement,
- Communications / Data Exchange,
- Incident Management,
- Maintenance, and
- Conclusion.

The most important section was the identification of major interoperability issues. In this section, respondents were asked to rank the importance of 13 issues on the three levels of interoperability (agency,

facility, and equipment), with a 1 through 5 or N/A rating – where 5 is "Most Important" and 1 is "Least Important." This identified the importance of each issue across all three levels. The 13 issues that were investigated in this section were:

- Geometric Design,
- Operations,
- Enforcement,
- Communications,
- Traffic Control Devices,
- Surveillance and Monitoring,
- Traveler Information Systems,
- Planning,
- Incident Management,
- Maintenance,
- Legislation,
- Evaluation, and
- Agency Staffing and Training.

Evaluating the results presented a challenge since the survey consisted of several different question types – numeric response, free text response, multiple choice, and select all that apply. With many different question types, it was necessary to format the data so that it could be easily interpreted. As stated above, a Microsoft Excel file was created so that when the unformatted data was simply pasted in, all of the calculations and formatting would be done automatically. For numeric responses, summary statistics were easily computed. However, for each text response question, a separate worksheet tab was created to display the results in a user-friendly format. The spreadsheet was designed to take up to 473 responses – this would allow for about a 9% response rate. The spreadsheet was not designed for the full 5300 responses because practicality dictated that the file size would be too large, and it would be unrealistic to expect a very high response rate.

Due to the fact that this was an online survey, a low response rate was expected. As of August 2, 2004, only 14 responses had been collected. This represents about a 0.2% response rate. While this is somewhat disappointing, the collected data has nonetheless proved to be quite useful.

From the survey responses, the relevant areas and their degree of importance were identified. The importance of each area was measured using a weighted average. To compute a weighted average, the strength of each response (1 through 5 or zero for N/A) was multiplied with the number of responses of that type. Then, by taking the average of those numbers, the mean response, a general measure of importance, was computed. The following formula shows this procedure:

[0*(# N/A) + 1*(# 1) + 2*(# 2) + 3*(# 3) + 4*(# 4) + 5*(# 5)] / (Total number of responses) = Importance

Table 3 shows the weighted averages for the results of the first section of the survey. With weighted averages, it was very simple to categorize each area in terms of importance. Each area was categorized using the following criteria: a weighted average of 3.5 – 3.75 signified that an area was somewhat important, a weighted average of 3.75 – 4.0 signified that it was important, and a weighted average of above 4.0 signified that it was very important. With this information, Table 4, a final matrix similar to Table 2, was developed. Table 4 will make it easy to identify which areas of the Managed Lanes Manual will need to address interoperability issues. Furthermore, this table is the primary contribution of this assignment since it displays both the areas that need to be addressed, and their respective scopes.

Table 3. Weighted Averages from Question 1

Issue	Agency	Facility	Equipment
Geometric Design	3.385	4.000	2.833
Operations	3.692	4.000	3.846
Enforcement	3.692	3.667	3.667
Communications	4.167	3.333	3.667
Traffic Control Devices	3.250	4.167	3.667
Planning	4.083	3.500	2.917
Incident Management	3.917	3.917	3.500
Legislation	4.167	3.083	2.250
Evaluation	3.917	3.833	3.250
Surveillance & Monitoring	3.455	3.818	4.182
Traveler Info Systems	3.667	3.750	3.583
Maintenance	3.083	3.333	3.083
Agency Staffing/Training	3.833	3.083	2.750

An important distinction between Tables 2 and 4 is that in addition to identifying which areas are important, Table 4 shows how important each area is. A comparison of Tables 2 and 4 indicates that there is a clear correlation between the information gathered from the literature review and the information gathered from the survey. Table 4 is longer, but it includes all of the same areas found in Table 2. Among the 27 areas that the two tables have in common, there is a correlation between 20 of them. That is to say that if a position in Table 2 is marked, then the corresponding position in Table 4 is also marked (to some degree of importance). Conversely, if a position in Table 2 is blank, the corresponding position in Table 4 is also blank. This result is very encouraging because it shows that the profession agrees with the original areas that were deemed to be relevant through the literature review.

One of the goals of the survey was to motivate areas for further research. In addition to the 13 issues listed in Table 4, other issues which previously were not even considered for interoperability were identified. The survey respondents suggested that the following topics be investigated for interoperability issues regarding managed lanes:

- HOT lanes,
- Emergency Response,
- Regional Planning and Land Use Input,
- Private Sector Financing,
- Local vs. Thruway Needs, and
- Environmental and Aesthetic Impacts.

Table 4. Relevant Areas Identified From the Survey

	Agency	Facility	Equipment
Geometric Design		●	
Operations	+	●	‡
Enforcement	+	+	+
Communications	●		+
Traffic Control Devices		●	+
Planning	●		
Incident Management	‡	‡	+
Legislation	●		
Evaluation	‡	‡	
Surveillance and Monitoring		‡	●
Traveler Information Systems	+	‡	+
Maintenance			
Agency Staffing and Training	‡		

+ = Somewhat important
‡ = Important
● = Very Important

Tables 5 through 9 are summary statistics for some of the questions found in the survey. Each response is on a 1 through 5 or N/A scale, and was calculated with the weighted average method described above. From Table 5, it is clear that the profession thinks lane separation and ramp spacing are the most important geometric design concerns. This comes as no surprise since much of the literature on managed lanes focuses on lane separation issues. It is probable to believe that because managed lanes are often designed to allow for free flow conditions, speed limits were not deemed to be an important interoperability concern.

The responses from question 6 indicate that the overwhelming number of operations on managed lanes should be coordinated at a metropolitan or regional level. Coordination at the state or national level does not seem to be desired except for on a few operations.

Table 7 indicates that toll authorities should primarily be responsible for creating the enforcement policies on managed lanes. Question 11 of the survey indicates that electronic toll collection and automatic vehicle identification are deemed to be the most important technologies for the enforcement process.

It is evident that transportation networks and incident management operations need to take advantage of information age technologies. The reliable and efficient exchange of information is critical for incident

Table 5. Results of Question 3

Geometric Design Issue	Rating
Ramp Design	3.900
Ramp Spacing	4.100
Ramp Type	3.800
Horizontal Curvature	3.000
Vertical Curvature	3.200
Shoulder Widths	3.444
Lane Width	3.500
Lane Markings	3.500
Speed Limits	2.909
Lane Separation	4.545
Design of Enforcement Areas	3.727

Table 6. Results of Question 6

Operation	Level of Coordination			
	Metro	Regional	State	National
Traveler Information Systems	2.700	4.400	4.364	1.900
Incident Response	4.636	2.000	2.800	4.364
Toll Collection	4.400	2.100	4.182	3.500
Congestion Management	4.182	4.273	2.100	2.600
Special Events	4.182	1.400	1.900	3.909
Homeland Security	3.818	3.500	3.909	3.500
Emergency Services	4.545	4.364	3.100	2.400
Enforcement Operations	4.545	4.364	2.900	1.600
Roadway Monitoring	4.364	4.091	1.500	2.600

Table 7. Results of Question 7

Enforcement Agency	Rating
Local Police	3.455
Special Police Force	3.727
State Police	3.818
Transit Agencies	3.545
State DOT	3.818
Toll Authorities	4.364
Emergency Services	3.818
Regional Mobility Authority	2.545
Metropolitan Planning Organization	2.455

Table 8. Results of Question 11

Enforcement Technology	Rating
Electronic Toll Collection	4.364
Automatic Vehicle Identification	4.182
License Plate Recognition	3.909
Weight-in-Motion Sensors	2.727
Speed Detection Technologies	2.818
Auto Vehicle Occupancy Detection	3.700
Surveillance Cameras	3.818

management operations. The survey proved to confirm this by indicating that a shared data network and regional response planning are effective solutions for improving incident management operations.

As stated above, the survey consisted of eight sections. The latter seven sections provided useful information about specific issues. Some other recommendations that survey respondents offered included the following:

- Investigate private sector financing,
- Visible lane permits may aid enforcement operations,

Table 9. Results of Question 19

Potential Solution	Rating
Central Dispatching	3.400
Common Equipment	3.500
Shared Data Network	4.100
Shared Radio Frequencies	3.300
Regional Response Planning	4.100
Inter-Agency Agreements	3.800

- In order to expedite incident management operations, respond with just the necessary equipment,
- Maintenance operations should be considered at the planning stage, and
- Investigate anti-gawk screens, or visual barriers, to prevent incidents from affecting adjacent traffic.

CONCLUSIONS

Early on, it was determined that while interoperability would need to be addressed in the Managed Lanes Manual, it would not be confined to a single chapter. Since interoperability is a concept that touches on aspects of several issues, it was decided that interoperability would be addressed as needed across many chapters of the Managed Lanes Manual. This revelation was the motivation for this assignment. The need to identify where interoperability is necessary has been the primary goal and challenge of this assignment.

There are only ten weeks allocated for the Undergraduate Fellows Program. Although this is a tight time frame, this assignment has fulfilled its original goal. Table 4 not only shows which areas need to address interoperability, but it also shows on what level(s) and to what extent each area should be considered. This contribution to the Managed Lanes Project will prove to be useful in serving as a guide for writing the Managed Lanes Manual.

While this research has not directly solved any problems, it has identified concerns that need to be addressed. Furthermore, this assignment has motivated other areas for research regarding interoperability and managed lanes. Hopefully, this investigation will serve as the impetus for further research in the ongoing work of improving the operations and safety of the transportation network.

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APPENDIX A

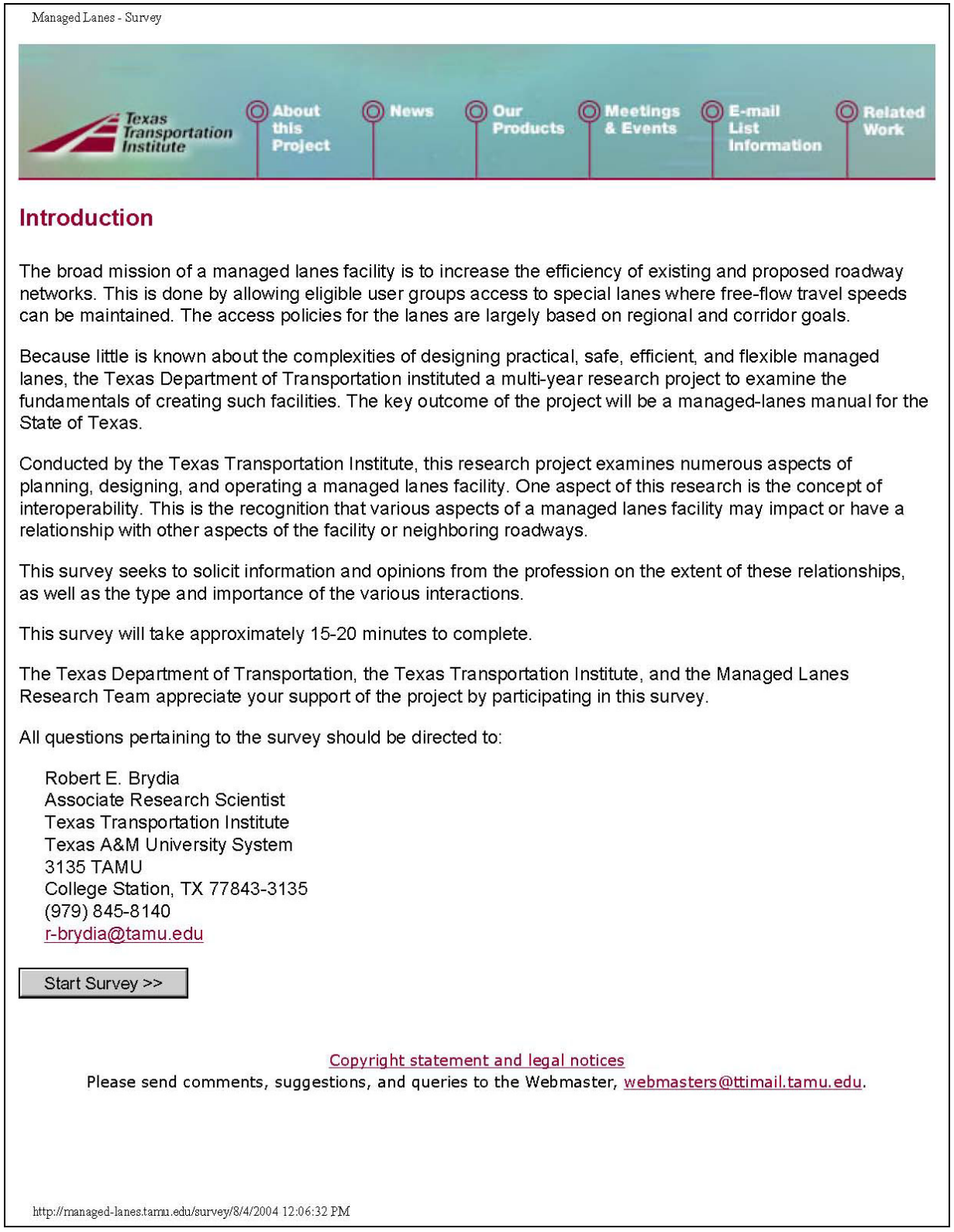

Figure A1. Survey Introduction

Managed Lanes - Survey

Identification of Major Interoperability Issues

Question 1: The table below identifies several issues pertaining to the interoperability of managed lanes.

For each issue, three different levels of interoperability are listed. They are:

- Agency - coordination between different organizations
- Facility - coordination between managed lane facilities or between a managed lane facility and adjacent roadways
- Equipment - coordination of equipment and compatible data.

For example, geometric design may be an important interoperability concept at the agency and/or facility level, but not at the equipment level.

For each issue, within each level of interoperability (Agency, Facility, Equipment), please identify how important you think it is with respect to interoperability.

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

	Level of Interoperability		
Issue	Agency	Facility	Equipment
Geometric Design	Select One	Select One	Select One
Operations	Select One	Select One	Select One
Enforcement	Select One	Select One	Select One
Communications	Select One	Select One	Select One
Traffic Control Devices	Select One	Select One	Select One
Surveillance and Monitoring	Select One	Select One	Select One
Traveler Information Systems	Select One	Select One	Select One
Planning	Select One	Select One	Select One
Incident Management	Select One	Select One	Select One
Maintenance	Select One	Select One	Select One
Legislation	Select One	Select One	Select One

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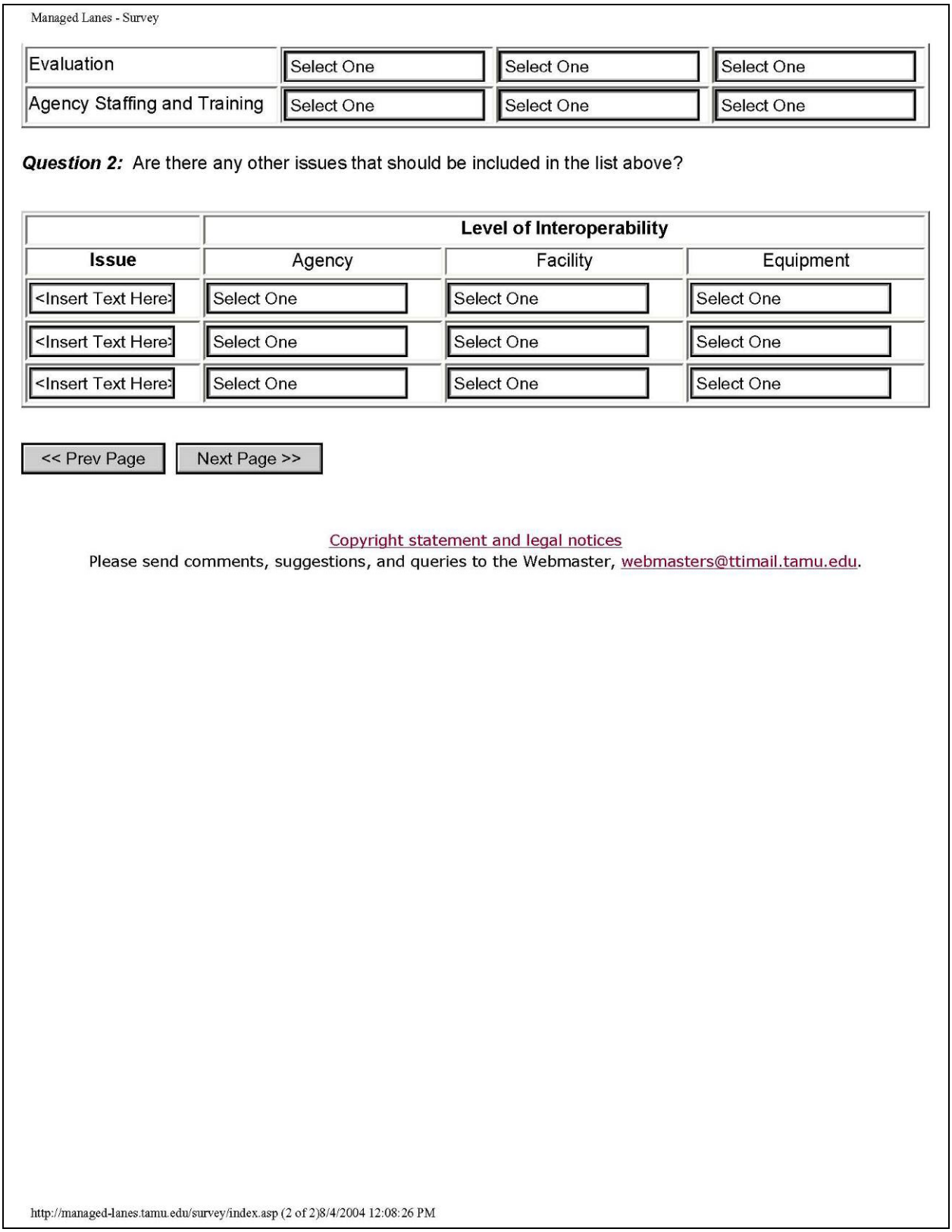
Figure A2. Identification of Major Interoperability Issues – 1



Managed Lanes - Survey

Evaluation	Select One	Select One	Select One
Agency Staffing and Training	Select One	Select One	Select One

Question 2: Are there any other issues that should be included in the list above?

	Level of Interoperability		
Issue	Agency	Facility	Equipment
<Insert Text Here>	Select One	Select One	Select One
<Insert Text Here>	Select One	Select One	Select One
<Insert Text Here>	Select One	Select One	Select One

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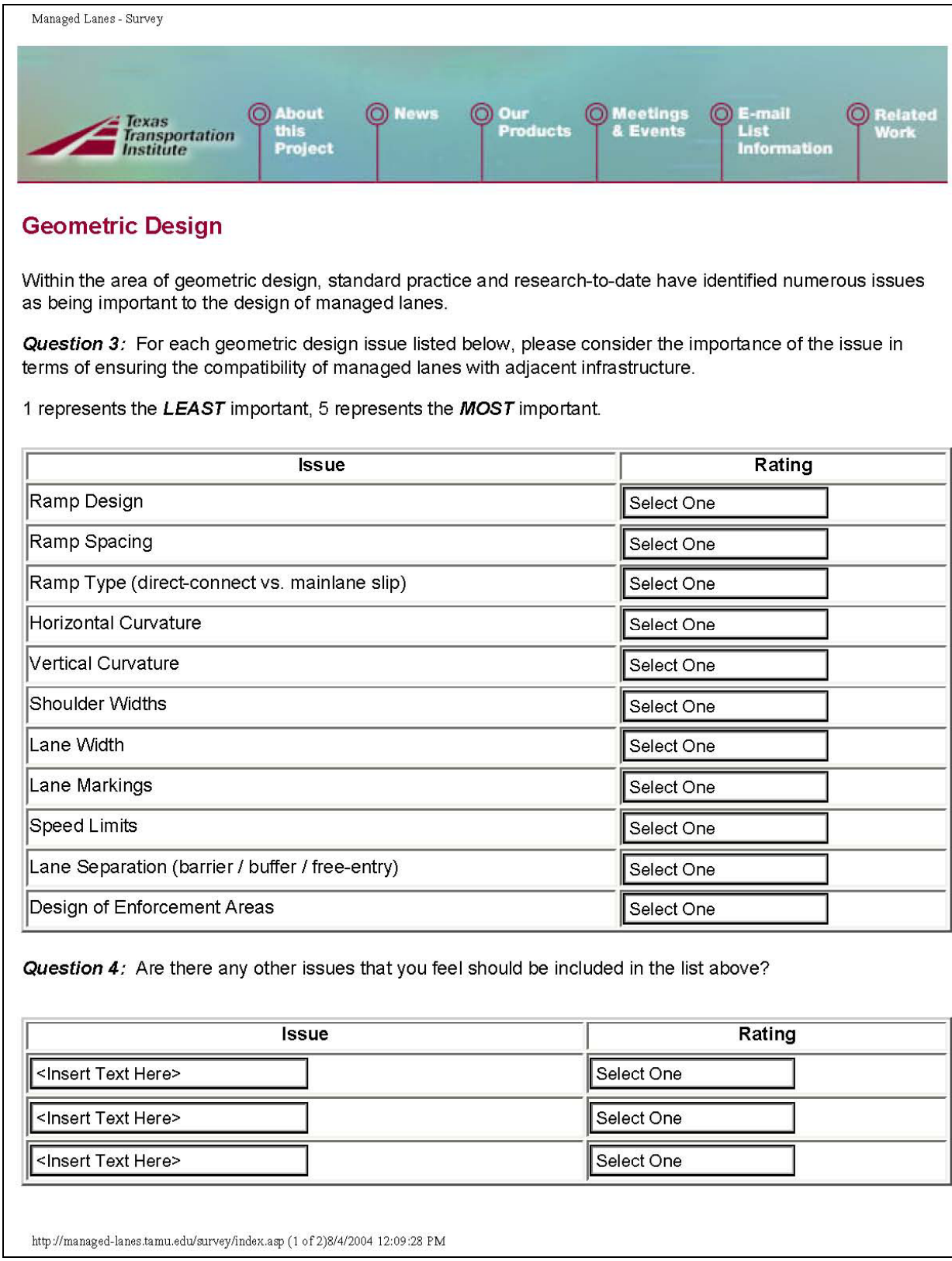
Figure A3. Identification of Major Interoperability Issues – 2



Managed Lanes - Survey

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Geometric Design

Within the area of geometric design, standard practice and research-to-date have identified numerous issues as being important to the design of managed lanes.

Question 3: For each geometric design issue listed below, please consider the importance of the issue in terms of ensuring the compatibility of managed lanes with adjacent infrastructure.

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

Issue	Rating
Ramp Design	Select One
Ramp Spacing	Select One
Ramp Type (direct-connect vs. mainlane slip)	Select One
Horizontal Curvature	Select One
Vertical Curvature	Select One
Shoulder Widths	Select One
Lane Width	Select One
Lane Markings	Select One
Speed Limits	Select One
Lane Separation (barrier / buffer / free-entry)	Select One
Design of Enforcement Areas	Select One

Question 4: Are there any other issues that you feel should be included in the list above?

Issue	Rating
<Insert Text Here>	Select One
<Insert Text Here>	Select One
<Insert Text Here>	Select One

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Figure A4. Geometric Design – 1

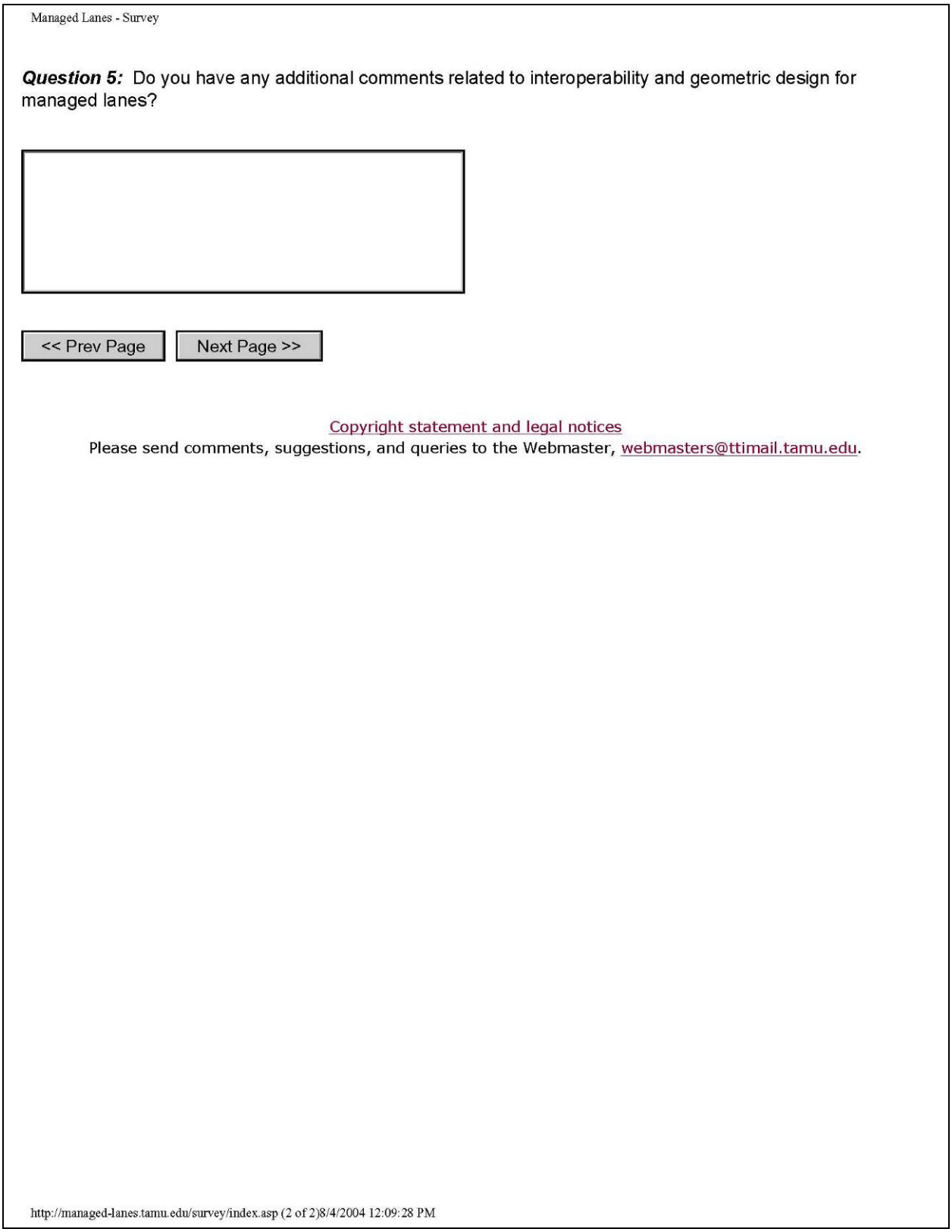
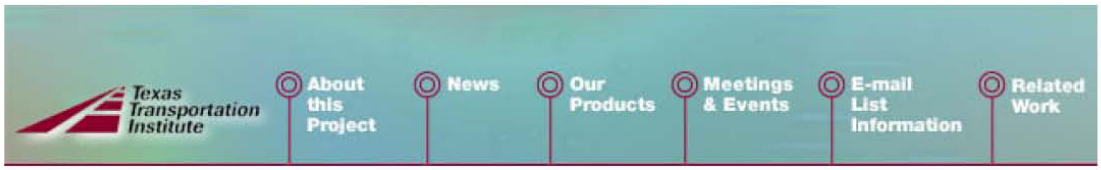


Figure A5. Geometric Design – 2

Managed Lanes - Survey



Operations

Interoperability in operations can take many forms. From incident management responses to unified toll collection activities, the efficiency of the managed lanes can be enhanced by coordinating their operations with other facilities.

This question addresses what activities are the most important to coordinate, and at which level that coordination should take place.

Question 6: For each operational issue listed below, four levels of coordination are listed. They are:

- Metropolitan - coordination across the city
- Regional - coordination across the city and surrounding areas
- State - coordination across the entire state
- National - coordination across the United States

For each issue, within each level, please identify how important you think it is.

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

	Level of Coordination			
Issue	Metro	Regional	State	National
Traveler Information Systems	Select One	Select One	Select One	Select One
Incident Response	Select One	Select One	Select One	Select One
Toll Collection	Select One	Select One	Select One	Select One
Congestion Management	Select One	Select One	Select One	Select One
Special Events	Select One	Select One	Select One	Select One
Homeland Security	Select One	Select One	Select One	Select One
Emergency Services	Select One	Select One	Select One	Select One
Enforcement Operations	Select One	Select One	Select One	Select One
Roadway Monitoring	Select One	Select One	Select One	Select One

Question 7: Are there any other issues that you feel should be included in the list above?

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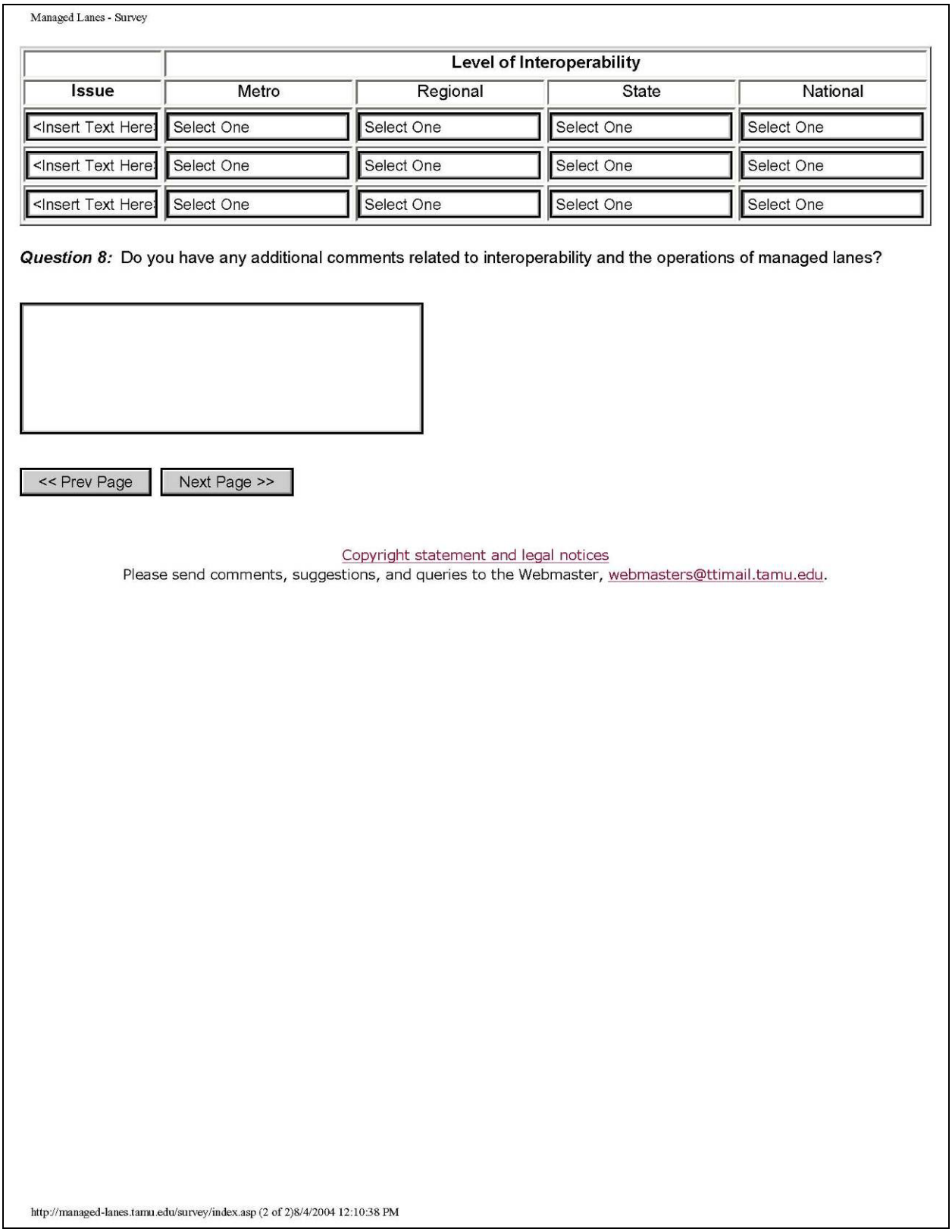
Figure A6. Operations – 1



Managed Lanes - Survey

	Level of Interoperability			
Issue	Metro	Regional	State	National
<Insert Text Here>	Select One	Select One	Select One	Select One
<Insert Text Here>	Select One	Select One	Select One	Select One
<Insert Text Here>	Select One	Select One	Select One	Select One

Question 8: Do you have any additional comments related to interoperability and the operations of managed lanes?

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Figure A7. Operations – 2

Managed Lanes - Survey

Enforcement

A successful managed lane requires effective enforcement to maintain the level of service appropriate to the management strategy in place.

While it is the responsibility of enforcement agencies to maintain the integrity of the facility, any number of organizations can cooperate to create the enforcement policies and procedures.

Question 9: Please rate the importance of each agency's involvement in creating these enforcement policies.

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

Agency	Rating
Local Police	Select One
Special Police Force (ex: transit agency law enforcement)	Select One
State Police	Select One
Transit Agencies	Select One
State Department of Transportation	Select One
Toll Authorities	Select One
Emergency Services	Select One
Regional Mobility Authority	Select One
Metropolitan Planning Organization	Select One

Question 10: Who should primarily be responsible for the enforcement of managed lanes? (Please select only one)

Agency	
Local Police	O
State Police	O
Special Police Force (ex: transit agency law enforcement)	O
Other <Insert Text Here>	O

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Figure A8. Enforcement – 1

Managed Lanes - Survey

Question 11: The technology available for enforcement is rapidly changing and advancing. How do the following technology areas rate in terms of being important to the enforcement process?

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

Issue	Rating
Electronic Toll Collection	Select One
Automatic Vehicle Identification	Select One
License Plate Recognition	Select One
Weigh-in-Motion Sensors	Select One
Speed Detection Technologies	Select One
Automated Vehicle Occupancy Detection	Select One
Surveillance Cameras	Select One

Question 12: Are there any other technology areas that you feel should be included in the list above?

Issue	Rating
<Insert Text Here>	Select One
<Insert Text Here>	Select One
<Insert Text Here>	Select One

Question 13: Do you have any additional comments related to interoperability and the enforcement of managed lanes?

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Figure A9. Enforcement – 2

Managed Lanes - Survey

Communications / Data Exchange

The information necessary to support the daily operations and management of a managed lane facility can be significant. This information may be exchanged with partner agencies, equipment, enforcement, vehicles, and the traveling public. A large scale and robust communications data network may be required to support these needs.

Question 14: Should communication networks for managed lane facilities primarily be: (Please select only one)

Leased from utility or telecommunication companies	O
Owned and shared by local agencies	O
Owned by the states	O
Any combination of the above	O
Other <Insert Text Here>	O

Question 15: Should a managed lane communications network: (Check all that apply)

use shared communication equipment lines (multiple devices per line)	☐
support video and data on the same network	☐
send all communications to a central point for dissemination	☐
have the ability to send communications to multiple agencies / partners	☐
Support the needs of: Operations	☐
Maintenance	☐
Enforcement	☐
Traveler Information Systems	☐

Question 16: Do you have any additional comments related to the interoperability of communication systems for managed lanes?

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Figure A10. Communications / Data Exchange – 1

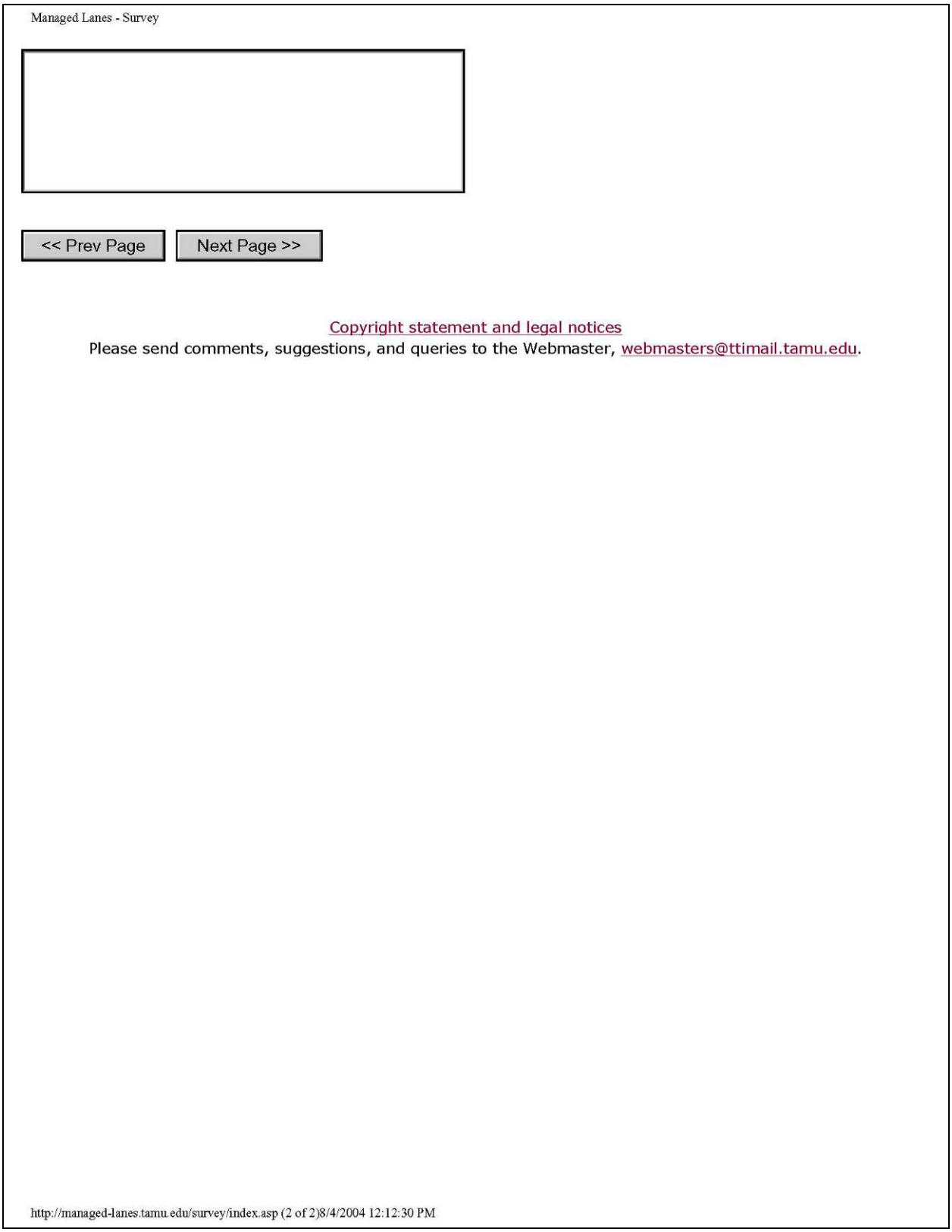

Figure A11. Communications / Data Exchange – 2

Managed Lanes - Survey

Incident Management

The state-of-the-practice has shown that incident management can benefit greatly from increased coordination between agencies. In fact, most traffic management centers or roadway coalitions have active programs to share items such as information, equipment, or personnel to respond as quickly and efficiently as possible to roadway incidents.

Question 17: Will the same degree of coordination be beneficial to incident management on a managed lane facility? (Please select only one)

- O Yes
- O No
- O Not Sure

Question 18: What agencies should be involved in incident management activities on a managed lane facility? (Check all that apply)

Agency	Planning	Response
Local Police	☐	☐
Special Police Force (ex: transit agency law enforcement)	☐	☐
State Police	☐	☐
Transit Agencies	☐	☐
State Department of Transportation	☐	☐
Toll Authorities	☐	☐
Emergency Services	☐	☐
Regional Mobility Authority	☐	☐
Metropolitan Planning Organization	☐	☐

Question 19: How important would the following potential solutions be to support more efficient incident management in a managed lane facility?

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

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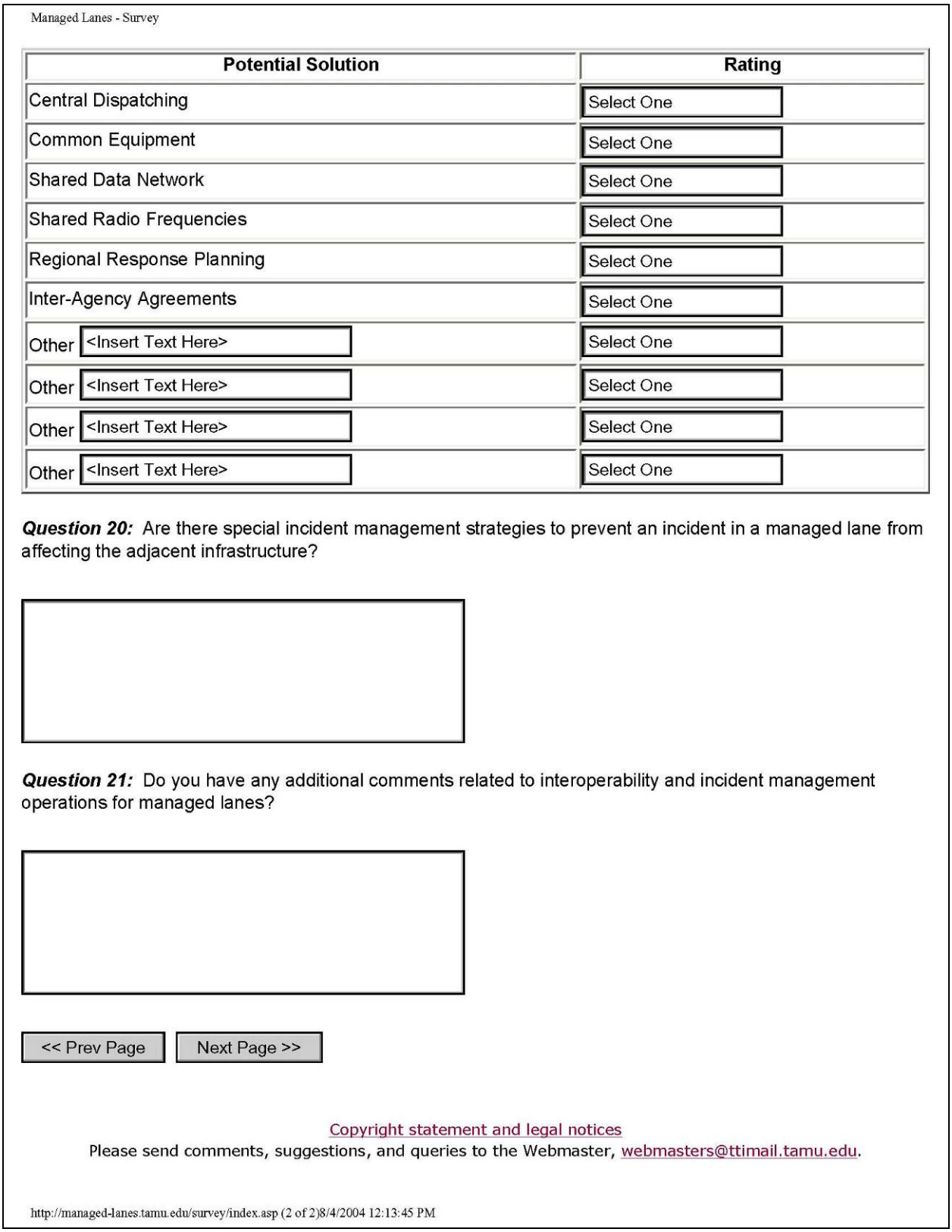
Figure A12. Incident Management – 1



Managed Lanes - Survey

Potential Solution	Rating
Central Dispatching	Select One
Common Equipment	Select One
Shared Data Network	Select One
Shared Radio Frequencies	Select One
Regional Response Planning	Select One
Inter-Agency Agreements	Select One
Other <Insert Text Here>	Select One
Other <Insert Text Here>	Select One
Other <Insert Text Here>	Select One
Other <Insert Text Here>	Select One

Question 20: Are there special incident management strategies to prevent an incident in a managed lane from affecting the adjacent infrastructure?

Question 21: Do you have any additional comments related to interoperability and incident management operations for managed lanes?

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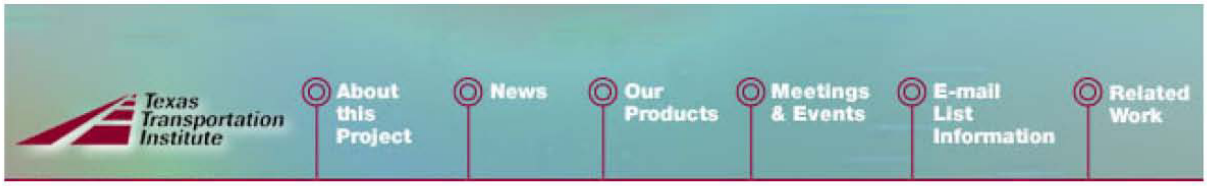
Figure A13. Incident Management – 2

Managed Lanes - Survey



Maintenance

Question 22: Maintenance operations have generally been considered after a facility is planned and designed. Are there specific concerns related to any of the following maintenance practices that should be considered early in the planning and design process of the facility?

Maintenance Issue	Concern
Drainage	
Road Surface Cleaning	
Repaving	
Mowing and Beautification Operations	
Equipment Upgrades	
Striping	
Signing and Signal Maintenance	
Other <Insert Text Here>	
Other <Insert Text Here>	
Other <Insert Text Here>	

Question 23: Do you have any additional comments related to interoperability and maintenance operations in a managed lane facility?

Figure A14. Maintenance – 1

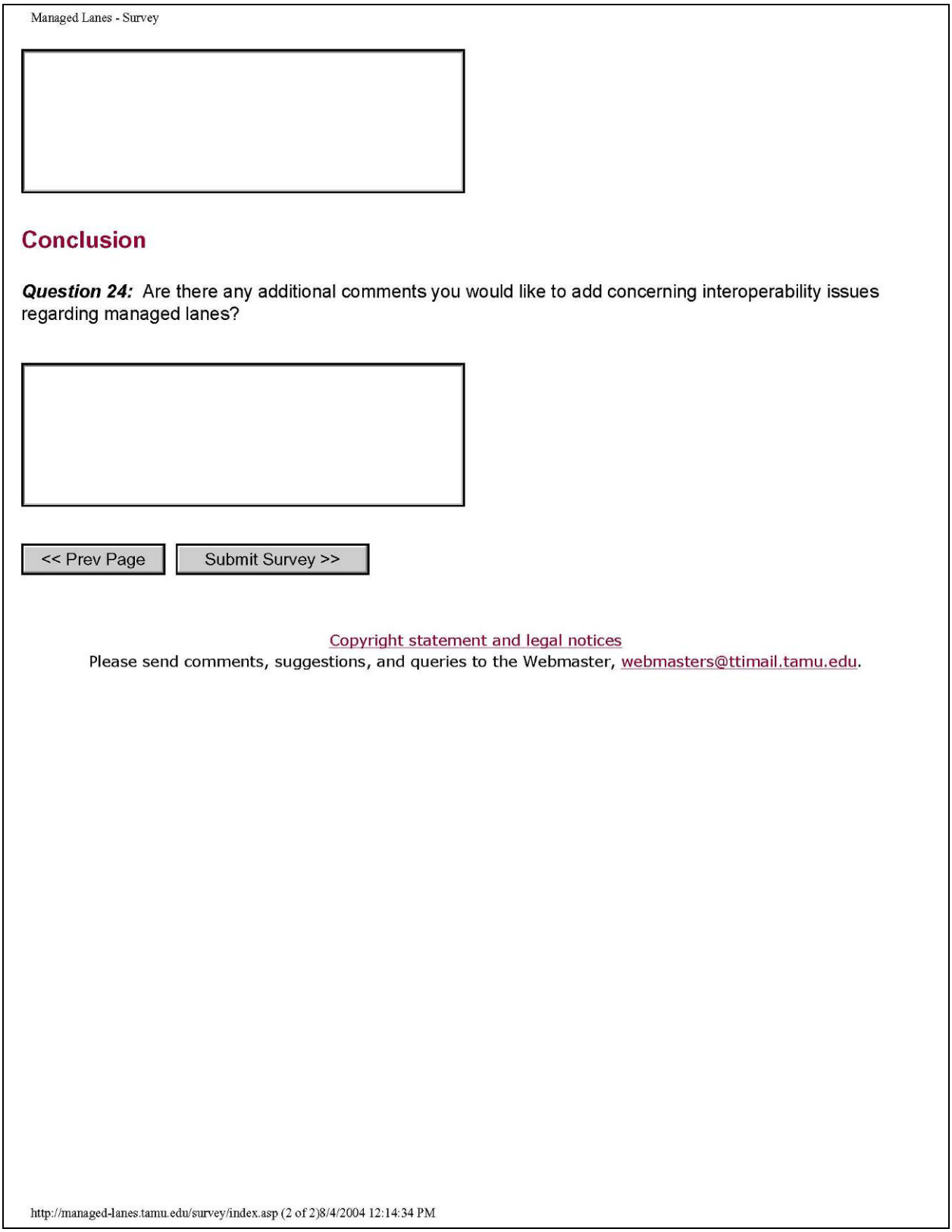


Figure A15. Maintenance – 2 / Conclusion

APPENDIX B

Table B1. Question 1 Responses

Rating	Geometric Design			Operations			Enforcement		
	Agency	Facility	Equip.	Agency	Facility	Equip.	Agency	Facility	Equip.
1	0	0	1	0	0	0	1	0	1
2	2	2	5	2	2	2	0	2	1
3	4	1	3	3	0	3	1	3	2
4	7	5	1	5	7	3	6	4	5
5	0	5	2	3	4	5	4	3	3
N/A	0	0	0	0	0	0	1	0	0
Total Responses	13	13	12	13	13	13	13	12	12
Blank	1	1	2	1	1	1	1	2	2
Total	14	14	14	14	14	14	14	14	14
% 1	0	0	7	0	0	0	7	0	7
% 2	14	14	36	14	14	14	0	14	7
% 3	29	7	21	21	0	21	7	21	14
% 4	50	36	7	36	50	21	43	29	36
% 5	0	36	14	21	29	36	29	21	21
% N/A	0	0	0	0	0	0	7	0	0
% Response	93	93	86	93	93	93	93	86	86
% Blank	7	7	14	7	7	7	7	14	14
% Total	100	100	100	100	100	100	100	100	100

Table B2. Question 1 Responses (Continued)

Rating	Communications			Traffic Control Devices			Surveillance and Monitoring		
	Agency	**Facility**	**Equip.**	**Agency**	**Facility**	**Equip.**	**Agency**	**Facility**	**Equip.**
1	0	1	1	0	0	2	0	0	0
2	1	1	2	2	0	0	1	1	1
3	1	5	2	7	2	2	5	1	1
4	5	3	2	1	6	4	4	8	4
5	5	2	5	2	4	4	1	1	5
N/A	0	0	0	0	0	0	0	0	0
Total Responses	12	12	12	12	12	12	11	11	11
Blank	2	2	2	2	2	2	3	3	3
Total	14	14	14	14	14	14	14	14	14
% 1	0	7	7	0	0	14	0	0	0
% 2	7	7	14	14	0	0	7	7	7
% 3	7	36	14	50	14	14	36	7	7
% 4	36	21	14	7	43	29	29	57	29
% 5	36	14	36	14	29	29	7	7	36
% N/A	0	0	0	0	0	0	0	0	0
% Response	86	86	86	86	86	86	79	79	79
% Blank	14	14	14	14	14	14	21	21	21
% Total	100	100	100	100	100	100	100	100	100

Table B3. Question 1 Responses (Continued)

Rating	Traveler Information Systems			Planning			Incident Management		
	Agency	**Facility**	**Equip.**	**Agency**	**Facility**	**Equip.**	**Agency**	**Facility**	**Equip.**
1	1	0	0	0	0	1	1	0	1
2	1	3	4	1	3	3	0	0	1
3	3	0	1	1	2	4	3	5	3
4	3	6	3	6	5	4	3	3	5
5	4	3	4	4	2	0	5	4	2
N/A	0	0	0	0	0	0	0	0	0
Total Responses	12	12	12	12	12	12	12	12	12
Blank	2	2	2	2	2	2	2	2	2
Total	14	14	14	14	14	14	14	14	14
% 1	7	0	0	0	0	7	7	0	7
% 2	7	21	29	7	21	21	0	0	7
% 3	21	0	7	7	14	29	21	36	21
% 4	21	43	21	43	36	29	21	21	36
% 5	29	21	29	29	14	0	36	29	14
% N/A	0	0	0	0	0	0	0	0	0
% Response	86	86	86	86	86	86	86	86	86
% Blank	14	14	14	14	14	14	14	14	14
% Total	100	100	100	100	100	100	100	100	100

Table B4. Question 1 Responses (Continued)

Rating	Maintenance			Legislation			Evaluation		
	Agency	**Facility**	**Equip.**	**Agency**	**Facility**	**Equip.**	**Agency**	**Facility**	**Equip.**
1	0	0	1	0	1	4	0	0	0
2	4	2	3	1	3	4	1	1	4
3	5	7	4	1	3	2	3	4	3
4	1	0	2	5	4	1	4	3	3
5	2	3	2	5	1	1	4	4	2
N/A	0	0	0	0	0	0	0	0	0
Total Responses	12	12	12	12	12	12	12	12	12
Blank	2	2	2	2	2	2	2	2	2
Total	14	14	14	14	14	14	14	14	14
% 1	0	0	7	0	7	29	0	0	0
% 2	29	14	21	7	21	29	7	7	29
% 3	36	50	29	7	21	14	21	29	21
% 4	7	0	14	36	29	7	29	21	21
% 5	14	21	14	36	7	7	29	29	14
% N/A	0	0	0	0	0	0	0	0	0
% Response	86	86	86	86	86	86	86	86	86
% Blank	14	14	14	14	14	14	14	14	14
% Total	100	100	100	100	100	100	100	100	100

Table B5. Question 1 Responses (Continued)

Rating	Agency Staffing and Training		
	Agency	**Facility**	**Equip.**
1	0	0	0
2	1	1	3
3	2	6	6
4	7	3	1
5	2	1	1
N/A	0	1	1
Total Responses	12	12	12
Blank	2	2	2
Total	14	14	14
% 1	0	0	0
% 2	7	7	21
% 3	14	43	43
% 4	50	21	7
% 5	14	7	7
% N/A	0	7	7
% Response	86	86	86
% Blank	14	14	14
% Total	100	100	100

Table B6. Question 2 Responses

Additional Issue	Agency	Facility	Equipment
HOT lane	5	5	5
emergency response	5	4	2
regional planning and land use input	4	5	3
Private Sector financing	5	5	5
local vs. thruway needs	4	5	3
Incorporate existing lanes as HOT lanes	4	4	4
environmental and aesthetic impacts	3	5	4

Table B7. Question 3 Responses

Rating	Ramp Design	Ramp Spacing	Ramp Type	Horizontal Curvature	Vertical Curvature	Shoulder Width	Lane Width
1	0	0	0	0	0	0	0
2	0	1	1	2	2	0	2
3	5	1	3	6	5	6	4
4	1	4	3	2	2	2	1
5	4	4	3	0	1	1	3
N/A	0	0	0	0	0	0	0
Total Responses	10	10	10	10	10	9	10
Blank	4	4	4	4	4	5	4
Total	14	14	14	14	14	14	14
% 1	0	0	0	0	0	0	0
% 2	0	7	7	14	14	0	14
% 3	36	7	21	43	36	43	29
% 4	7	29	21	14	14	14	7
% 5	29	29	21	0	7	7	21
% N/A	0	0	0	0	0	0	0
% Response	71	71	71	71	71	64	71
% Blank	29	29	29	29	29	36	29
% Total	100	100	100	100	100	100	100

Table B8. Question 3 Responses, Continued

Rating	Lane Markings	Speed Limits	Lane Separation	Design of Enforcement Areas
1	0	1	0	0
2	2	1	0	0
3	2	7	0	1
4	5	2	5	7
5	1	0	6	2
N/A	0	0	0	1
Total Responses	10	11	11	11
Blank	4	3	3	3
Total	14	14	14	14
% 1	0	7	0	0
% 2	14	7	0	0
% 3	14	50	0	7
% 4	36	14	36	50
% 5	7	0	43	14
% N/A	0	0	0	7
% Response	71	79	79	79
% Blank	29	21	21	21
% Total	100	100	100	100

Table B9. Question 4 Responses

Issue	Rating
Consistency/Type of lane management strategy	5
Fly over ramps	5
accurate and sufficient advance signage	5
Physical barrier between HOT lanes & regular	5
Opportunities for access and egress	4
Need HOT lane system on majority of congested freeway miles	5

Table B10. Question 5 Responses

Additional Comments for Geometric Design
The goal of the system's lane management strategy should be consistent. If one highway's has a management goal of earning revenue and another has the goal of encouraging transit by providing free HOV passage the system goal is inconsistent and ultimately does not provide a true "system"
Not sure that the design of this survey is going to reveal anything. Everything has to be in place for success and safety.
I've skipped a few questions that were outside my area of expertise.

Table B11. Question 6 Responses

Rating	Traveler Information Systems				Incident Response			
	Metro	**Regional**	**State**	**National**	**Metro**	**Regional**	**State**	**National**
1	1	0	0	2	0	3	0	0
2	2	0	0	7	0	4	3	0
3	6	0	1	1	0	3	6	1
4	1	6	5	0	4	0	1	5
5	0	4	5	0	7	0	0	5
N/A	0	0	0	0	0	0	0	0
Total Responses	10	10	11	10	11	10	10	11
Blank	4	4	3	4	3	4	4	3
Total	14	14	14	14	14	14	14	14
% 1	7	0	0	14	0	21	0	0
% 2	14	0	0	50	0	29	21	0
% 3	43	0	7	7	0	21	43	7
% 4	7	43	36	0	29	0	7	36
% 5	0	29	36	0	50	0	0	36
% N/A	0	0	0	0	0	0	0	0
% Response	71	71	79	71	79	71	71	79
% Blank	29	29	21	29	21	29	29	21
% Total	100	100	100	100	100	100	100	100

Table B12. Question 6 Responses, Continued

Rating	Toll Collection				Congestion Management			
	Metro	**Regional**	**State**	**National**	**Metro**	**Regional**	**State**	**National**
1	0	5	0	0	0	0	2	1
2	0	2	0	1	1	1	5	2
3	0	0	2	5	1	1	3	7
4	6	3	5	2	4	3	0	0
5	4	0	4	2	5	6	0	0
N/A	0	0	0	0	0	0	0	0
Total Responses	10	10	11	10	11	11	10	10
Blank	4	4	3	4	3	3	4	4
Total	14	14	14	14	14	14	14	14
% 1	0	36	0	0	0	0	14	7
% 2	0	14	0	7	7	7	36	14
% 3	0	0	14	36	7	7	21	50
% 4	43	21	36	14	29	21	0	0
% 5	29	0	29	14	36	43	0	0
% N/A	0	0	0	0	0	0	0	0
% Response	71	71	79	71	79	79	71	71
% Blank	29	29	21	29	21	21	29	29
% Total	100	100	100	100	100	100	100	100

Table B14. Question 6 Responses, Continued

Rating	Special Events				Homeland Security			
	Metro	**Regional**	**State**	**National**	**Metro**	**Regional**	**State**	**National**
1	0	5	2	0	0	1	0	1
2	1	3	4	1	1	1	1	0
3	1	1	3	3	3	3	3	4
4	4	0	0	3	4	2	3	3
5	5	0	0	4	3	3	4	2
N/A	0	1	1	0	0	0	0	0
Total Responses	11	10	10	11	11	10	11	10
Blank	3	4	4	3	3	4	3	4
Total	14	14	14	14	14	14	14	14
% 1	0	36	14	0	0	7	0	7
% 2	7	21	29	7	7	7	7	0
% 3	7	7	21	21	21	21	21	29
% 4	29	0	0	21	29	14	21	21
% 5	36	0	0	29	21	21	29	14
% N/A	0	7	7	0	0	0	0	0
% Response	79	71	71	79	79	71	79	71
% Blank	21	29	29	21	21	29	21	29
% Total	100	100	100	100	100	100	100	100

Table B15. Question 6 Responses, Continued

Rating	Emergency Services				Enforcement Operations			
	Metro	**Regional**	**State**	**National**	**Metro**	**Regional**	**State**	**National**
1	0	0	1	2	0	0	0	3
2	0	0	1	3	0	0	2	5
3	1	1	5	4	1	1	7	1
4	3	5	2	1	3	5	1	0
5	7	5	1	0	7	5	0	0
N/A	0	0	0	0	0	0	0	1
Total Responses	11	11	10	10	11	11	10	10
Blank	3	3	4	4	3	3	4	4
% 1	0	0	7	14	0	0	0	21
% 2	0	0	7	21	0	0	14	36
% 3	7	7	36	29	7	7	50	7
% 4	21	36	14	7	21	36	7	0
% 5	50	36	7	0	50	36	0	0
% N/A	0	0	0	0	0	0	0	7
% Response	79	79	71	71	79	79	71	71
% Blank	21	21	29	29	21	21	29	29
% Total	100	100	100	100	100	100	100	100

Table B16. Question 6 Responses, Continued

Rating	Roadway Monitoring			
	Metro	**Regional**	**State**	**National**
1	0	0	3	1
2	0	0	3	2
3	1	3	2	7
4	5	4	0	0
5	5	4	0	0
N/A	0	0	2	0
Total Responses	11	11	10	10
Blank	3	3	4	4
Total	14	14	14	14
% 1	0	0	21	7
% 2	0	0	21	14
% 3	7	21	14	50
% 4	36	29	0	0
% 5	36	29	0	0
% N/A	0	0	14	0
% Response	79	79	71	71
% Blank	21	21	29	29
% Total	100	100	100	100

Table B17. Question 7 Responses

Issue	Metro	Regional	State	National
Private sector involvement	5	4	2	1
Private Sector Funding	5	5	5	5

There were no responses for question 8, which asked for additional comments related to interoperability and the operations of managed lanes.

Table B18. Question 9 Responses

Rating	Local Police	Special Police	State Police	Transit Agencies	State DOT	Toll Authority	EMS	Regional Mobility	MPO
1	1	2	1	1	1	0	0	1	2
2	2	0	1	2	0	0	0	4	4
3	2	1	2	1	2	2	5	5	4
4	3	4	2	4	5	3	3	1	0
5	3	4	5	3	3	6	3	0	1
N/A	0	0	0	0	0	0	0	0	0
Total Responses	11	11	11	11	11	11	11	11	11
Blank	3	3	3	3	3	3	3	3	3
Total	14	14	14	14	14	14	14	14	14
% 1	7	14	7	7	7	0	0	7	14
% 2	14	0	7	14	0	0	0	29	29
% 3	14	7	14	7	14	14	36	36	29
% 4	21	29	14	29	36	21	21	7	0
% 5	21	29	36	21	21	43	21	0	7
% N/A	0	0	0	0	0	0	0	0	0
% Response	79	79	79	79	79	79	79	79	79
% Blank	21	21	21	21	21	21	21	21	21
% Total	100	100	100	100	100	100	100	100	100

Table B19. Question 10 Responses

Local	0	**% Local**	0
State	3	**% State**	27
Special	2	**% Special**	18
Other	2	**% Other**	18
Total Responses	7	**% Response**	64
Blank	4	**% Blank**	36
Total	11	**% Total**	100
Other Responses			
Special based on strategy (transit, toll, state, etc.)			
Operating Toll Authority			

Table B20. Question 11 Responses

Rating	Electronic Toll Collection	Auto Vehicle ID	License Plate Recognition	Weigh-in Sensors	Speed Detection	Auto Vehicle Occupancy	Cameras
1	0	0	0	2	1	0	0
2	0	0	0	3	3	2	1
3	0	1	2	4	5	2	2
4	7	7	8	0	1	3	6
5	4	3	1	2	1	3	2
N/A	0	0	0	0	0	0	0
Responded	11	11	11	11	11	10	11
Blank	3	3	3	3	3	4	3
Total	14	14	14	14	14	14	14
% 1	0	0	0	14	7	0	0
% 2	0	0	0	21	21	14	7
% 3	0	7	14	29	36	14	14
% 4	50	50	57	0	7	21	43
% 5	29	21	7	14	7	21	14
% N/A	0	0	0	0	0	0	0
% Response	79	79	79	79	79	71	79
% Blank	21	21	21	21	21	29	21
% Total	100	100	100	100	100	100	100

Table B21. Question 12 Responses

Issue	Rating
harge all vehicles	5
automated tolling	4
Communications	5
visible lane permits	5

Table B22. Question 13 Responses

Additional Comments for Enforcement
Automated Vehicle Occupancy Detection does not exist.
By charging all vehicles many of the enforcement issues disappear. With Growing interest in Hybrid cars HOT lanes could be congested with SOVs. Due to occupancy levels the tolls are automatically split by riders and automatically cheaper than SOVs
Additional facilities and new types of operations will require public education and enforcement. This will require resources to make the facilities successful. "Visible lane permits" is supposed to refer to a sign or decal that motorists in a managed lane display for enforcement purposes, as well as for mainline motorists (to reduce their aggravation about apparent violation rates).

Table B23. Question 14 Responses

Leased	1	**% Leased**	9
Local Owned	1	**% Local**	9
State Owned	1	**% State**	9
Combination	3	**% Combination**	27
Other	1	**% Other**	9
Total Responses	7	**% Response**	64
Blank	4	**% Blank**	36
Total	11	**% Total**	100
Other Responses			
Owned by the Toll Authority			

Table B24. Question 15 Responses

use shared communication equipment lines		5
support video and data on the same network		5
send all communications to a central point for dissemination		5
have the ability to send communications to multiple agencies		8
Support the needs of:	Operations	7
	Maintenance	7
	Enforcement	8
	Traveler Information Systems	6
% use shared communication equipment lines		45
% support video and data on the same network		45
% send all communications to a central point for dissemination		45
% have the ability to send communications to multiple agencies		73
Support the needs of:	% Operations	64
	% Maintenance	64
	% Enforcement	73
	% Traveler Information Systems	55

Table B25. Question 16 Responses

Additional Comments for Communication
On private sector HOT lanes they would decide communications system.
Not too many opinions on this topic.

Table B26. Question 17 Responses

Yes	7
No	0
Not Sure	0
Total Responses	7
Blank	4
Total	11
% Yes	64
% No	0
% Not Sure	0
% Response	64
% Blank	36
% Total	100

Table B27. Question 18 Responses

Agency	Planning	Response
Local Police	8	7
Special Police Force	7	7
State Police	8	7
Transit Agencies	10	6
State Department of Transportation	10	7
Toll Authorities	11	5
Emergency Services	9	10
Regional Mobility Authority	7	1
Metropolitan Planning Organization	7	0
% Local Police	57	50
% Special Police Force	50	50
% State Police	57	50
% Transit Agencies	71	43
% State Department of Transportation	71	50
% Toll Authorities	79	36
% Emergency Services	64	71
% Regional Mobility Authority	50	7
% Metropolitan Planning Organization	50	0

Table B28. Question 19 Responses

Rating	Central Dispatch	Common Equip.	Shared Network	Shared Radio	Regional Planning	Inter-agency Agreements
1	0	0	0	1	0	0
2	2	0	1	1	0	0
3	1	4	1	2	2	1
4	3	2	4	1	5	5
5	3	3	4	4	3	3
N/A	1	1	0	1	0	1
Total Responses	10	10	10	10	10	10
Blank	4	4	4	4	4	4
Total	14	14	14	14	14	14
% 1	0	0	0	7	0	0
% 2	14	0	7	7	0	0
% 3	7	29	7	14	14	7
% 4	21	14	29	7	36	36
% 5	21	21	29	29	21	21
% N/A	7	7	0	7	0	7
% Response	71	71	71	71	71	71
% Blank	29	29	29	29	29	29
% Total	100	100	100	100	100	100

Table B29. Question 19 Responses Continued

Other Potential Solutions	Rating
radio interoperability	5
traffic management centers	4
media communication	4
alt. route planning	3

Table B30. Question 20 Responses

Potential Strategies
Visual barriers between HOT lanes & regular lanes ideal
Fast response; quick clearance. Respond with just the necessary equipment rather than the full range of emergency responders. Investigate anti-gawk screens. If resources are available, have officers speed traffic up on adjacent facilities.

Table B21. Question 21 Responses

Additional Comments for Incident Management
Provide adequate resources to be the best possible or if privately owned this should happen automatically to improve returns.

Table B22. Question 22 Responses

Issue	Comments
Drainage	If managed lanes are barrier separated, areas for water retention and for snow placement are not found within the "typical section" Areas for these functions must be included in the planning and design process.
Drainage	No flooding on the managed lanes.
Drainage	It is very likely that drainage facilities (located on inside shoulder or other) are impacted in the conversion to managed lane operation. Costs to re-locate or re-design these facilities can be significant.
Repaving	Some managed lane facilities are converted shoulders, this leaves no room for maint. of traffic during resurfacing or incident management.
Mowing and Beautification Operations	Limited opportunities but similar to divided highways, small (width) areas between moving lanes of traffic should not be greened unless there is a safe clear zone for maintenance activities to occur in.
Equipment Upgrades	Managed lanes adjacent or within existing highway facilities will require more automation to minimize exposure of personnel.
Striping	Striped appropriately and once a year
Signing and Signal Maintenance	Light maintenance systems and other automated devices that reduces personnel exposure to traffic and/or reduces the need for lane closures are important.

Table B32. Question 23 Responses

Additional Comments for Maintenance
All of the above are important, each address a specific requirement and need.
All the above are normal maintenance activities.
No comments here.
While maintenance may likely reduce operations temporarily, design the system so that it will not require shutdown of system.

Table B33. Question 24 Responses

Additional Comments
The 3 toll authorities, major airports, and any new RMA's need to be resolving this issue now. It needs to be very easy for regional and statewide travelers to seamlessly access toll roads, no matter who builds or operates it.
Reversible lanes should become standard where volumes & ROW justify (two- one-way, two- one-way & one in opposing direction)
Get public input in the planning process so you better appreciate public concerns.

STEPHEN SONG

Stephen Song is from Houston, TX. He currently attends Cornell University, where he is majoring in Civil and Environmental Engineering and he plans on graduating in May 2005. Prior to coming to Cornell, he studied at the University of California – Berkeley for one year. At Cornell, he is a teaching assistant for an AutoCAD class, and he enjoys playing intramural ice hockey. He is also a member of ASCE, and has competed in the concrete canoe competition with both Berkeley and Cornell. Stephen plans to attend graduate school, but he is still undecided as to what field he will pursue.

EVALUATION OF THE EFFECTIVENESS OF DUAL PORTABLE CHANGEABLE MESSAGE SIGNS (PCMS) IN THE DISPLAY OF A SINGLE MESSAGE

by

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SUMMARY

Portable changeable message signs (PCMS) are an excellent means of conveying traffic information to motorists. To ensure the continuing, effective use of PCMS, research must be done to make certain the signs are being implemented correctly. This pilot-study research focused on the possible use of dual PCMS versus a single large sign in the display of a single four-unit message. In the dual PCMS configuration, each PCMS presented two units of information of the message, while the single large sign presented all four units of information at one time. In addition to investigating the effectiveness of splitting the message into two, two-unit portions, the separation distance between the dual signs was simulated to be either 1000 feet apart (resulting in a 4.4 second pause between the display of the first and second portions of the message and 2640 feet apart (resulting in a 24.7 second pause between message portions). The use of these signs was tested by a laptop computer simulation in which subjects saw simulated messages on the computer screen while performing a simple task using the computer mouse as a way to simulate driver workload. The effectiveness of the signs was measured through questions recording the comprehension and retention of the information seen.

Data were collected and sorted for analysis in terms of percentage of correct responses. The percentage of correct responses was plotted against the question asked to determine trends within the data. These plots showed little impact in separation distance and, surprisingly, that a dual PCMS configuration performed better than presenting all information on a single sign, particularly in terms of retaining the last two units of information presented in the message.

Being a pilot study, the research succeeded in showing how the future research can be done effectively and the trends on which to focus. Further analysis of separation distances should be done with a larger sample size to confirm the apparent insignificance of the variable from the research. Future research should focus on many variations on a dual PCMS configuration, such as exposure time, information unit ordering, and message breakdown.

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INTRODUCTION

As the amount of traffic volume on all types of roadways increases, the need for better traffic control and roadway organization in cases of accidents or roadwork becomes increasingly important. Increasing traffic volumes cause a dramatic increase in the amount of maintenance and construction required for the upkeep of the transportation infrastructure. Aside from implementing work zone traffic control, motorists must be made aware of disruptions in normal traffic flow that may come from accidents or other traffic incidents.

The need for improving traffic safety and mobility under congested conditions requires effective communication of current roadway conditions to motorists. A widely-used form of communicating information to motorists is the Portable Changeable Message Sign (PCMS). The frequent use of PCMS is primarily due to versatility and ability to quickly convey real-time information to motorists (*1*). The signs can be moved and changed quickly to convey traffic information to motorists and ease or prevent traffic congestion by suggesting an alternative route.

Although they provide an effective means of communication with motorists, the improper use of PCMS may lead to confusion, which can worsen traffic flow and safety characteristics in some instances (*2*). It is also interesting to note that PCMSs operate very similarly to larger permanent dynamic message signs, perhaps the most familiar aspects of Intelligent Transportation Systems to the public, so it is necessary to operate PCMS in as effective and applicable manner as possible (*3*).

Many applications of PCMSs have been documented thoroughly and are now governed to some degree by federal guidelines. These applications include Advisory Signs, Guide Signs, and Advance Signs (*4*). Conversely, there are several aspects of the operation of PCMS that have not been extensively researched and thus are open to research to determine their effective application (*1*).

LITERATURE REVIEW

In order to fully understand the project and previous research, a review of relevant literature was done. This review ensured the researcher the proper knowledge and perspective needed to conduct relevant and useful research. The specific points of interest and information found in the literature are as follows:

- Use of PCMS vs. Traditional Static Signs and large permanent Dynamic Message Signs (DMS) - Review of this topic led to the decision to use a large single sign as our control in the experiment,
- Variation, Format, and Layout of PCMS- A study of information type, exposure time, and sign spacing along roadsides led to the choice of 2 variables to be tested: separation distance and sign format,
- Surveying Procedures- Previous research projects concerning PCMS were consulted as a basis and template for message design and questioning methods for the research, and
- Statistical Analysis- A brief review of statistical methods was done for the analysis portion of the research.

RESEARCH OBJECTIVES

The specific area in the use of PCMSs that was researched and documented in this paper is the use of dual PCMSs to display a single message. Research for this particular implementation of PCMS continued from previous work done in the field using similar techniques of data collection and analysis used in previous projects (*2*). The effectiveness of using two consecutive PCMSs to display one four unit message was to be determined. The study consisted of comparing the motorist comprehension and information retention of a single message either divided into two parts and placed on two consecutive

PCMSs, or placed on one large single DMS. The large single sign served as a reference in the study. The experiment was done using previously developed software and a laptop computer. It is important to note that this was a pilot study and the analysis of this research has given insight into the continuing research of improvement and new implementation of PCMSs.

This research project had the following three objectives:

- Determine the level of comprehension and retention of information viewed on dual PCMSs as compared to being presented on a single DMS,
- Determine the effects of the separation distance between the two PCMSs on the comprehension and retention of information viewed, and
- Analyze the results of this data and determine if using a dual PCMS configuration, and varying the distance between the dual signs produces suitable comprehension and retention levels for motorists.

PROCEDURE

The procedure will outline the basic steps of the research.

Study Methods

The success of Data Collection depended primarily on the proper and exact development of the method to be used. Subjects were tested using a laptop computer that simulates a driving experience with previously developed software. The software displays messages at specified rates and lengths of exposure while requiring the subject to focus on a side activity to simulate driver workload. The subjects consisted of 60 non- traffic engineering Texas Transportation Institute (TTI) employees. The use of a laptop enabled the researcher to go to the subjects as opposed to having each employee report to a driving simulator at a scheduled time.

Message Development

The experiment consisted of testing of two different messages on simulated PCMS signs, as well as simulation of the same two messages (counterbalanced among the subjects) on a single large sign. Two messages were required so the subjects would not see the same information twice; this ensured that the subjects had not already learned the information and thus gave a true measure of their retention and comprehension. The two test messages contained 4 units of information over which 4 questions were asked after the simulation. Figure 1 contains the test messages and formats used while Appendix A contains test messages and questions.

In the case of the single large sign, the display or exposure time was 8 seconds keeping with the recommended 2 seconds per unit of information (*4*). The information on the dual signs was displayed with the first two units alternating, for 2 seconds each and a total of 2 cycles on the first sign and the last two units alternating on the second sign.

Separation Distance

In order to test the effect of differing separation distances between the dual signs, two separation distances of 1,000 feet and 2,640 feet were converted into measures of time for use in the simulation. After the viewing of the first sign, the distance traveled between the first and second sign was simulated as a wait time in which no message was seen. See Figure 2 for the 1,000-foot example. We assumed a traveling speed of 55 mph for work zones and a reading threshold of 650 feet (8 seconds) prior to the sign (*3*). These assumptions lead to a separation time of 4.4 seconds for 1,000 feet and 27.4 seconds for 2,640 feet.

Test Message 1:

DUAL SIGN CONFIGURATION

SIGN 1:	SIGN 2:
PHASE 1:	PHASE 1:
ROADWORK	**2 LANES CLOSED**
PHASE 2:	PHASE 2:
WED-FRI	**NEXT 5 MILES**

SINGLE SIGN CONFIGURATION

ROADWORK WED-FRI
2 LANES CLOSED
NEXT 5 MILES

Test Message 2:

DUAL SIGN CONFIGURATION

SIGN 1:	SIGN 2:
PHASE 1:	PHASE 1:
ACCIDENT	**LEFT LANE CLOSED**
PHASE 2:	PHASE 2:
AT 255	**EXPECT DELAYS**

SINGLE SIGN CONFIGURATION

ACCIDENT AT 255
LEFT LANE CLOSED
EXPECT DELAYS

Figure 1. Test Messages and Formats

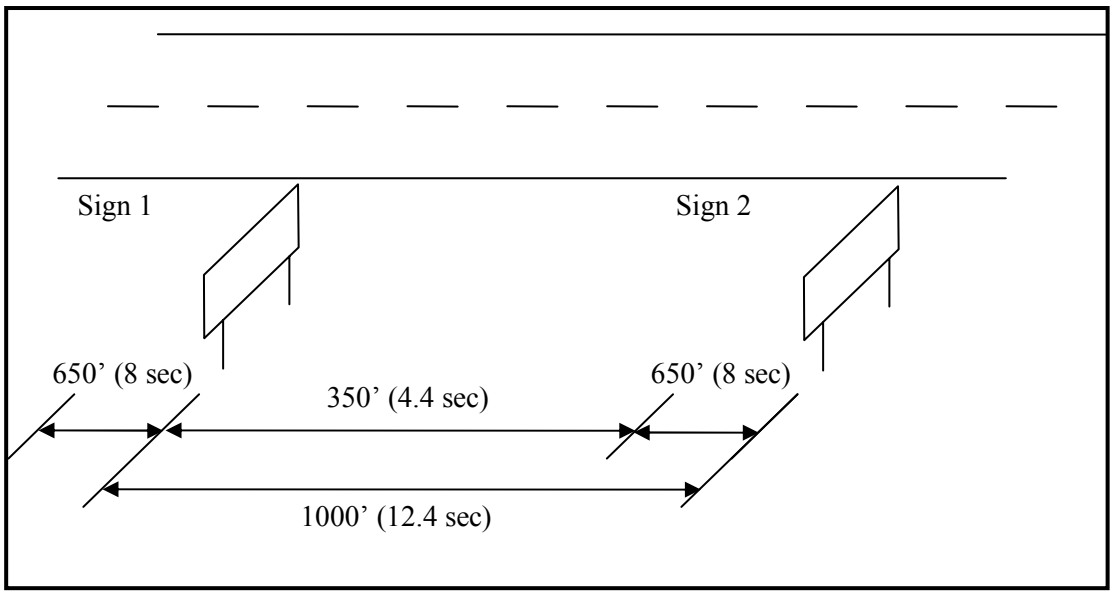

Figure 2. Timing Breakdown for 1000’ Separation Distance

Data Collection Procedures

Data were gathered using questions over the information viewed in the laptop simulation. It was necessary to have 4 variations of the test and survey because 2 variables, format and separation distance, were being tested. Both surveys contained 2 test messages, one being the single sign format and one being the dual sign format. The surveys were counterbalanced such that one survey showed the test messages in each format and the other survey variation each test message in an opposite format. In addition to the 2 survey variations, 30 subjects took the survey at 1000 feet and 30 took the survey at 2640 feet; therefore, 15 subjects took each variation of the test. The questions asked in the survey after each set of signs tested comprehension and retention of the following units of information:

- Source of the traffic problem,
- Physical nature of the traffic problem,
- Location of the traffic problem, and
- Advisory information concerning the traffic problem.

In addition to the rigorous planning and implementation of the test messages, each survey contained two example sets and two "dummy" sets of signs and questions before the test questions. The purpose of these preceding questions was to acclimate the subjects to the simulation program and eliminate uncertainty and confusion as data were being collected.

Data Analysis

In order to get useful information, the data were reduced by recording the answers given to each test question and determining whether the response given was correct, incorrect, or was not remembered. The response given was said to be correct if, when compared to the other responses to a particular question, the general idea was both comprehended and retained. The data were analyzed by sorting and evaluating the data according to percentages of correct responses for each question. Appendix B contains these percentages and the responses given. Analysis was performed on the following comparisons:

- 1 Sign vs. Dual Signs at 1000',
- 1 Sign vs. Dual Signs at 2640', and
- Dual Sign separation of 1000' vs. 2640'.

The analysis consisted of individual test message comparisons of the percentages of correct responses between the formats and separation distances. The purpose of this test was to look for trends in the behavior of the responses and the effect of the variables on the responses. A test of proportions was done, but because the sample size was small (as a pilot study) very few statistically significant results were found. The element tested in the test of proportions was the percentage of correct response for each question in the four groups (format tests over the two separation distances and separation distance tests over the two formats).

RESULTS

Correct responses for each test message were plotted against the question asked to create graphs in which trends could be seen in the data. An exhaustive listing of the data from the results tests is available in Appendix C. It was assumed that message content would not significantly affect the responses and thus, trends could be seen in analyzing the presented comparisons.

The format comparisons showed very similar trends in the number of correct response between both the dual signs and the single signs individually. As shown in Figure 3 in the case of the single signs, the percentage of correct responses decreased with each unit of information in the message, and then spiked higher for the last unit of information presented in the message. With the exception of test message 2 in the 1,000-foot case, all single sign configurations exhibited this behavior. After the responses from this exception were reexamined to determine possible reasoning for this deviation, no clear message confusion or other reason could be determined. It is possible that a larger sample size with more responses may show a more consistent trend. The dual signs showed a completely consistent trend in which the first unit of information presented on the first PCMS was retained well, and the third and fourth units (presented on the second PCMS) were retained as well or better than the single sign format. Figure 3 illustrates subjects at both distances were more likely to remember the last units of information (between 80 and 100 percent for the last unit of information), whereas only 35 to 60 percent of subjects remembered this information when presented on a single sign. One possible reason for this could be the amount of time the subject was required to retain the information. In the case of the single sign format, the subject was forced to retain the third and fourth units of information for as long as the first and second. Contrast this with the dual sign format in which the third and forth units of information would have to be remembered for a smaller period of time because the second of the dual signs appears further downstream on the roadway. This suggests that the use of dual signs may be more conducive to motorist retention of information, especially in the last units, when motorists must also share attention between reading the information and performing other tasks.

With the exception of the question regarding location in test message 1 in Figure 4, all correct response percentages were extremely close for each distance. The second unit of information showed on the single sign showed an inconsistent trend possibly due to the type of information shown (location vs. advisory information). An interesting occurrence on both test messages showed the percentage of correct responses on the third unit of information was the same. As the third unit of information is the first unit seen after the separation distance (for the dual PCMS display configuration), the similarity in responses shows that separation distance may have little or no effect on retention and comprehension.

The null hypothesis, for the test of proportions, was that the test proportion for choice 1 (Single Sign in the format tests) was equal to the test proportion for choice 2(Dual Sign in the format tests). The alternate hypothesis was that the two proportions were not equal. The null hypothesis was rejected if the test statistic, Z, was greater than 1.96, which corresponds to a level of significance of α equal to 0.05. Rejecting the null hypothesis indicated there was a significant difference in the number of correct responses given in each test (*5*).

Test Statistic for Test of Proportions (*5*)

$$Z = \frac{f_1 / n_1 - f_2 / n_2}{\sqrt{\frac{f_1 + f_2}{n_1 + n_2}\left(1 - \frac{f_1 + f_2}{n_1 + n_2}\right)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Where:

f_1= number of correct responses from choice 1,
f_2= number of correct responses from choice 2,
n_1= number of responses in choice 1, and
n_2= number of responses in choice 2.

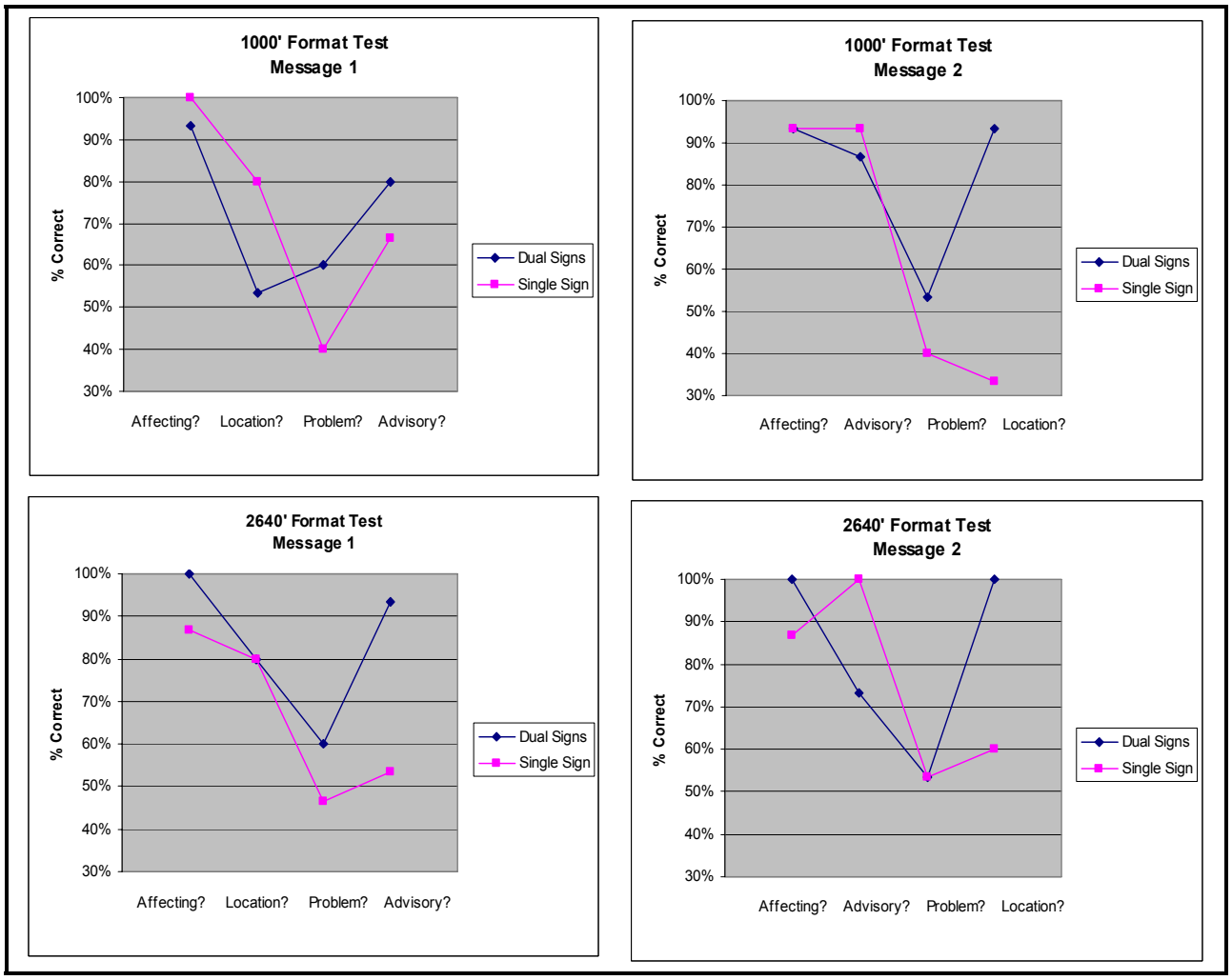

Figure 3. Format Comparison

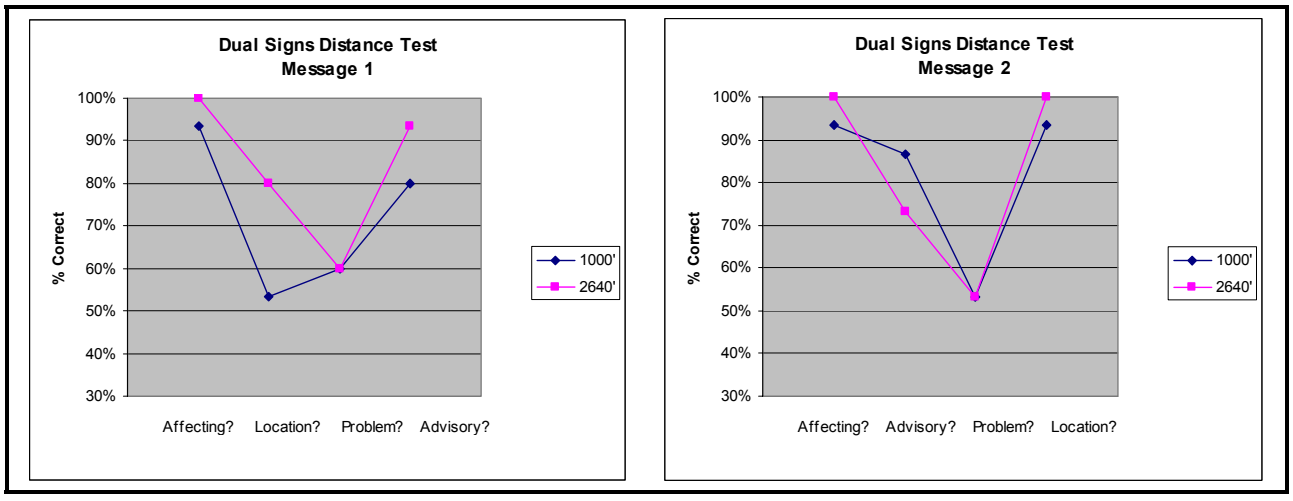

Figure 4. Separation Distance Comparison

The statistical test of proportions yielded one statistical difference in the percentage of correct responses concerning "What was affecting traffic?" in the 2,640-foot format test. As this significant difference was an isolated case within the data, it is clear that a larger sample size is needed for a more accurate test of proportions. Information on the demographic used can be found in Appendix D.

CONCLUSIONS

After analyzing these results, there are a few points that need reiterating. Plots of the data were constructed and used to determine possible trends in the number of correct responses for each question in each test message. The conclusions made were as follows:

- There is little advantage or drawback in sign spacing when using dual signs, as most of the questions compared had similar percentages of correct responses.
- The dual sign configuration was shown to be more effective than a single sign in displaying four units of information in a way that subjects could remember. This was especially true in the case of the third and fourth units of information displayed.
- A statistical test revealed the need for a larger sample size in future research.

RECOMMENDATIONS

As this was a pilot study, the recommendations here are for future research. The idea of using dual signs to convey messages that are too long for single PCMSs should be researched further as there is evidence that the dual signs may perform better. It is recommended that attention be given to the testing of format comparisons, specifically memory issues with the splitting up of a message that were beyond the scope of this project. There is a need to find and eliminate possible message variables, such as order and information type; this need was shown in the consistent spikes that appeared in the data. A focus on effectively setting up and testing the message format will provide useful information into the proper implementation of PCMS. In addition to these focus points, thought should be given on possible ways to let the motorist know that the first in a pair of dual signs is going to be followed with a second. This was a concern during the research as generally all subjects had to be told the set up of the dual sign configuration during the example sets of signs.

ACKNOWLEDGEMENTS

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- Geza Pesti,
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APPENDIX A: SURVEY TEST QUESTIONS AND FORMATS

Survey 1a

Test Message 1 (1P1a-b):

SIGN 1:

PHASE 1:

ROADWORK

PHASE 2:

WED-FRI

SIGN 2:

PHASE 1:

2 LANES **CLOSED**

PHASE 2:

NEXT **5 MILES**

Questions:

1. What is affecting traffic? ○ _____
2. What is the traffic problem? ○ ○ ○ _____
3. Where is the traffic problem located? ○ ○ ○ _____
4. When will the traffic be affected? ○ ○ ○ _____

Test Message 2 (2S1):

ACCIDENT AT EXIT 255 **LEFT LANE CLOSED** **EXPECT DELAYS**

Questions:

1. What is the effect on traffic? ○ ○ _____
2. What is affecting traffic? ○ _____
3. Where is the traffic problem located? ○ ○ ○ _____
4. What is the traffic problem? ○ ○ ○ _____

Survey 2a
Test Message 1 (1P2a-b):

SIGN 1:

PHASE 1:

ACCIDENT

PHASE 2:

AT **EXIT 255**

SIGN 2:

PHASE 1:

LEFT **LANE** **CLOSED**

PHASE 2:

EXPECT **DELAYS**

Questions:

1. What is affecting traffic? ○ _____
2. What is the traffic problem? ○ ○ ○ _____
3. Where is the traffic problem located? ○ ○ ○ _____
4. What is the effect on traffic? ○ ○ _____

Test Message 2 (2S1):

ROADWORK WED-FRI **2 LANES CLOSED** **NEXT 5 MILES**

Questions:

1. When will the traffic be affected? ○ ○ ○ _____
2. What is affecting traffic? ○ _____
3. Where is the traffic problem located? ○ ○ ○ _____
4. What is the traffic problem? ○ ○ ○ _____

APPENDIX B: SURVEY DATA AND RESPONSES

Table B1. What is the traffic problem?

Dual Signs

1000'
Message 1 (a)- 2 Lanes Closed
Message 2 (b)- Left Lane Closed

2640'
Message 1 (a)- 2 Lanes Closed
Message 2 (b)- Left Lane Closed

	Correct		Other Responses		Correct		Other Responses
a	9		Lanes Closed	a	9		Lane closed (2)
			its closed				closed
			delays				Didn't Remember(3)
			Didn't Remember(3)				
b	7		Lane Closed (5)		8		Lane closed(4)
			something in the left lane	b			traffic is stopped
			b- closed down				closed
			Didn't Remember(1)				Didn't Remember(1)

Single Sign

1000'
Message 1 (a)- Left Lane Closed
Message 2 (b)- 2 Lanes Closed

2640'
Message 1 (a)- Left Lane Closed
Message 2 (b)- 2 Lanes Closed

	Correct		Other Responses		Correct		Other Responses
a	6		2 lanes closed	a	7		lane closed(2)
			lane closed				2 lanes closed
			its closed				delays
			road blocked				exit 255 closed
			Didn't Remember(5)				closed
							Didn't Remember(2)
b	7		Lanes closed(2)	b	8		some lane closed
			delays(2)				closed
			closed down				delays
			its closed				closed down
			Didn't Remember(2)				Didn't Remember(3)

Table B2. What is the affecting traffic?

Dual Signs

1000'
Message 1 (a)- Roadwork
Message 2 (b)- Accident

2640'
Message 1 (a)- Roadwork
Message 2 (b)- Accident

	Correct		**Other Responses**		**Correct**		**Other Responses**
a	14		Didn't Remember(1)	a	15		none
b	14		Didn't Remember(1)	b	15		none

Single Sign

1000'
Message 1 (a)- Accident
Message 2 (b)- Roadwork

2640'
Message 1 (a)- Accident
Message 2 (b)- Roadwork

	Correct		**Other Responses**		**Correct**		**Other Responses**
a	15		none	a	13		Didn't Remember(2)
b	14		Didn't Remember(1)	b	12		construction
							Didn't Remember(2)

Table B3. Where is the traffic problem located?

Dual Signs

1000'
Message 1 (a)- Next 5 miles
Message 2 (b)- Exit 255

2640'
Message 1 (a)- Next 5 miles
Message 2 (b)- Exit 255

	Correct		**Other Responses**		**Correct**		**Other Responses**
a	8		Didn't Remember(7)	a	12		Didn't Remember(3)
b	13		255	b	13		255 (2)
			Didn't Remember(1)				

Single Sign

1000'
Message 1 (a)- Exit 255
Message 2 (b)- Next 5 miles

2640'
Message 1 (a)- Exit 255
Message 2 (b)- Next 5 miles

	Correct		**Other Responses**		**Correct**		**Other Responses**
a	11		255	a	9		255 (3)
			next exit				lane 255
			Didn't Remember(2)				Didn't Remember(2)
b	5		next 2 miles	b	9		some miles ahead
			exit 255				Didn't Remember(5)
			Didn't Remember(8)				

Table B4. What advisory information is given?

Dual Signs

1000'
Message 1 (a)- Wed-Fri
Message 2 (b)- Except Delays

2640'
Message 1 (a)- Wed-Fri
Message 2 (b)- Except Delays

	Correct		**Other Responses**		**Correct**		**Other Responses**
a	12		Mon-Fri	a	14		Didn't Remember(1)
			Tues-Fri				
			Mon-Thurs				
b	13		expect something	b	11		slowed traffic
			Didn't Remember(1)				traffic will slow down
							Didn't Remember(2)

Single Sign

1000'
Message 1 (a)- Except Delays
Message 2 (b)- Wed-Fri

2640'
Message 1 (a)- Except Delays
Message 2 (b)- Wed-Fri

	Correct		**Other Responses**		**Correct**		**Other Responses**
a	10		take longer	a	8		slowed traffic
			it will stop				closed lanes
			accidents				Didn't Remember(5)
			Didn't Remember(2)				
b	14		b- Mon-Fri	b	15		none

APPENDIX C: RESULTS

Table C1. Test of Proportions

From 1a and 1b

(T1 Dual)

	1	*2*	*3*	*4*
Correct	28	17	22	25
Incorrect	0	8	0	4
Didn't know	2	5	8	1
Total	30	30	30	30

(T2 Single)

	1	*2*	*3*	*4*
Correct	29	13	17	24
Incorrect	0	8	3	4
Didn't know	1	9	10	2
Total	30	30	30	30

1000' Format Test		*1*	*2*	*3*	*4*
Z scores		-0.59	1.03	1.35	0.33

2640' Format Test		*1*	*2*	*3*	*4*
Z scores		2.07	0.52	1.94	0.65

Dual Sign Distance Test		*1*	*2*	*3*	*4*
Z scores		-1.44	0.00	-1.67	0.00

From 2a and 2b

(T1 Dual)

	1	*2*	*3*	*4*
Correct	30	17	27	25
Incorrect	0	9	0	2
Didn't know	0	4	3	3
Total	30	30	30	30

(T2 Single)

	1	*2*	*3*	*4*
Correct	26	15	21	23
Incorrect	0	7	2	2
Didn't know	4	8	7	5
Total	30	30	30	30

1	Affecting
2	Problem
3	Location
4	Advisory

Individual Message Plots

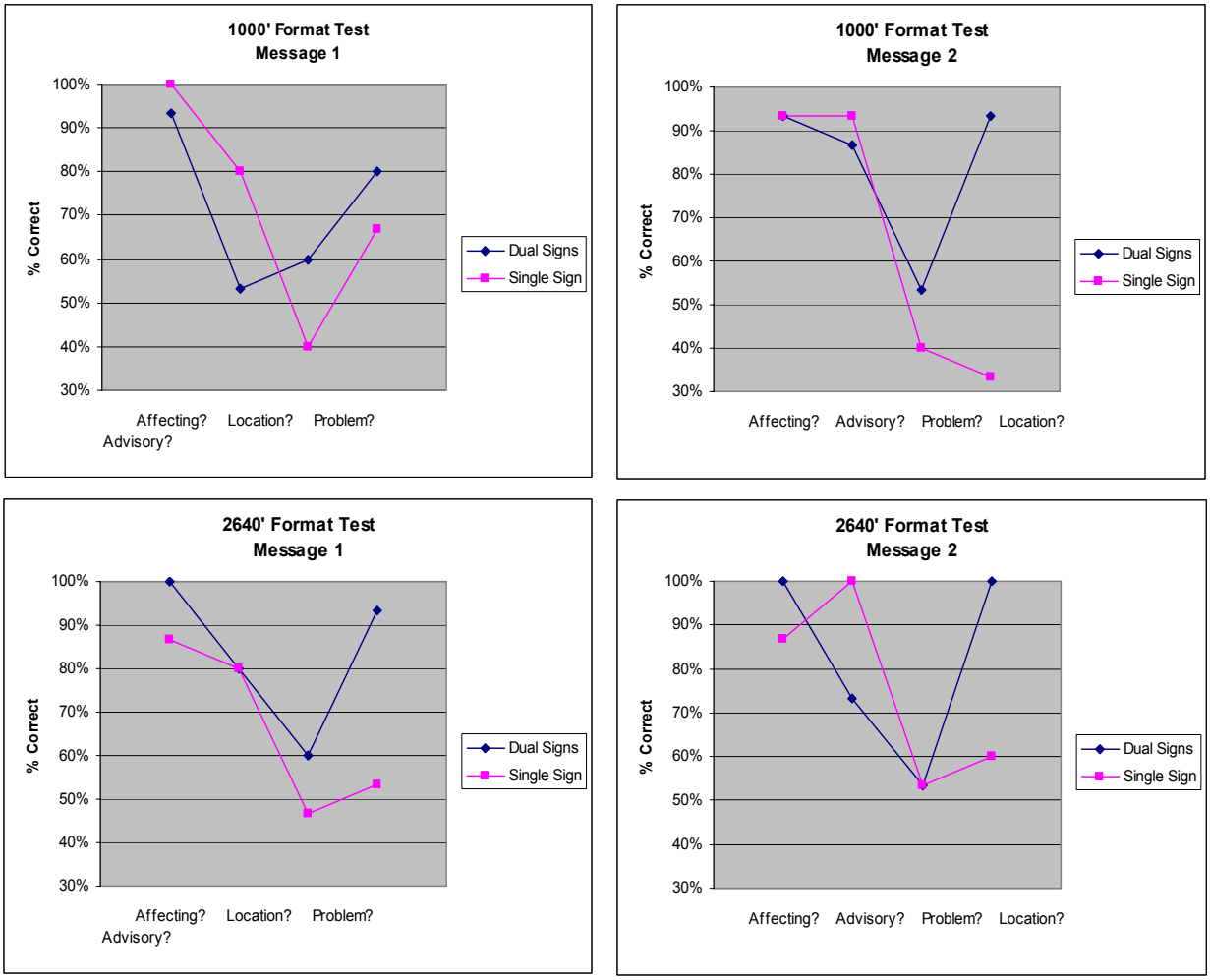

Figure C1. Format Test

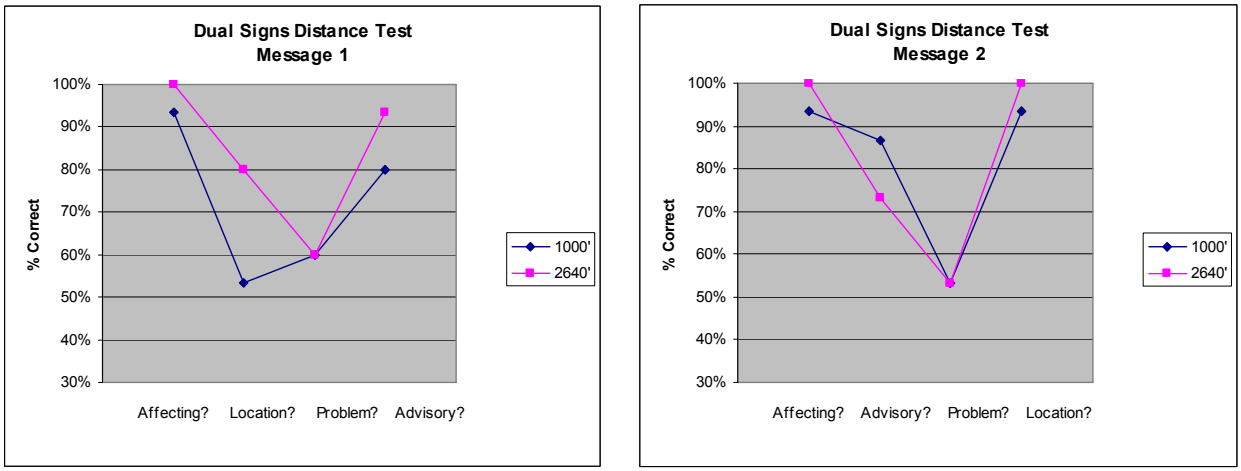

Figure C2. Distance Test

APPENDIX D: DEMOGRAPHIC DATA

Table D1. Subject List

Subject	Age	Education	Group
1	51	College	1a
2	24	College	2b
3	20	College	2a
4	26	High School	1b
5	20	College	1a
6	33	High School	1b
7	19	College	2a
8	44	High School	2b
9	50	College	1a
10	44	College	1b
11	25	College	2a
12	28	College	2b
13	51	College	1a
14	51	College	1b
15	22	College	2a
16	56	College	2b
17	38	College	1a
18	41	College	1b
19	48	College	2a
20	49	College	2b
21	53	College	1a
22	33	College	1b

23	55	College	2a
24	32	College	2b
25	48	High School	1a
26	38	High School	1b
27	36	College	2a
28	42	College	2b
29	59	High School	1a
30	50	High School	1b
31	34	College	2a
32	45	College	2b
33	47	College	1a
34	19	College	1b
35	43	High School	2a
36	48	College	2b
37	22	College	1a
38	35	College	1b
39	35	College	2a
40	35	College	2b
41	45	College	1a
42	22	College	1b
43	21	College	2a
44	34	College	2b
45	29	College	1a
46	57	College	1b
47	22	College	2a
48	44	College	2b

49	47	College	1a
50	52	College	1b
51	48	College	2a
52	26	College	2b
53	20	College	1a
54	53	High School	1b
55	19	College	2a
56	21	College	2b
57	19	College	1a
58	21	College	1b
59	23	College	2a
60	19	College	2b

Table D2. Demographic Breakdown

Age	**High School Diploma or Less (50%)**	**Some College or College Degree (50%)**	**Total**
18-39 (47%)	3	30	33
40-54 (29%)	4	19	23
55+ (24%)	1	3	4
Total	8	52	60

BRETT STORY

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EVALUATION OF HORIZONTAL SIGNING APPLICATIONS

by

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SUMMARY

The objective of this research was to evaluate the effect of horizontal signs on driver behavior. Sites were chosen where researchers believed the installation of horizontal signing could provide the greatest benefits to traffic safety. As a result, emphasis was then placed on resolving two major issues: lane conflicts on two-way frontage roads and speed reduction in rural curves. Before and after data was collected from sites in Abilene, Blackwell, and College Station.

The research found in this report is a small segment of a much larger project being sponsored by the Texas Department of Transportation. Further research will involve: analyzing speed reduction in an urban curve, obtaining driver feedback using video and still photos, and analyzing the durability of materials.

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INTRODUCTION

As the population continues to grow and the number of drivers increases, a greater emphasis is being placed on improving the safety and efficiency of transportation. New ideas and techniques are sought to help reach these goals. One such idea currently being studied is the implementation of horizontal signing.

Horizontal signs are the use of pavement markings in lieu of vertical signs or as a supplement to vertical signs to guide people in transportation situations (*1*). These markings can be used to convey regulatory, warning, or guidance information to travelers. Horizontal signs have two distinct advantages over vertical signs. One advantage is that horizontal signs are more economical than vertical signs. These vertical signs are often placed along the shoulder of the roadway, and in some instances overhead multiple lanes of traffic making them extremely expensive (*2*). The other advantage horizontal signs have over vertical signs occurs in the area of aesthetics. Horizontal signs lie flat, tightly fixed to the road surface making them rather inconspicuous. Vertical signs on the other hand, often clutter up the surrounding environment. Even with these advantages however, a number of issues remain in order for them to become more predominantly used (*2*):

- Visibility,
- Durability, and
- Drivers' acceptance.

Visibility addresses a driver's ability to see and process information from these signs. These messages must be conveyed regardless of the time of day or current weather conditions. This visibility relies heavily on the marking material and roadway surface. Another factor affecting the visibility of horizontal signs is traffic density. Heavily congested areas can often obstruct a driver's view of the roadway. By hindering this view, the likelihood that these signs are effective is greatly reduced.

Durability of pavement markings is also of great concern. These materials will experience a great deal of wear and tear, especially in areas with large amounts of daily traffic. Some could be located in dense areas where it might impossible to access them quite frequently, meaning they must be able to suffice to the necessary design life. Concerns include but are not limited to:

- Dirt,
- Color fading,
- Loss of reflectivity, and
- Worn areas.

The final issue addresses how these signs would be accepted. It remains unclear whether drivers would successfully acknowledge or obey the regulatory, warning, or guidance information that these signs would provide. While horizontal signing has several advantages, further research is required to resolve these issues.

LITERATURE REVIEW

While visibility and durability issues remain, analyzing the effects of horizontal signs on driver behavior is important. A key objective of this project was to examine situations in which their use may have resulted in levels of safety and efficiency greater than those previously observed. These areas included a two-way frontage road in College Station and a set of rural curves located in the Abilene district. To assist in these evaluations research pertaining to experimental design, field data collection methods, measures of effectiveness, and data analysis was sought (*3*).

A study by Lyles in the late 1970s evaluated the effectiveness of curve signs supplemented by various advisory and regulatory speed signs for controlling speeds at horizontal curves (*4*). Researchers hypothesized that typical curve signs and speed advisories were less effective in large part to overuse, being overly conservative, and being used inconsistently (*3*). In response, researchers used a pair of horizontal curves on rural two-lane highways to test five different curve sign configurations. Speed data were collected throughout the curve, as well as the approach. Principle dependent variables were (*3*):

- initial speed change,
- speed changes in the vicinity of the sign locations,
- speed at the curve itself,
- distance from the entry point to that of minimum speed, and
- speed upon exiting the curve.

The study found that no configuration was seemingly more effective than any of the others in regard to alleviating the number of potential accidents.

Retting and Farmer evaluated the effectiveness of a curve warning message placed on the pavement surface as a supplement to typical curve signing on a suburban two-lane highway (*5*). The message consisted of the word "SLOW" followed by a curve arrow. Before and after speed data were collected from the curve approach using pneumatic road tubes. Principle dependent variables included:

- mean speed,
- 90th percentile speed, and
- percentage of vehicles exceeding given speed thresholds.

The curve warning message resulted in statistically significant reductions of both day and nighttime speeds.

The literature review proved to be very useful. Researchers found aid in developing field evaluation scenarios, data collection techniques, measures of effectiveness, and analysis procedures.

PROBLEM STATEMENT

This research was designed to examine the effect of horizontal signs on driver performance. The study focused on a two-way frontage road in College Station and rural curves located in the Abilene district. Monitoring the airport exit in College Station allowed researchers to make inferences regarding the use of horizontal arrows to convey proper lane designations. Rural curves in Abilene and Blackwell were used to study the relationship between the addition of supplemental curve warning signs and speed-related changes in driver behavior. Time constraints restricted this research to a "before and after" study of these locations. As mentioned previously however, future objectives will include: analyzing an urban curve in Corpus Christi, obtaining driver feedback from video and still photos, and analyzing material durability.

RESEARCH OBJECTIVES

A list of objectives for the research can be found below.

- Analyze the effect of horizontal signs in the reduction of lane conflicts and collisions on two-way frontage roads.

- Analyze the effect of horizontal signs on speed-related changes in driver behavior prior to rural curves.
- Study the effect that various designs and messages have on motorists.

PROCEDURE

This portion of the proposal briefly outlines the activities that were required in order to meet the necessary research requirements.

Step 1: Literature Review

A brief review of literature was performed to gain a better understanding of topics involved in the project. References for this information consisted of personal contacts, reports, and various other sources deemed necessary.

Personal Contacts

- Dr. Susan Chrysler. Texas Transportation Institute (TTI). s-chrysler@tamu.edu.

Potential References

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- Griffin, III, Lindsay I, and Robert N. Reinhardt, *A Review of Two Innovative Pavement Marking Patterns that have been Developed to Reduce Traffic Speeds and Crashes*, Prepared for the AAA Foundation for Traffic Safety, Texas Transportation Institute, College Station, Texas, August 1995.
- Meyer, Eric, Application of Optical Speed Bars to Highway Work Zones, Presented at the Annual Transportation Research Board Meeting, 1999.

Step 2: Site Identification

The purpose of this step was to select applicable field sites at which the effect of horizontal signing on driver performance could be determined. A list of the selected locations and their benefits may be found below:

Airport Exit in College Station

- Experiences a large number of motorists unfamiliar with the area,
- Frequency of lane conflicts and collisions, and
- Relative proximity to the research facility.

FM 707 in Abilene

- Located within 1 mile vicinity of Interstate 20, and
- Ease of data collection.

TX70 in Blackwell

- 10 miles of essentially straight road prior to Blackwell, allows drivers to choose their desired speed, and
- Potential to desensitize drivers to their surroundings, increasing the likelihood that drivers will miss evidence of the impending curve.

Step 3: Data Collection

College Station

Figure 1. Airport Exit in College Station

A traffic camera was used to monitor the two-lane frontage road at FM 60 and Turkey Creek Road in College Station. Video was captured for a week before and after the installation of horizontal arrows. A schematic of the exit may be found in Appendix A.

Abilene and Blackwell

In Abilene and Blackwell, researchers used a series of three traffic counters to collect speed information. These counters were strategically placed to monitor speed-related changes in driver behavior. Data were collected before and after the installation of supplemental curve advisories. Counter locations were the same for the before and after period at each location. Schematics detailing the pavement marking used at each site and a layout of the counter locations can be found in Appendix B.

Step 4: Data Reduction and Analysis

College Station

Researchers used the captured video along with the data collection sheet found in Appendix A to monitor driver behavior during the before and after periods. As a result, traffic was first categorized by maneuver:

- Left turn,
- Straight through, and
- Right turn.

Motorists were then categorized by lane choice:

- 100% Correct: Drivers who chose the correct lane throughout the area of interest.
- 100% Wrong: Drivers who chose the incorrect lane throughout the area of interest.
- <100% Wrong: Drivers who began in one lane, yet eventually switched lanes at some point in the area of interest.

This step was taken to imply the degree to which motorists understood the proper lane designations.

Using this data, researchers were able to examine the relationship between the installation of pavement markings and lane choice. In order to accomplish this, the percentage of vehicles to successfully/unsuccessfully navigate correctly through the area of interest during the before and after period was determined. With heavy emphasis placed on reducing the number of lane conflicts and collisions, researchers decided to include those in the "<100% Wrong" category as unsuccessful. Thus they were placed in the "100% Wrong" category.

Abilene and Blackwell

After extracting data from the counters, researchers were able to compute the headway between vehicles. Vehicles with a five second headway or less were then removed. In order to properly determine the effect of horizontal signs on speed-related changes in driver behavior, it was imperative that researchers only examine drivers that were able to make their own decisions. Motorists following too closely to the vehicle in front of them are more likely make decisions based on what is going on in front of them.

Once the data had been reduced, researchers were able to find the mean, standard deviation, range, and 85th percentile at each counter. With this information it was then possible to determine whether the difference in mean values at each counter was statistically significant at a level of $\alpha = 0.05$. In order to show the smallest level at which the data was significant, P-values were also calculated.

These procedures were followed for each of the following categories:

- Overall,
- Day,
- Night,
- Dawn and dusk,
- Cars, and
- Trucks.

RESULTS

Airport Exit in College Station

Results from the traffic study performed in College Station may be found in Figure 3 below. The largest source of error was derived from those making a left turn at the intersection. This may be explained by the high volume of traffic in route to the airport.

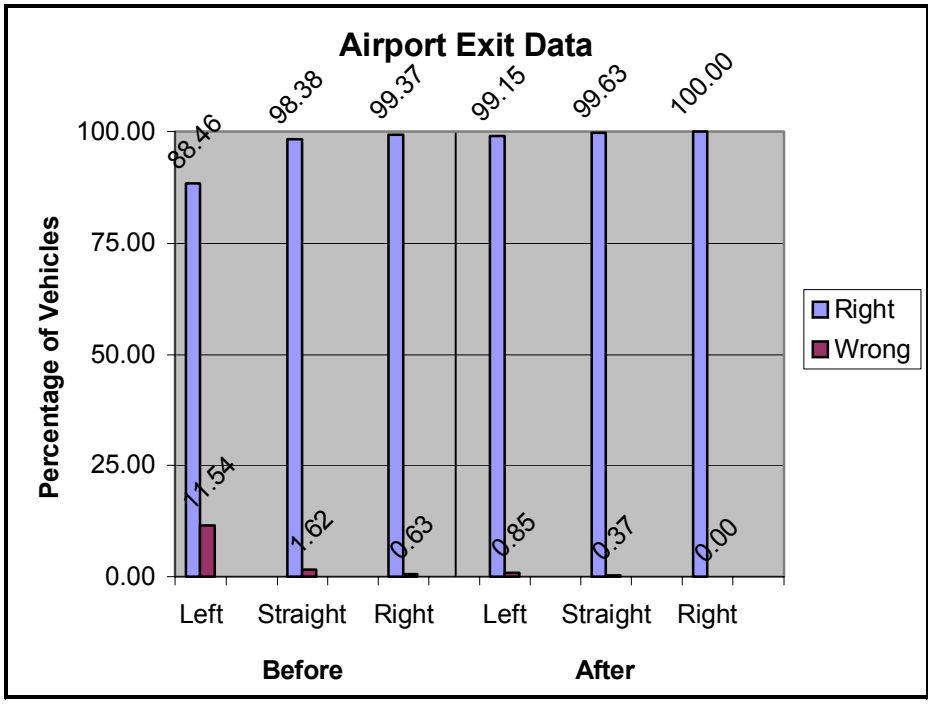

Figure 2. Percentage of Vehicles – Overall

Although a warning sign and yellow center line were clearly visible, it is likely that motorists made this mistake for a number of reasons:

- Unfamiliar with the area,
- In a hurry to catch flights or pick up travelers, or
- Anticipated their need to turn left at the stop sign and feel they must be in the left lane to do so.

The most significant result was discovered in motorists turning left. Prior to the installation of the arrows 11.54% made errors, as opposed to 0.85% afterward. The net result was a reduction of almost 11%.

Similar procedures were followed to establish day and night comparisons. These comparisons may be found in Appendix C. One somewhat surprising result from these comparisons was the fact that the percentage of those to make errors turning left was actually less at night, than during the day. This was explained by furthering examining data from the videos. A vast majority of the nighttime motorists arrived around 5 a.m. and turned left towards Easterwood Airport. Given that the airport opens up around this time a large percentage of these vehicles were likely airport employees, and thus familiar with the location.

Abilene and Blackwell

The most encouraging results for the use of horizontal signs on the approach to a rural curve were observed in Blackwell. The speed profile in Figure 3 below was constructed by plotting the mean velocity at each counter location, and then applying error bars using the standard deviation. Values for means and standard deviations may be found in Appendix D. Ideally, mean speeds at counter location 1 would have been approximately the same. This was not the case however. Further research indicated that this was likely caused by differing weather conditions during the before and after data collection.

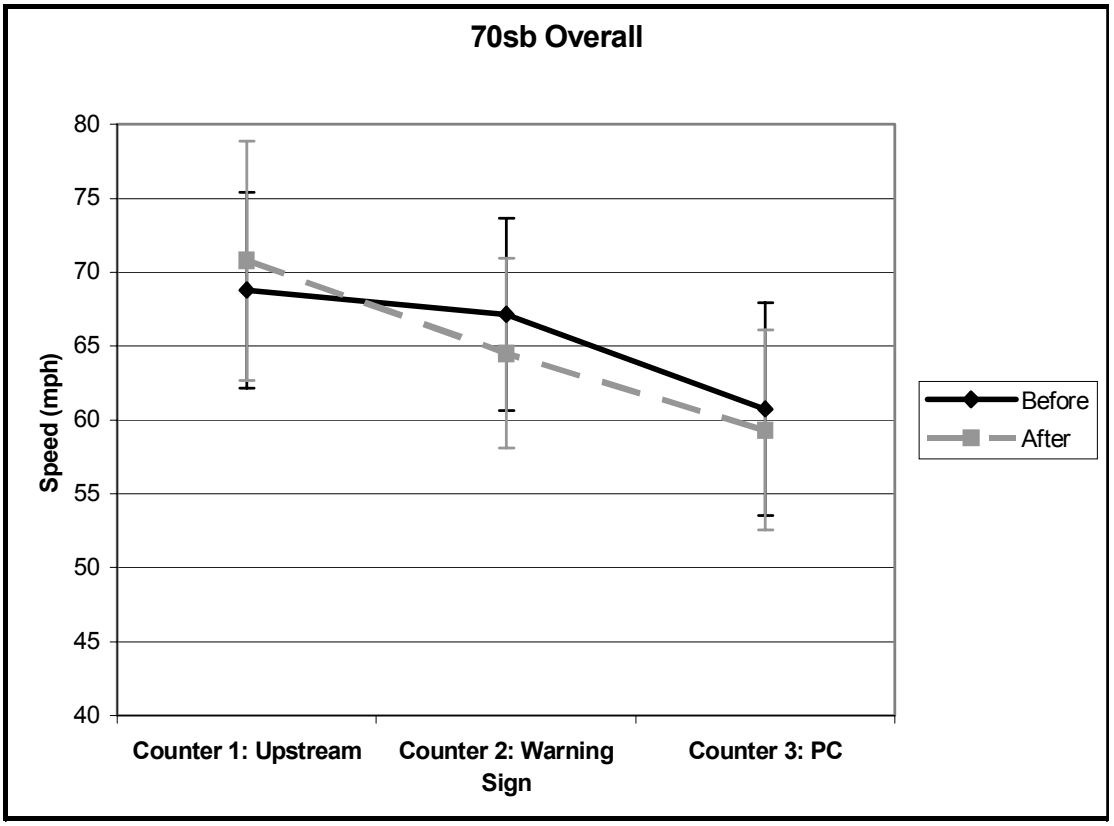

Figure 3. Speed Profile for TX70 South Bound in Blackwell

Although the "After" speed was initially higher at counter location 1, there appeared to be speed reductions at counter locations 2 and 3. Reductions at counter location 3 are most important because this is the point at which motorists begin to enter the rural curve. Also note the slope of the "After" data compared to that of the "Before". Deceleration in the approach seems to be more constant in the "After".

Speed profiles for FM707 in Abilene may be found in Figures 4 and 5. Again, the data required to produce these figures may be found in Appendix D.

The results from FM707 are less clear. It is almost impossible to explain the acceleration between locations 1 and 2 for the "Before" and "After". As a result, researchers were unable to gather any useful conclusions.

CONCLUSIONS

Airport Exit

The benefits of installing horizontal arrows on the two-way frontage road in College Station were somewhat surprising. This is especially true given the fact that most traffic control devices providing that significant a change in safety are already being used. Improvements were so clearly defined that researchers recommend the use of these arrows on other two-way frontage roads experiencing similar issues. It may prove beneficial however to wait until further research has been conducted on material durability.

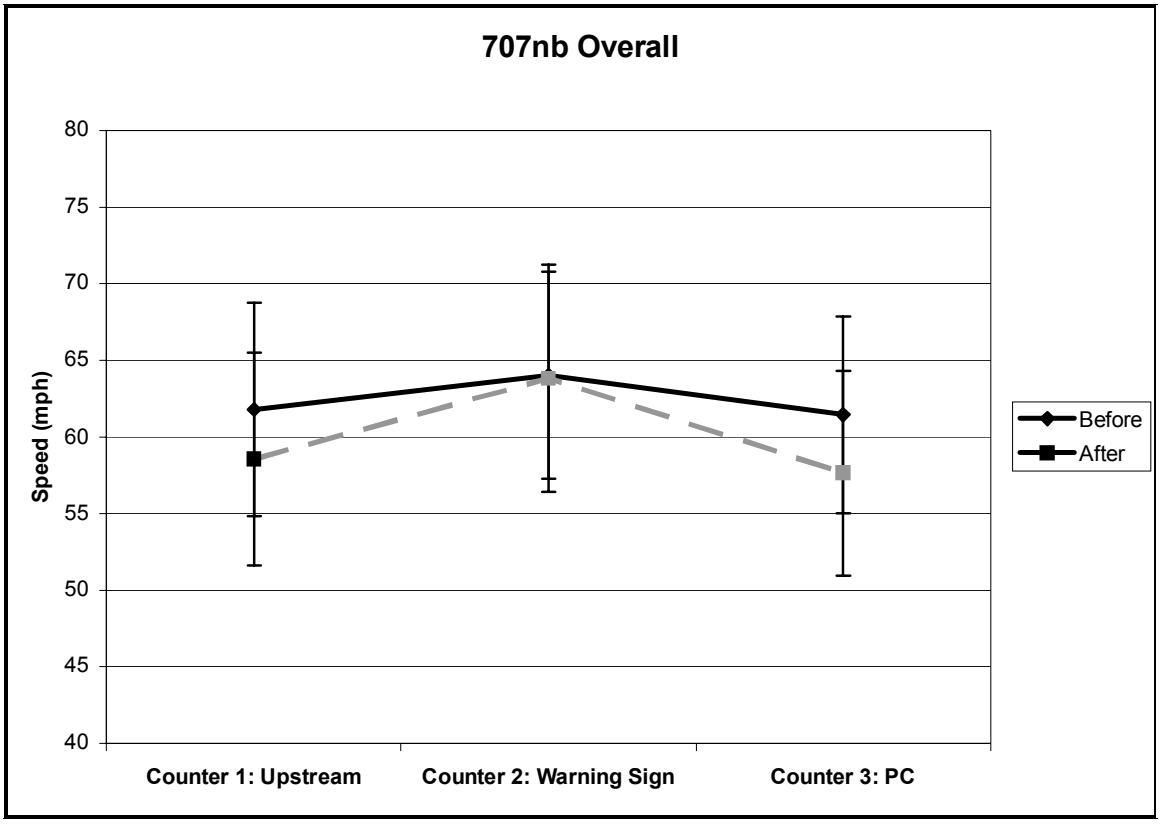

Figure 4. Speed Profile for FM707 North Bound in Abilene

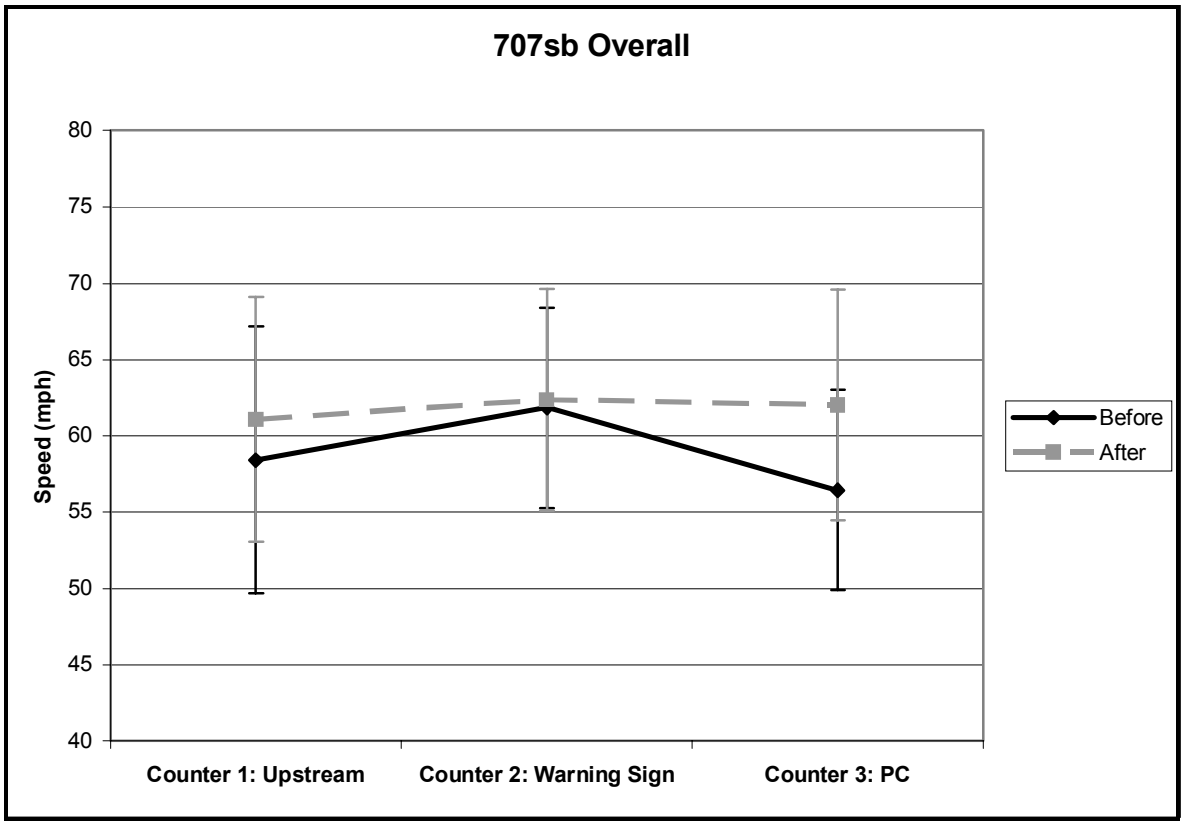

Figure 5. Speed Profile for FM707 South Bound in Abilene

Abilene/Blackwell

Results from Blackwell were most encouraging. "After" data at this location showed a constant deceleration throughout the approach, rather than at the end. Another positive was the speed reduction found at locations 2 and 3. Researchers were unable to draw many conclusions from the Abilene results, thus further research is recommended.

RECOMMENDATIONS

Time constraints limited this research to the "before and after" studies in Abilene, Blackwell, and College Station. Although some of the concerns about the use of horizontal signs were answered, further research is still required. Recommendations for this research may be found below:

- The study conducted in College Station showed that applying arrows to the pavement on a two-way frontage road was extremely effective. Given the fact that they are relative inexpensive and easy to install, these arrows should be placed in other areas experiencing similar problems with lane conflicts.
- Conduct further studies on the use of horizontal signs prior to rural curves. Results from the study performed in Blackwell were encouraging; however this was not the case with the Abilene study. Future research would provide better results, thus enabling conclusions to be drawn about effectiveness.
- Future studies should be conducted with more regard to weather conditions. It would be easier to draw conclusions about speed-related changes in driver behavior if conditions were the same in before and after data collection periods.

ACKNOWLEDGEMENTS

I would personally like to thank everyone who has assisted me in completing this research. First and foremost, I would like to thank my mentor, Dr. Susan Chrysler, for all the support and guidance that she has given me. A complete list of those who have donated time and effort to this project may be found below:

Texas Department of Transportation (TxDOT)

- Mr. Roy Wright, P.E.

Texas Transportation Institute (TTI)

- Dr. Susan Chrysler
- Mr. Steven Schrock, P.E.
- Dr. Conrad Dudek, P.E.
- Mr. Gary Barricklow
- Mr. Dan Walker
- Ms. Amanda Anderle
- Mr. Lane Roberts

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1. *Horizontal Signage and Specialty Markings*. Flint Trading, Inc. http://www.flinttrading.com/specialty_pavement_markings.htm. Accessed June 16, 2004.

2. Chrysler, S.T., S.D. Schrock, and T.J. Gates. *Evaluation of Horizontal Signing Applications: Year 1 Activities*. Research Report 0-4471-1. Texas Transportation Institute, College Station, Texas. Unpublished Report.

3. Gates, T.J., H.G. Hawkins, Jr., S.T. Chrysler, P.J. Carlson, A.J. Holick, and C.H. Spiegelman. *Traffic Operational Impacts of Higher-Conspicuity Sign Materials*. Research Report 4271-1. Texas Transportation Institute, College Station, Texas, August 2003.

4. Lyles, R.W. *An Evaluation of Warning and Regulatory Signs for Curves on Rural Roads*. Final Report. Maine University at Orono, Social Science Research Institute, Federal Highway Administration, March 1980.

5. Retting, R.A., and C.M. Farmer. Use of Pavement Markings to Reduce Excessive Traffic Speeds on Hazardous Curves. *ITE Journal*, Vol. 68, No. 9, Institute of Transportation Engineers, Washington, D.C., September 1998, pp. 30-34.

APPENDIX A. COLLEGE STATION DATA COLLECTION

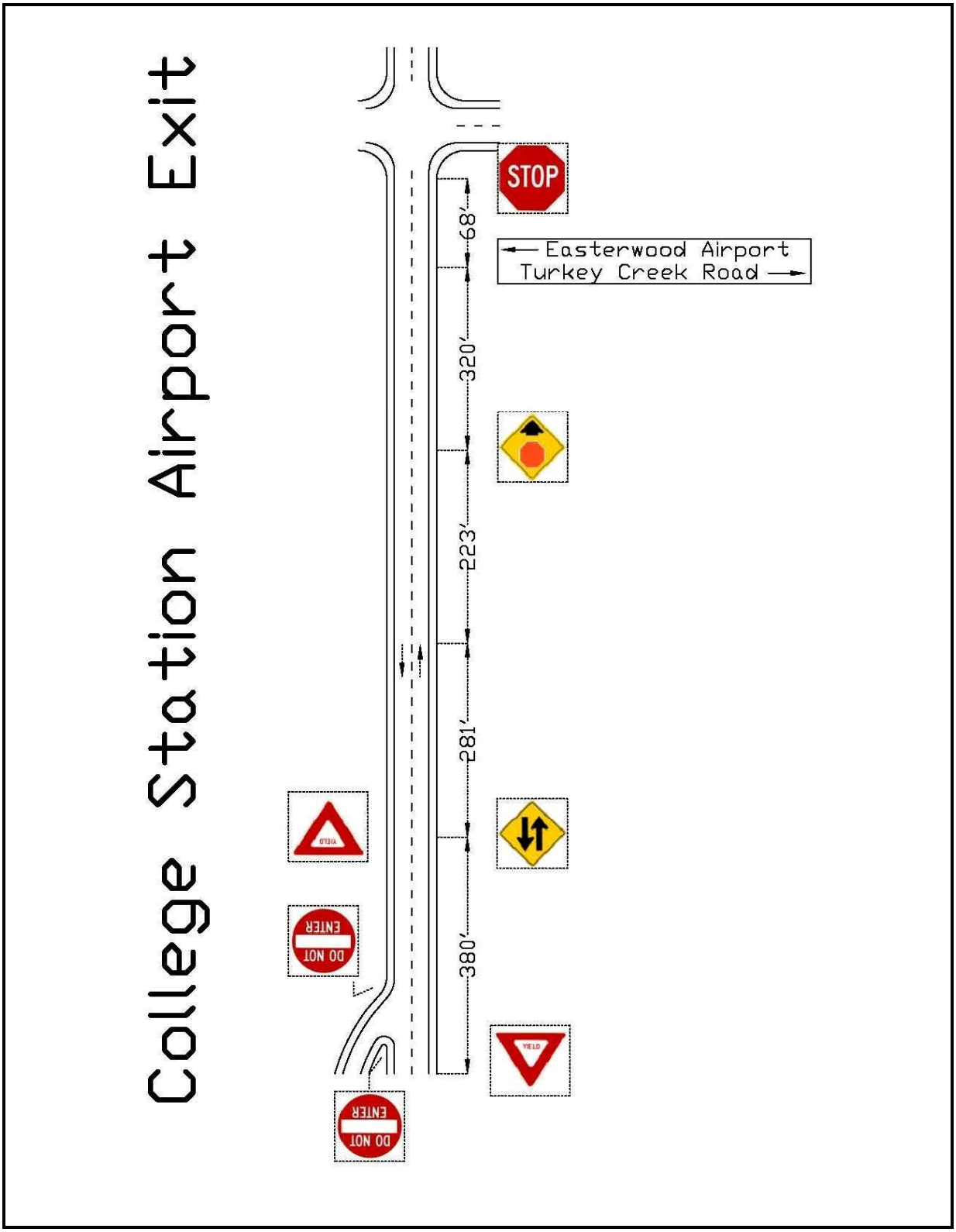

Figure A1. College Station Airport Exit

TWO-WAY DIRECTION ARROW DATA SHEET

Location Westbound offramp to College Station airport, FM 60, College Station, Texas

Date of Taping _____ Time _____ Day/Night Page _____

Data Reducer _____ Date of Data Reduction _____

Head-on Conflict

Double Left Turn Conflict

Other – Please Describe

	Left Turn			Straight Through			Right Turn		
	Correct Action	Incorrect Action		Correct Action	Incorrect Action		Correct Action	Incorrect Action	
	100% right	100% wrong	<100% wrong	100% right	100% wrong	<100% wrong	100% right	100% wrong	<100% wrong
Isolated									
Following a vehicle									
Oncoming Vehicle									

- **100% Correct**: applies when a driver chooses the correct lane all the way through the Area of Interest,
- **100% Wrong**: applies when a driver uses the wrong lane all the way through the Area of Interest, and
- **<100% Wrong**: applies when a driver begins in one lane and moves to the other lane at some point in the Area of Interest.

Project 4471
Project 4471 College Station Data Collection 030204.doc
Last Update: 03/02/2004

Figure A2. Airport Exit Data Collection Sheet

APPENDIX B: ABILENE AND BLACKWELL DATA COLLECTION

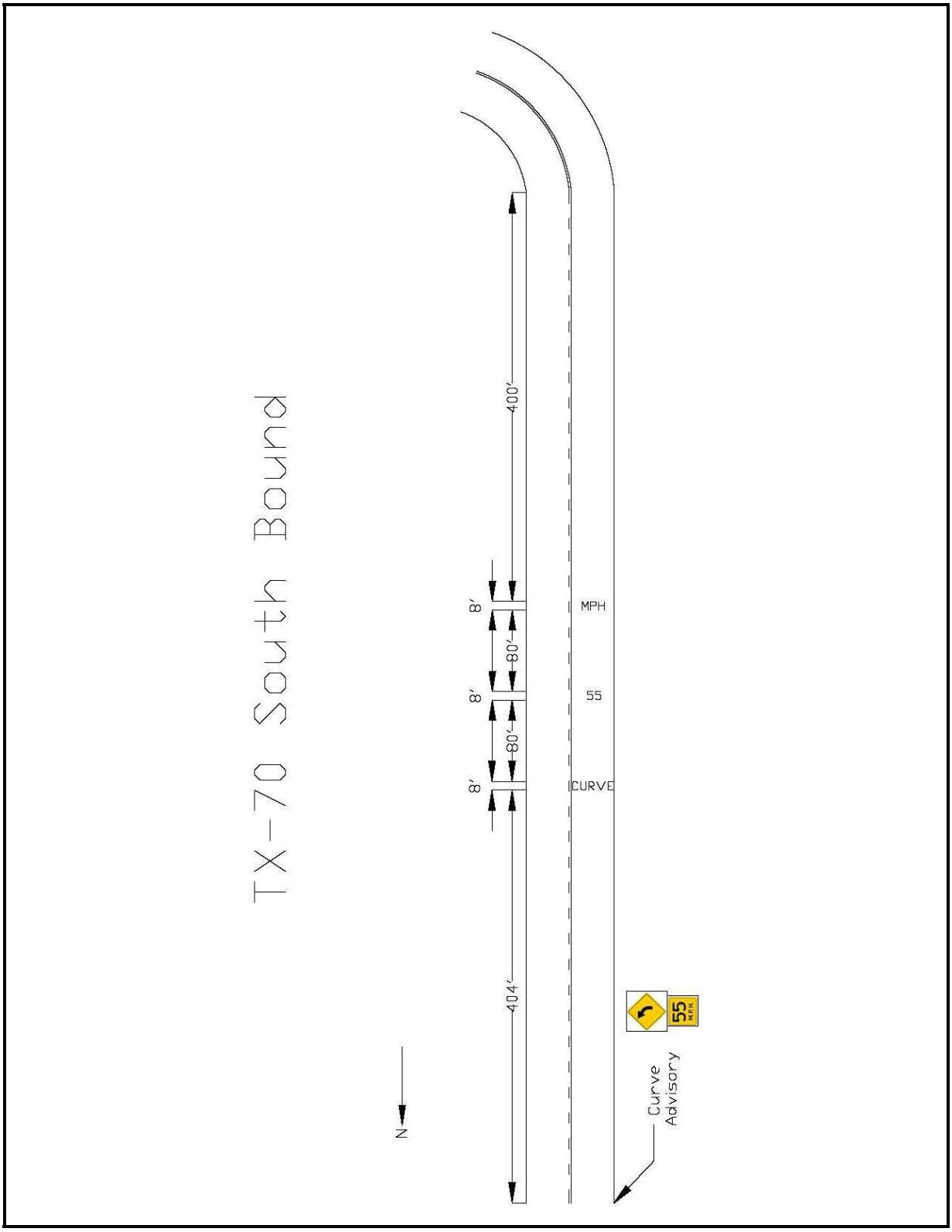

Figure B1. State Highway 70 South Bound

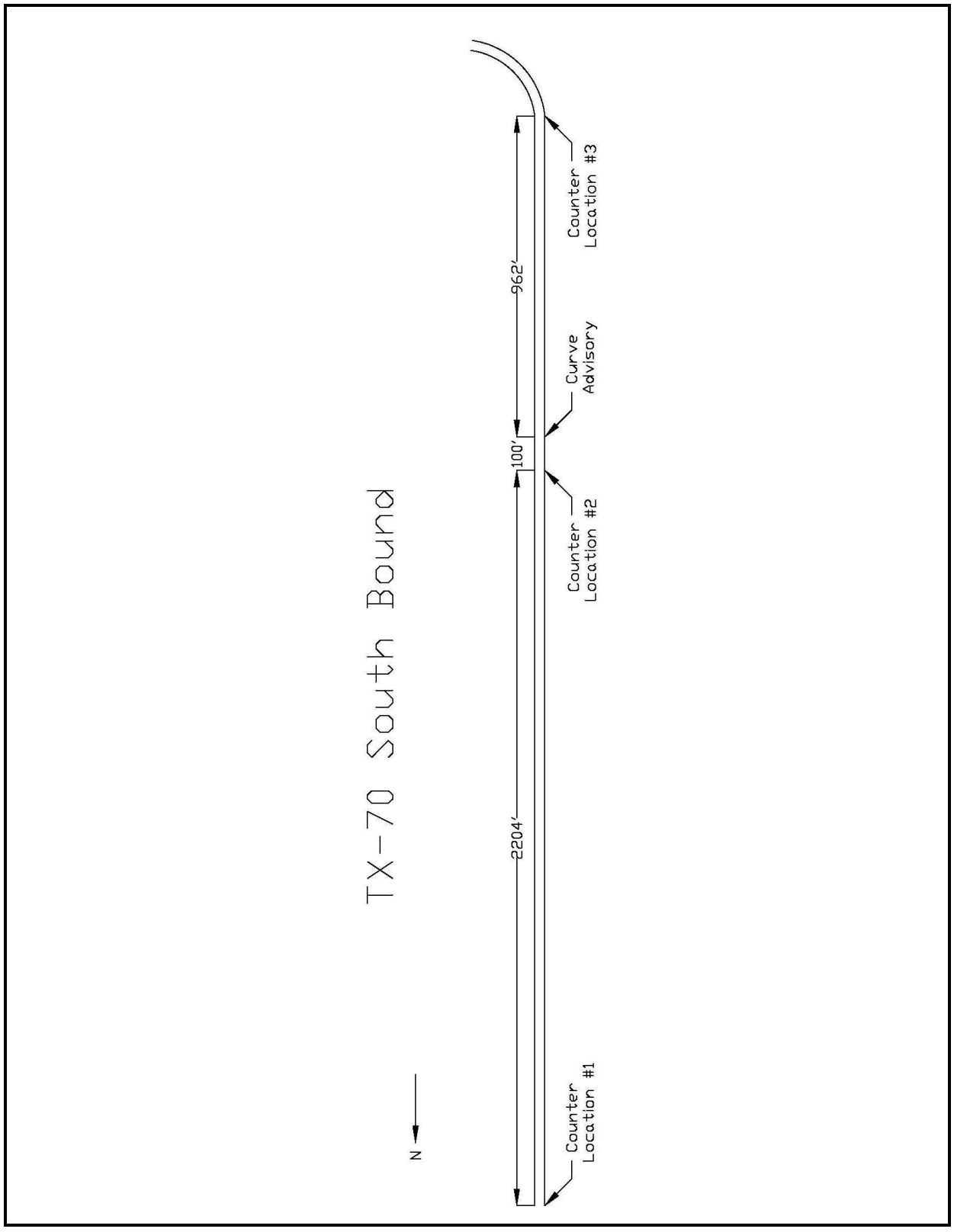

Figure B2. State Highway 70 South Bound Counters

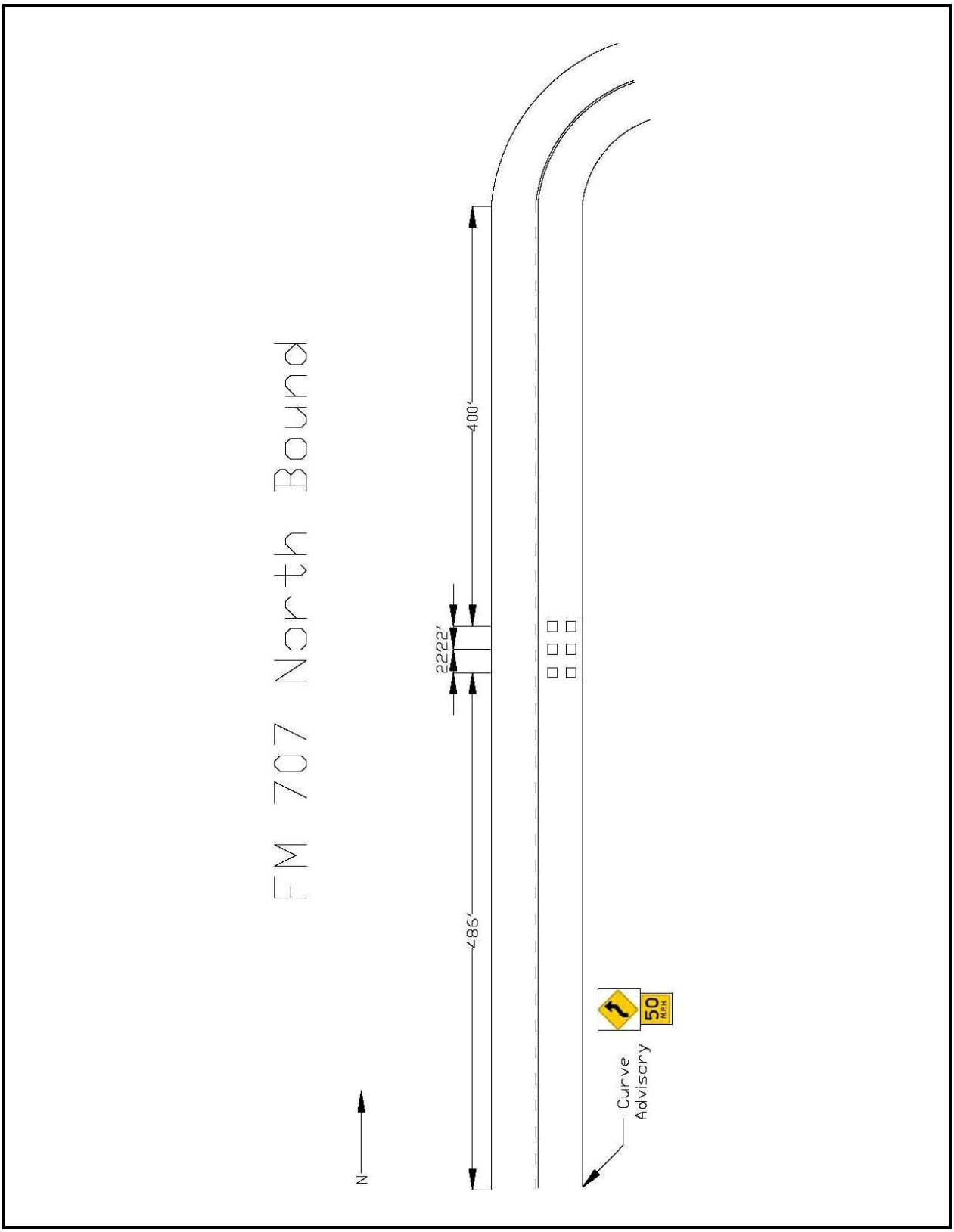

Figure B3. FM 707 North Bound

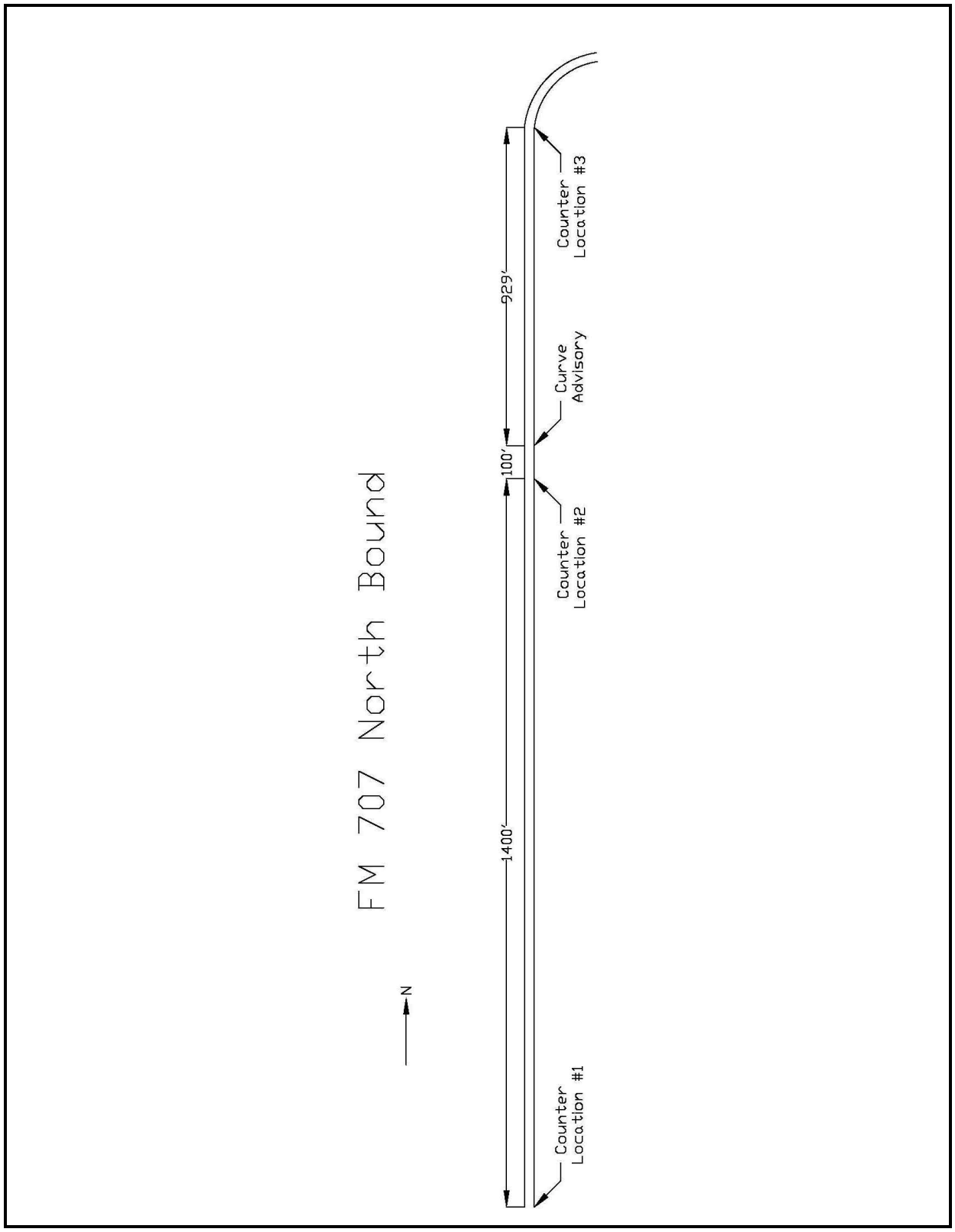

Figure B4. FM 707 North Bound Counters

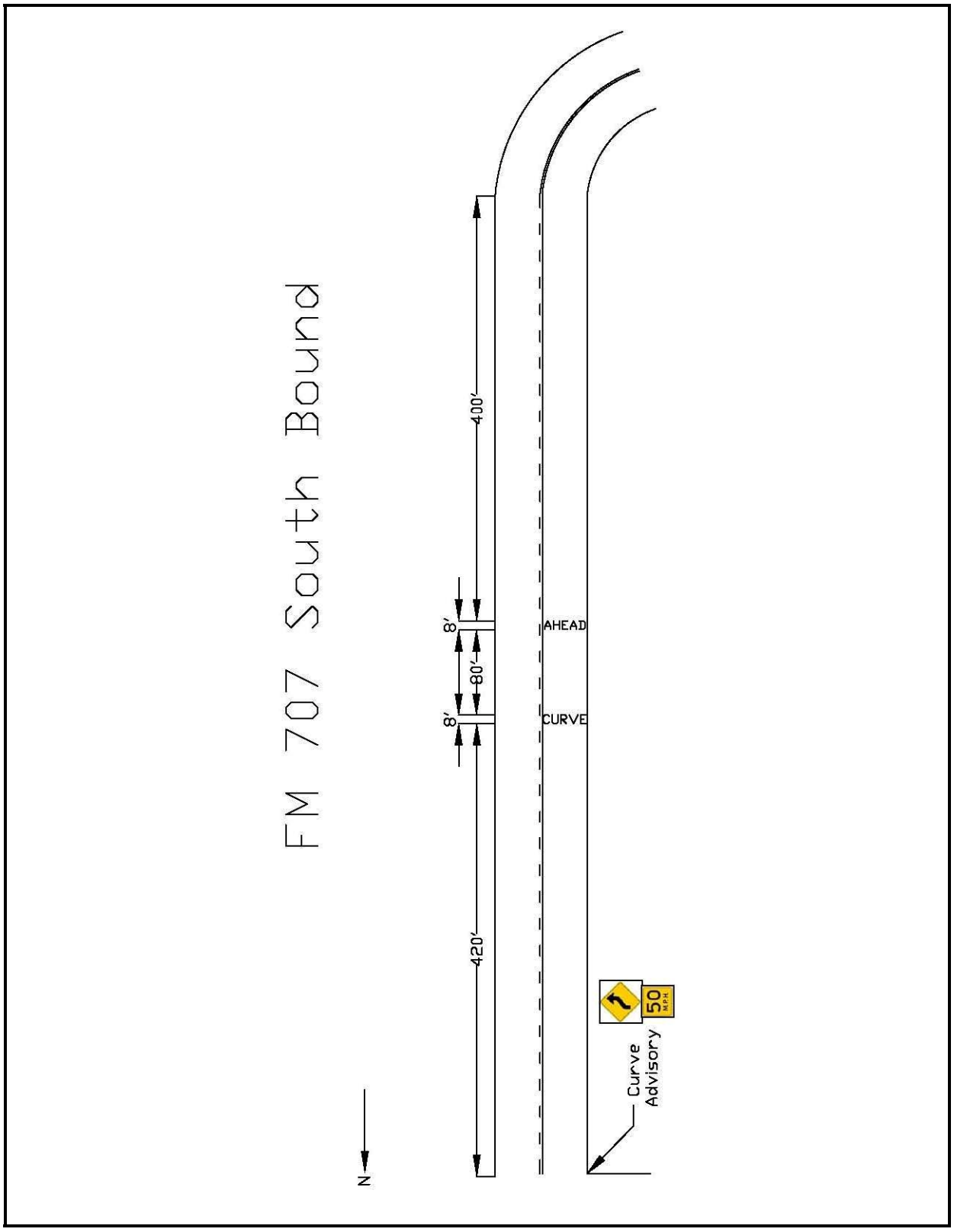

Figure B5. FM 707 South Bound

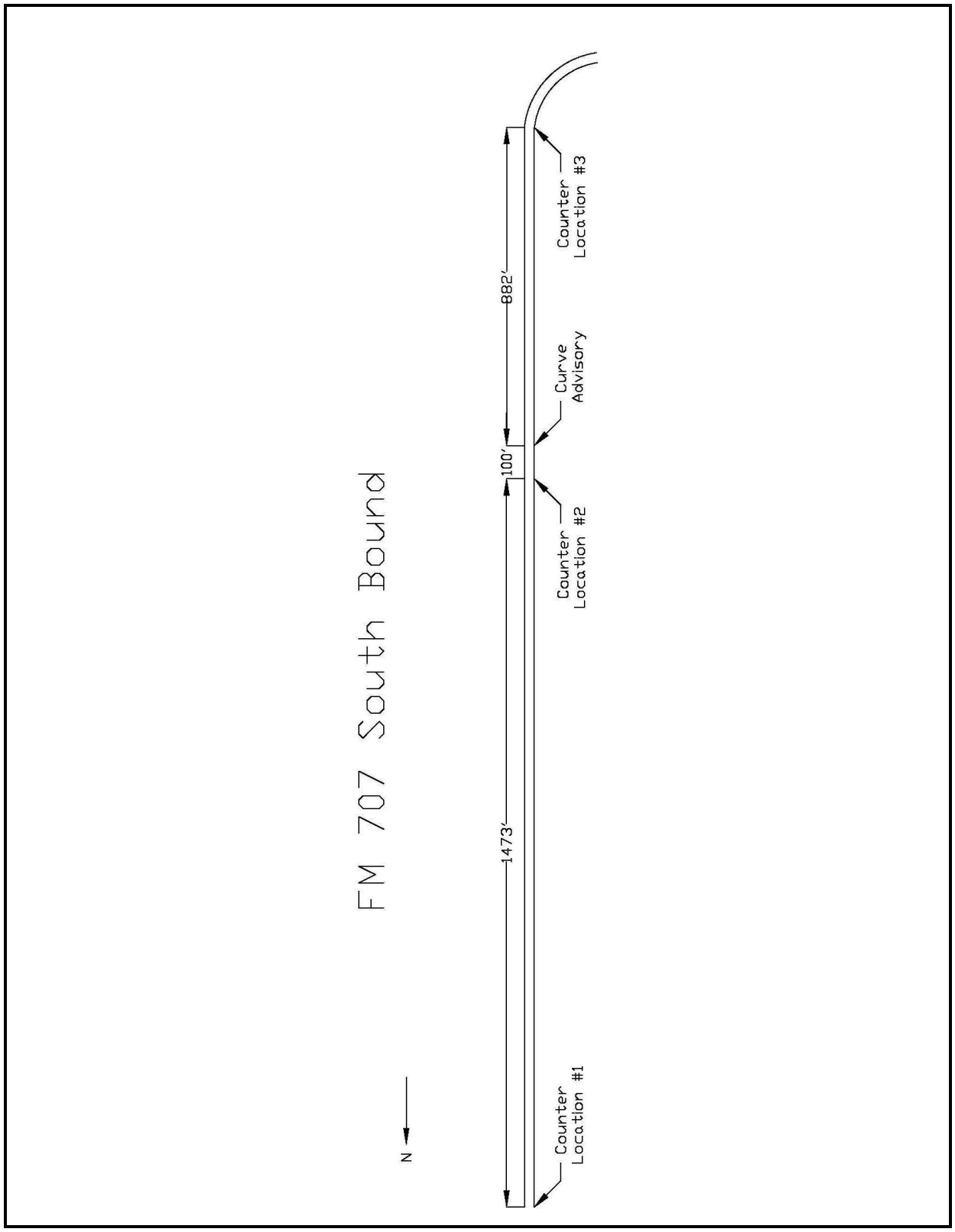

Figure B6. FM 707 South Bound Counters

APPENDIX C: COLLEGE STATION DATA

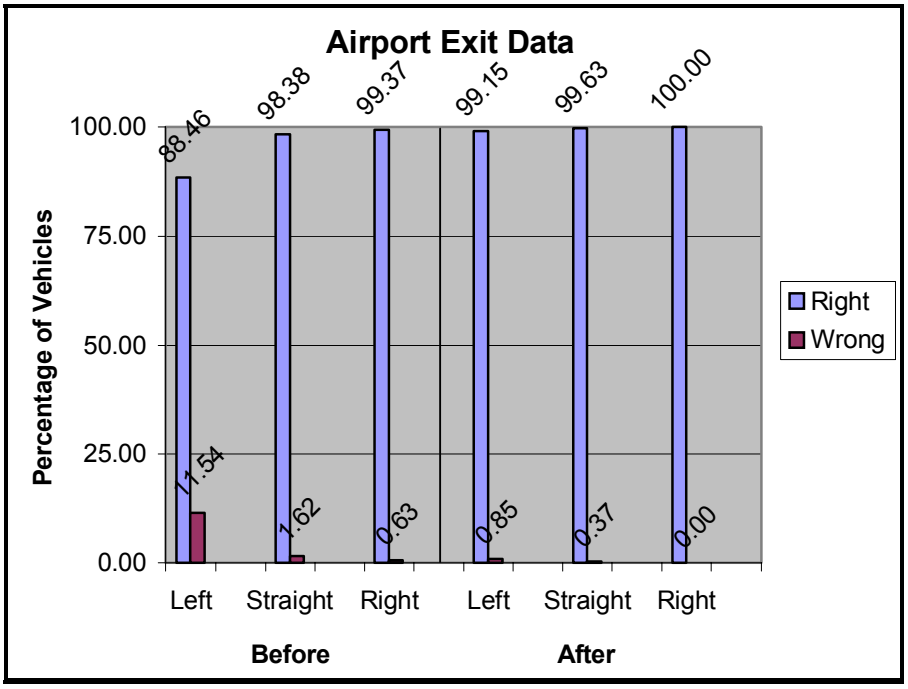

Figure C1. Percentage of Vehicles – Day

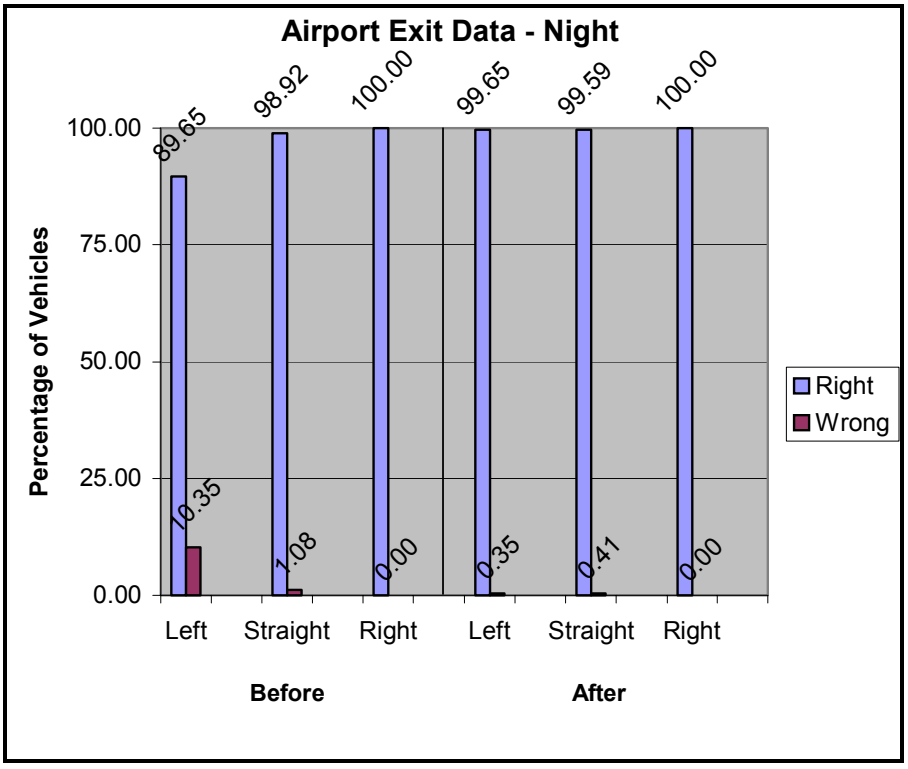

Figure C2. Percentage of Vehicles - Night

APPENDIX D: ABILENE AND BLACKWELL DATA

Overall

Table D1. TX70 Southbound in Blackwell

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	68.78	6.62	74	106	75	Yes	0.0004
	After	70.78	8.12	71	97	77		
	Change	2.00	1.50	-3	-9	2		
Counter Location #2	Before	67.16	6.50	58	105	73	Yes	0.0004
	After	64.52	6.42	50	88	71		
	Change	-2.64	-0.08	-8	-17	-3		
Counter Location #3	Before	60.74	7.22	51	89	68	Yes	0.0004
	After	59.32	6.77	46	84	66		
	Change	-1.42	-0.44	-6	-5	-2		

Table D2. FM707 Northbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	61.79	6.94	50	83	69	Yes	0.0004
	After	58.55	6.94	60	85	65		
	Change	-3.23	0.00	10	2	-4		
Counter Location #2	Before	64.02	6.74	55	92	71	No	0.4966
	After	63.82	7.42	82	91	71		
	Change	-0.20	0.68	27	-1	0		
Counter Location #3	Before	61.47	6.41	52	89	68	Yes	0.0004
	After	57.65	6.69	53	78	64		
	Change	-3.82	0.28	1	-11	-4		

Table D3. FM707 Southbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	58.42	8.76	63	77	66	Yes	0.0004
	After	61.07	8.00	66	81	69		
	Change	2.66	-0.76	3	4	3		
Counter Location #2	Before	61.84	6.55	47	87	69	No	0.1444
	After	62.37	7.27	56	85	70		
	Change	0.54	0.72	9	-2	1		
Counter Location #3	Before	56.44	6.55	42	77	63	Yes	0.0004
	After	62.00	7.57	56	82	70		
	Change	5.56	1.02	14	5	7		

Day

Table D4. TX70 Southbound in Blackwell

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	**St. Dev.**	**Range**	**Max**	**85th Percentile**		
Counter Location #1	Before	69.48	6.91	74	106	75	Yes	0.0004
	After	71.43	8.59	71	97	78		
	Change	1.95	1.68	-3	-9	3		
Counter Location #2	Before	68.15	6.34	56	105	74	Yes	0.0004
	After	65.28	6.54	50	88	71		
	Change	-2.87	0.20	-6	-17	-3		
Counter Location #3	Before	61.38	7.43	51	89	69	Yes	0.0004
	After	60.01	6.66	37	77	67		
	Change	-1.37	-0.76	-14	-12	-2		

Table D5. FM707 Northbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	61.56	6.98	50	83	69	Yes	0.0004
	After	59.05	6.84	60	85	65		
	Change	-2.51	-0.15	10	2	-4		
Counter Location #2	Before	64.30	6.91	55	92	71	No	0.4066
	After	64.61	6.91	50	91	71		
	Change	0.31	-0.01	-5	-1	0		
Counter Location #3	Before	61.17	6.44	40	82	68	Yes	0.0004
	After	57.95	6.54	53	78	65		
	Change	-3.22	0.10	13	-4	-3		

Table D6. FM707 Southbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	58.91	9.24	63	77	67	Yes	0.0004
	After	61.96	7.89	61	81	70		
	Change	3.05	-1.35	-2	4	3		
Counter Location #2	Before	62.52	6.55	47	87	69	Yes	0.0488
	After	63.40	6.97	51	85	70		
	Change	0.89	0.43	4	-2	1		
Counter Location #3	Before	57.55	6.67	42	77	64	Yes	0.0004
	After	62.71	7.47	56	82	70		
	Change	5.15	0.80	14	5	6		

Night

Table D7. TX70 Southbound in Blackwell

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	**St. Dev.**	**Range**	**Max**	**85th Percentile**		
Counter Location #1	Before	66.79	6.10	49	85	72	Yes	0.0054
	After	68.49	6.16	47	89	73		
	Change	1.70	0.06	-2	4	1		
Counter Location #2	Before	64.72	6.30	44	91	69	Yes	0.0004
	After	62.11	5.67	35	77	67		
	Change	-2.61	-0.62	-9	-14	-2		
Counter Location #3	Before	59.14	6.71	44	85	66	Yes	0.0028
	After	57.17	6.52	46	84	64		
	Change	-1.97	-0.19	2	-1	-2		

Table D8. FM707 Northbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	59.98	6.96	44	80	67	Yes	0.0004
	After	55.99	7.16	48	75	63		
	Change	-3.99	0.20	4	-5	-4		
Counter Location #2	Before	61.95	6.57	48	87	68	Yes	0.0300
	After	60.54	8.02	69	78	68		
	Change	-1.41	1.45	21	-10	0		
Counter Location #3	Before	60.09	6.46	52	89	66	Yes	0.0004
	After	55.59	6.86	44	72	63		
	Change	-4.50	0.40	-8	-17	-3		

Table D9. FM707 Southbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	58.40	6.25	25	72	65	No	0.9680
	After	58.36	8.32	64	79	67		
	Change	-0.03	2.07	39	7	2		
Counter Location #2	Before	60.67	6.67	29	76	68	No	0.1286
	After	59.39	7.77	46	76	67		
	Change	-1.28	1.10	17	0	0		
Counter Location #3	Before	54.52	6.15	28	69	61	Yes	0.0004
	After	60.13	7.79	45	80	69		
	Change	5.61	1.64	17	11	8		

Dawn/Dusk

Table D10. TX70 Southbound in Blackwell

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	**St. Dev.**	**Range**	**Max**	**85th Percentile**		
Counter Location #1	Before	68.86	5.43	39	89	74	Yes	0.0466
	After	70.65	7.18	57	89	76		
	Change	1.79	1.75	18	0	2		
Counter Location #2	Before	66.67	6.47	33	81	72	Yes	0.0004
	After	63.79	5.55	31	79	69		
	Change	-2.88	-0.92	-2	-2	-3		
Counter Location #3	Before	60.50	6.67	32	77	67	Yes	0.0424
	After	58.56	7.18	36	76	64		
	Change	-1.94	0.51	4	-1	-3		

Table D11. FM707 Northbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	64.25	6.08	39	82	70	Yes	0.0004
	After	59.87	6.29	43	80	66		
	Change	-4.38	0.21	4	-2	-4		
Counter Location #2	Before	65.43	5.95	44	91	71	No	0.5286
	After	65.04	7.27	60	87	71		
	Change	-0.39	1.32	16	-4	0		
Counter Location #3	Before	63.68	5.72	32	79	70	Yes	0.0004
	After	59.03	6.45	40	76	65		
	Change	-4.65	0.74	8	-3	-4		

Table D12. FM707 Southbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	56.43	9.31	58	76	64	Yes	0.0004
	After	60.66	6.93	40	79	68		
	Change	4.23	-2.38	-18	3	4		
Counter Location #2	Before	60.54	6.04	28	74	67	No	0.2380
	After	61.59	6.48	38	76	69		
	Change	1.05	0.45	10	2	2		
Counter Location #3	Before	54.37	5.47	32	67	60	Yes	0.0004
	After	61.19	7.15	38	75	69		
	Change	6.82	1.68	6	8	9		

Day – Car

Table D13. TX70 Southbound in Blackwell

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	69.86	7.04	74	106	76	Yes	0.0004
	After	71.68	8.77	71	96	78		
	Change	1.83	1.73	-3	-10	2		
Counter Location #2	Before	68.59	6.35	55	105	74	Yes	0.0004
	After	65.83	6.27	45	82	71		
	Change	-2.76	-0.07	-11	-23	-3		
Counter Location #3	Before	61.75	7.53	51	89	69	Yes	0.0032
	After	60.48	6.74	37	77	67		
	Change	-1.28	-0.79	-14	-12	-2		

Table D14. FM707 Northbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	62.08	7.02	50	83	69	Yes	0.0004
	After	69.48	6.75	60	85	65		
	Change	-2.59	-0.27	10	2	-4		
Counter Location #2	Before	64.86	6.92	55	92	72	No	0.5824
	After	65.07	6.90	50	91	72		
	Change	0.22	-0.02	-5	-1	0		
Counter Location #3	Before	61.68	6.45	40	40	68	Yes	0.0004
	After	58.39	6.58	53	78	65		
	Change	-3.29	0.14	13	38	-3		

Table D15. FM707 Southbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	59.48	8.77	63	77	67	Yes	0.0004
	After	62.49	7.82	61	81	70		
	Change	3.01	-0.95	-2	4	3		
Counter Location #2	Before	62.97	6.58	47	87	69	Yes	0.0384
	After	63.95	6.86	51	85	70		
	Change	0.98	0.28	4	-2	1		
Counter Location #3	Before	57.84	6.84	42	77	65	Yes	0.0004
	After	63.32	7.43	56	82	71		
	Change	5.48	0.59	14	5	6		

Day – Truck

Table D16. TX70 Southbound in Blackwell

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	**St. Dev.**	**Range**	**Max**	**85th Percentile**		
Counter Location #1	Before	66.26	4.53	19	77	71	Yes	0.0004
	After	70.22	7.60	42	97	76		
	Change	3.96	3.07	23	20	5		
Counter Location #2	Before	64.36	4.88	26	75	70	No	0.0574
	After	62.63	7.17	46	88	68		
	Change	-1.73	2.29	20	13	-2		
Counter Location #3	Before	58.15	5.55	30	70	64	No	0.6818
	After	57.78	5.84	33	75	63		
	Change	-0.36	0.29	3	5	-1		

Table D17. FM707 Northbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	57.36	5.07	27	72	62	Yes	0.0204
	After	55.09	6.42	44	80	59		
	Change	-2.27	1.36	17	8	-3		
Counter Location #2	Before	59.72	4.90	26	72	65	No	0.4592
	After	60.37	5.44	37	81	65		
	Change	0.65	0.54	11	9	0		
Counter Location #3	Before	56.97	4.61	24	68	62	Yes	0.0004
	After	53.89	4.45	22	63	58		
	Change	-3.08	-0.16	-2	-5	-4		

Table D18. FM707 Southbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	53.72	11.70	52	66	62	No	0.1032
	After	57.46	7.04	46	74	64		
	Change	3.73	-4.66	-6	8	2		
Counter Location #2	Before	58.41	4.61	20	66	63	No	0.7566
	After	58.74	6.20	34	76	65		
	Change	0.33	1.59	14	10	2		
Counter Location #3	Before	54.97	4.07	18	60	59	Yes	0.0076
	After	57.49	5.57	25	70	63		
	Change	2.52	1.50	7	10	4		

Night – Car

Table D19. TX70 Southbound in Blackwell

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	**St. Dev.**	**Range**	**Max**	**85th Percentile**		
Counter Location #1	Before	67.04	5.97	49	85	73	Yes	0.0102
	After	68.94	5.89	42	84	73		
	Change	1.90	-0.08	-7	-1	0		
Counter Location #2	Before	65.61	6.21	44	91	70	Yes	0.0022
	After	63.57	4.72	23	74	68		
	Change	-2.04	-1.49	-21	-17	-2		
Counter Location #3	Before	60.11	6.67	44	85	67	No	0.0524
	After	58.68	5.40	24	70	65		
	Change	-1.43	-1.27	-20	-15	-2		

Table D20. FM707 Northbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	60.18	6.97	44	80	67	Yes	0.0004
	After	56.43	7.13	48	75	63		
	Change	-3.75	0.16	4	-5	-4		
Counter Location #2	Before	62.17	6.59	48	87	68	No	0.1052
	After	61.12	7.43	44	78	69		
	Change	-1.05	0.84	-4	-10	1		
Counter Location #3	Before	60.30	6.45	52	89	66	Yes	0.0004
	After	56.12	6.57	42	72	63		
	Change	-4.18	0.12	-10	-17	-3		

Table D21. FM707 Southbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	58.68	6.17	25	72	65	No	0.9124
	After	58.78	8.42	64	79	67		
	Change	0.10	2.25	39	7	2		
Counter Location #2	Before	60.72	6.59	29	76	67	No	0.2076
	After	59.63	7.86	46	75	67		
	Change	-1.10	1.27	17	-1	0		
Counter Location #3	Before	54.59	6.08	28	69	61	Yes	0.0004
	After	60.47	8.03	45	80	70		
	Change	5.88	1.96	17	11	9		

Night – Truck

Table D22. TX70 Southbound in Blackwell

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	65.92	6.49	30	85	72	No	0.0872
	After	67.92	6.47	37	89	73		
	Change	2.00	-0.02	7	4	1		
Counter Location #2	Before	61.65	5.64	29	80	67	No	0.1970
	After	60.28	6.24	35	77	65		
	Change	-1.37	0.60	6	-3	-2		
Counter Location #3	Before	55.77	5.72	25	69	62	No	0.6600
	After	55.27	7.31	46	84	61		
	Change	-0.50	1.59	21	15	-1		

Table D23. FM707 Northbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	56.71	6.21	18	66	65	Yes	0.0098
	After	51.44	5.84	27	60	57		
	Change	-5.27	-0.37	9	-6	-8		
Counter Location #2	Before	58.36	5.20	13	65	65	No	0.1528
	After	54.56	11.11	56	65	63		
	Change	-3.79	5.91	43	0	-2		
Counter Location #3	Before	56.79	6.00	18	67	63	Yes	0.0026
	After	50.11	7.54	35	62	58		
	Change	-6.68	1.54	17	-5	-5		

Table D24. FM707 Southbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	52.25	5.19	11	60	56	No	0.2224
	After	55.73	7.19	41	71	61		
	Change	3.48	2.00	30	11	6		
Counter Location #2	Before	59.50	9.40	21	71	67	No	0.7414
	After	57.89	7.13	40	76	65		
	Change	-1.61	-2.26	19	5	-2		
Counter Location #3	Before	53.00	8.60	20	64	60	No	0.2584
	After	57.96	5.64	29	69	63		
	Change	4.96	-2.96	9	5	3		

Dawn/Dusk – Car

Table D25. TX70 Southbound in Blackwell

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	68.98	5.52	39	89	75	No	0.0990
	After	70.62	7.57	57	89	77		
	Change	1.64	2.05	18	0	2		
Counter Location #2	Before	66.76	6.58	33	81	73	Yes	0.0012
	After	63.92	5.79	31	79	69		
	Change	-2.84	-0.79	-2	-2	-4		
Counter Location #3	Before	60.60	6.79	32	77	67	Yes	0.0424
	After	58.47	7.51	36	76	67		
	Change	-2.13	0.72	4	-1	0		

Table D26. FM707 Northbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	64.17	6.15	39	82	70	Yes	0.0004
	After	59.73	6.30	43	80	66		
	Change	-4.44	0.15	4	-2	-4		
Counter Location #2	Before	65.29	5.93	44	91	71	No	0.4654
	After	64.83	7.30	60	87	71		
	Change	-0.46	1.37	16	-4	0		
Counter Location #3	Before	63.62	5.78	32	79	70	Yes	0.0004
	After	58.87	6.49	40	76	65		
	Change	-4.74	0.71	8	-3	-5		

Table D27. FM707 Southbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	56.69	9.56	58	76	64	Yes	0.0014
	After	60.91	6.95	40	79	68		
	Change	4.22	-2.60	-18	3	4		
Counter Location #2	Before	60.78	6.08	28	74	68	No	0.2938
	After	61.77	6.61	38	76	69		
	Change	0.98	0.54	10	2	1		
Counter Location #3	Before	54.49	5.49	32	67	60	Yes	0.0004
	After	61.31	7.29	38	75	69		
	Change	6.82	1.81	6	8	9		

Dawn/Dusk – Truck

Table D28. TX70 Southbound in Blackwell

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	66.57	2.51	7	70	69	Yes	0.0026
	After	70.85	3.50	11	75	75		
	Change	4.27	1.00	4	5	6		
Counter Location #2	Before	65.14	4.02	13	70	67	No	0.2320
	After	62.94	3.47	12	68	67		
	Change	-2.21	-0.55	-1	-2	0		
Counter Location #3	Before	58.71	3.55	10	63	63	No	0.8104
	After	59.16	4.29	15	68	63		
	Change	0.45	0.74	5	5	0		

Table D29. FM707 Northbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	66.86	2.04	6	70	69	Yes	0.0174
	After	62.54	5.70	21	72	68		
	Change	-4.32	3.66	15	2	-1		
Counter Location #2	Before	69.86	5.15	16	80	73	No	0.7264
	After	68.98	5.70	17	80	75		
	Change	-0.88	0.55	1	0	3		
Counter Location #3	Before	65.57	2.57	7	69	68	Yes	0.0414
	After	61.97	5.12	20	73	65		
	Change	-3.60	2.54	13	4	-3		

Table D30. FM707 Southbound in Abilene

Overall		Speed (mph)					Statistically Significant?	P-Value
		Mean	St. Dev.	Range	Max	85th Percentile		
Counter Location #1	Before	53.00	4.24	10	57	57	No	0.0562
	After	57.92	6.26	25	69	63		
	Change	4.92	2.02	15	12	6		
Counter Location #2	Before	57.40	4.98	12	64	62	No	0.3734
	After	59.69	4.67	14	69	64		
	Change	2.29	-0.31	2	5	2		
Counter Location #3	Before	52.80	5.63	14	61	57	Yes	0.0156
	After	59.90	5.42	21	75	63		
	Change	7.10	-0.22	7	14	6		

JEFF STRONG

Jeff Strong is a senior at Texas A&M University, and plans to graduate in December 2004 with a Bachelor of Science in Civil Engineering. He has been an active volunteer for Habitat for Humanity while a full-time student. Jeff has previous work experience as a merchandising manager at Six Flags Over Texas in Arlington, Texas. Upon graduation, Jeff hopes to improve the transportation infrastructure in Texas to better accommodate the increasing demands placed upon it, and has interests in new technologies that can reduce congestion while improving safety.

RED BORDER SPEED LIMIT SIGNS

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SUMMARY

Speeding is a major safety issue, especially where speed limits decrease. The reduced speed zones are a particular concern because drivers traveling at 70 mph (day)/65 mph (night) are approaching city traffic that is moving at slower speeds and closer together. The problem exists because a majority of drivers are not aware that the speed limit has decreased to a lower speed. This study looked to address the issue by making the Speed Limit sign more conspicuous. The results of a focus group from a previous Texas Transportation Institute (TTI) study found that a red border around the standard Speed Limit sign communicates the importance of adhering to the speed limit.

The red border Speed Limit sign was tested at three locations in a before and after study approach. The sites were State Highway 21 near Caldwell, State Highway 60 outside of Snook, and State Highway 36 on the edge of Milano. These sites were selected because the surroundings and design of the road do not communicate to drivers a need to slow down. The measures of effectiveness for the research were mean speed, 85th percentile speed, and the percent of drivers exceeding a range of speeds throughout the sites. The results of the study show that the red border Speed Limit sign was effective in Caldwell and Snook and not effective at the Milano study site. Overall, the red border proved to be a potential tool for improving compliance with speed limits.

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INTRODUCTION

Researchers from the Texas Transportation Institute (TTI) have observed, "Unexpected changes in speed limit may result in unfavorable traffic operational characteristics such as high speeds, high speed variances, and erratic decelerations, each of which may be associated with higher crash occurrences (*1*)." The increase in speed related crashes have motivated researchers to determine what measures could be taken to get the attention of drivers entering reduced speed zones. Approaches to increase driver recognition of decreased speed limits rarely change the appearance of the Speed Limit sign but attach treatments to the sign. Some treatments include larger signs, orange flags attached to the sign, and placing a colored plaque at the top of the sign.

Another treatment, tested in a recent TTI study, was the use of a red border around a standard Speed Limit sign. The advantage to this treatment is that it has the potential to be a more permanent part of the sign than orange flags or colored plaques. This research further evaluated the impact of the red border Speed Limit sign as a means of increasing the conspicuity of the sign. This research report includes a discussion of the problem, research objectives, a summary on speed management, and research results, conclusions, and recommendations.

PROBLEM STATEMENT

Excessive speed is a significant safety concern for the highway system. The National Highway Traffic Safety Administration (NHTSA) Toll of Vehicle Crashes reports that 41 percent of fatal crashes in Texas and 31 percent of fatal crashes in the United States were speed related in 2002 (*2*). Drivers typically speed for two simple reasons: 1) the driver ignores the change in speed limit or 2) the driver is unaware of the change in speed limit. Endless reasons exist for why a driver may ignore the speed limit, some of which include the driver does not perceive a need to slow down, the driver is in a hurry, and/or the driver is careless. Changes to improve the conspicuity of the Speed Limit sign may not improve the traffic conditions caused by careless drivers. Although sign treatments do not impact every driver, measures are needed to improve the probability that a compliant driver is aware of the speed limit.

In the previous TTI red border Speed Limit sign evaluation, the researchers hypothesized that the red border around the Speed Limit sign would benefit the unaware driver by drawing more attention to the sign. Then, the drivers that were speeding in the before condition because they had not seen the sign may be more likely to slow down in the after condition (*1*). In addition, the red border is likely to add emphasis to the Speed Limit sign so careless drivers may feel that the red border indicates the importance of slowing down. Because the previous TTI study was limited to only one study site, this research tested the effectiveness of the red border Speed Limit sign at several additional study sites. The results from the study sites showed some decreases in vehicle speed, and occasionally, more drivers complied with the speed limit after the red border Speed Limit sign was installed.

LITERATURE REVIEW

Speeding drivers put their own lives at risk and are hazards for safe motorists. A speeding vehicle requires more distance to stop, and sometimes, the driver cannot stop or maneuver the vehicle soon enough to avoid a crash. These types of crashes cause 41 % percent of fatal crashes in Texas. State departments of transportation and law enforcement agencies have responded to the high percentage of speed related crashes by managing vehicle speed on highways and reduced speed zones.

Reductions in the speed limit are common on highways leading into rural towns and even on freeways approaching a city. The speed limit is reduced because traffic congestion increases, and the distance decreases between vehicles. Approaches to communicate the importance of driving at safe speeds are

necessary when the speed changes as much as 15 mph. Some methods include signs with flashing lights, law enforcement, and radar trailers (*3*). Flashing lights are often used to warn drivers of school speed zones, and research has shown that speeds decrease 5-7 mph when a sign with flashing lights is used in a school zone (*4*). The flashing lights are not used with Speed Limit signs outside of school zones, but electronic vehicle activated Speed Limit signs with light emitting diodes are used in Europe (*5*). Law enforcement and radar trailers also encourage compliance with the speed limit but are only effective when officers are on patrol and the radar trailers are present. An adaptation of the radar trailer has been implemented in some cases. Permanent, electronic speed radar signs combined with the Speed Limit sign aware the driver how fast they are driving compared to the posted speed limit.

Pavement markings and the Speed Limit sign are also used to communicate reduced speeds and offer a more permanent solution to reduce the number of speed limit violations. The possibility of speed related fatalities call for permanent speed management techniques that perform comparably to the temporary presence of radar trailers or law enforcement. The problem with pavement markings and most speed management techniques is that the conspicuity of the Speed Limit sign does not improve with the treatment. If most drivers paid attention to Speed Limit signs, then other speed management methods would not be as important. The NHTSA crash data implies that the current conspicuity of the Speed Limit sign does not adequately inform drivers of the importance of driving the speed limit. Changes to the Speed Limit sign may help to improve driver awareness of the Speed Limit sign.

A review of the international Speed Limit signs in Figure 1 show obvious differences when compared against the standard United States Speed Limit sign. Most international Speed Limit signs have a colored border other than black, and the colored border is thicker than the thin, black border for the United States Speed Limit sign. Researchers from a previous TTI study reached the same conclusion about the border of the Speed Limit sign and tested the impact of a 3-inch, red border around a Speed Limit sign. The color, red, was chosen over yellow as a more appropriate border color by focus groups. Based on the insight from the focus groups, the researchers selected red as the best color. The Speed Limit sign shown in Figure 2 was the sign used for the TTI study.

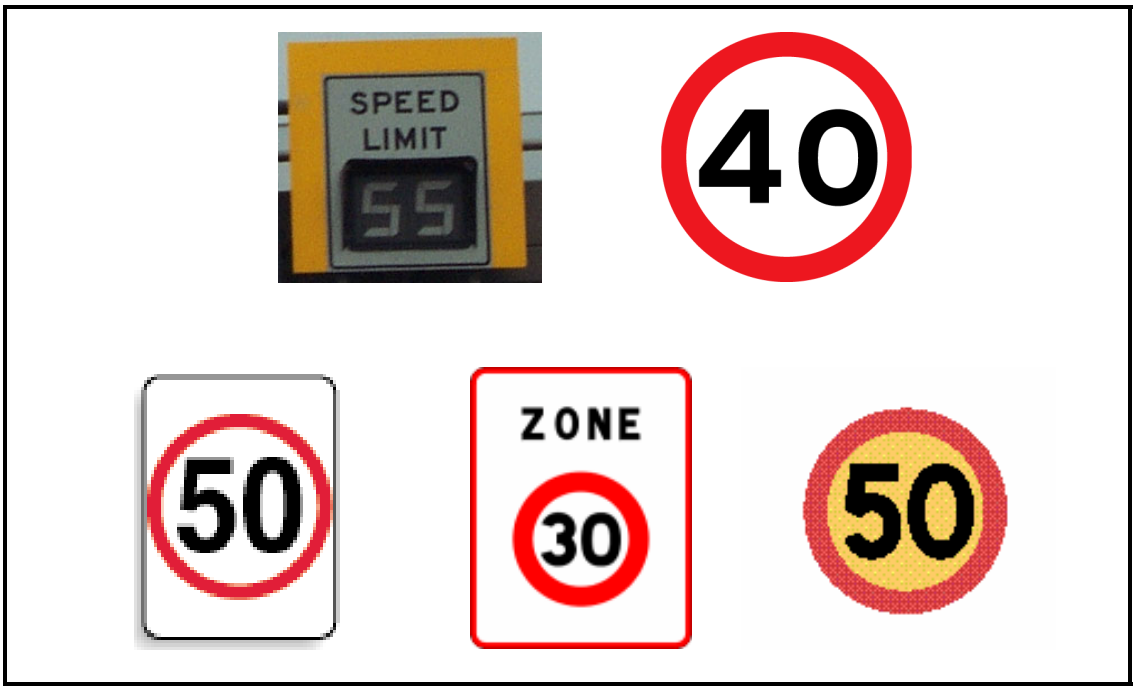

Figure 1. Speed Limit Signs with Colored Borders

Figure 2. Red Border Speed Limit Sign

The results from the TTI study concluded that a red border placed around the Speed Limit sign significantly reduces vehicle speed and speed limit violations. A 1.92 mph reduction in average speed was observed at the Speed Limit sign and a 1.99 mph reduction in speed was observed 500 feet after the Speed Limit sign in the before and after studies. More evidence for the success of the red border is that the rate of vehicles exceeding the speed limit dropped 15% (80%-before, 65%-after). These promising results demonstrated the possibilities of the red border, but more research is needed to test the validity of the results.

OBJECTIVES

The research conducted a before-and-after evaluation of the effectiveness of the red border Speed Limit sign at several sites. The goals for this research were:

- Establish criteria for site selection,
- Evaluate the traffic impacts of a red border Speed Limit sign at test sites,
- Evaluate the data to determine the effectiveness of the treatment and compare the results to the previous study, and
- Make recommendations for the use of red border Speed Limit signs and sign conspicuity.

RESEARCH METHODOLOGY

The methodology used in this research was a before-and-after study. First, traffic operations data were collected with the original Speed Limit sign. Then, the existing sign was replaced with the red border Speed Limit sign. After a minimum one week waiting period, traffic operations data were collected for the after data. Two weeks of wait time was the preferred amount of elapsed time between before and after data collection, but unpredictable circumstances required that the wait period be shortened to one week. Timestamps, vehicle speed, and vehicle class data were collected to determine the mean speed, 85th percentile speed, and percentage of vehicles exceeding a range of speeds near the sign. Timestamps are the time of day when the vehicle was detected. The timestamp allows the vehicles to be divided into day and night categories. The times of sunrise and sunset were used to establish daytime periods. The nighttime period started thirty minutes after sunset and stopped thirty minutes after sunrise. The 85th

percentile speed is used by the Texas Department of Transportation for defining speed zones and has been proven in several before-and-after studies as an appropriate standard for establishing speed limits(*6*) The vehicle class data was necessary to divide the vehicles into passenger vehicles and heavy vehicles.

Establish Site Criteria

The previous TTI study on the red border Speed Limit sign was limited to one site. Since this research expanded the previous research to three sites, criteria were needed to select test sites. Criteria came from inferences during the literature review, site visits, and the guidelines of the Texas Department of Transportation manual on *Procedures for Establishing Speed Zones* (6) The criteria describe the design and operation details for an ideal test site. Speed zones with straight horizontal alignment, level to positive grades, and consistent roadside design with sparse development make for a good test site. Also, the Speed Limit sign should not compete with other signs for the attention of drivers, and drivers should not perceive a need to decelerate. Other important factors are that the Speed Limit sign should be farther than 0.2 miles from signalized intersections, not within or near a school zone, and a minimum of 125 vehicles must travel through the test site within a 2 hour period. The selection of sites was more objective with the test site criteria established, and the reason for selecting sites better defined.

Based on the criteria, three sites were selected. Several sites were examined as potential sites, but sites near Caldwell, Snook, and Milano were chosen as test sites. The Caldwell test site was on State Highway 21 West. The next site was on State Highway 60 East outside of Snook. The highway is a two-lane road with twelve-foot lanes and no shoulder. This site was unique to the other selected sites because it is a four-lane highway with median. The traffic volume at this location was greater than any other test site. The last site was near Milano on State Highway 36 North. The road is a two-lane road with a twelve-foot lane and a ten-foot shoulder.

Data Collection

Data were collected before and after the red border treatment to the Speed Limit sign. Traffic counters and vehicles sensors were used to collect the data. The counter used for this research was the PEEK Traffic Automatic Data Recorder 2000 Plus. Sensors were connected to the counters and placed on the roadway to measure and record the speed of a detected vehicle. Piezoelectric sensors were used predominantly over pneumatic tubes because piezoelectric sensors are less noticeable to drivers than the pneumatic tubes. Pneumatic tubes were used at the Caldwell test site only because the piezoelectric sensors used for this study were approximately six feet long and can not be extended across two lanes. Five counters were positioned at predetermined locations at each test site. The first counter was located at a control point out of sight of the Speed Limit sign. The before and after average vehicle speeds at the control point should not show a significant decrease in speed because the speed limit sign is not visible at this location. The second classifier was stationed at the threshold distance from the Speed Limit sign. The threshold point is where drivers can first read the Speed Limit sign. The third classifier was positioned halfway between the second classifier and the Speed Limit sign. The next classifier was placed at the Speed Limit sign. The fifth and final classifier was located downstream of the Speed Limit sign. Figure 3 illustrates the classifier arrangement at a test site. Table 1 outlines the data collection schedule and Table 2 summarizes the sample sizes for each study site.

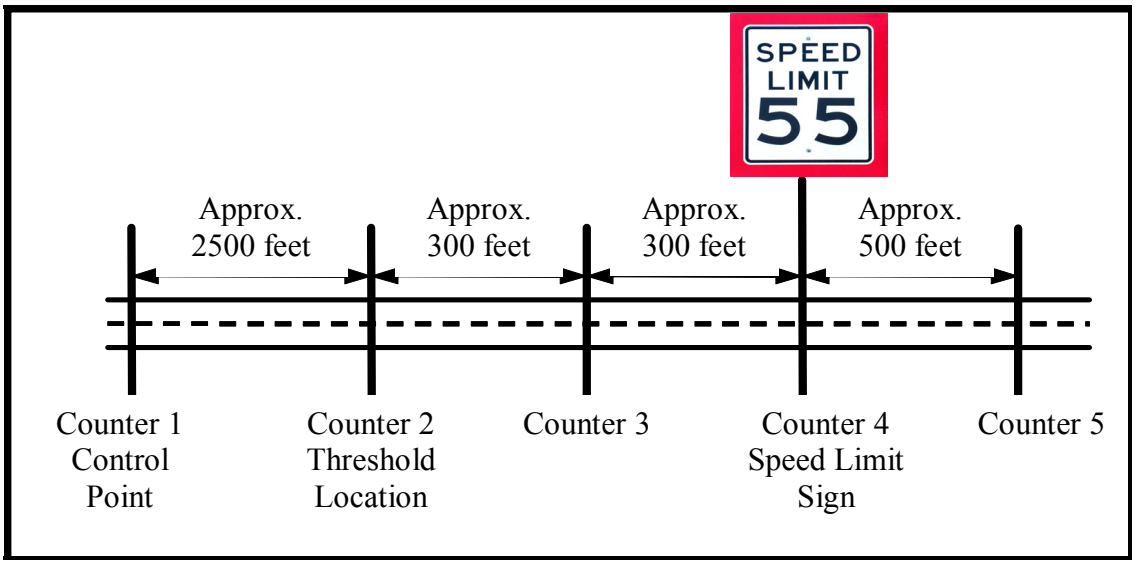

Figure 3. Counter Layout at Test Sites

Table 1. Data Collection Schedule

Test Sites	Before Dates	After Dates	Day Hours	Night Hours
Caldwell - SH 21 West	6/16,17, 18	7/8, 9	13.5	9
Snook - SH 60 East	7/1, 2, 3	7/16, 17, 18	20	20.5
Milano - SH 36 North	6/28, 29, 30	7/20, 21, 22	9	NA

Table 2. Sample Sizes

Site	Vehicle Type	Day Before	Day After	Night Before	Night After
Caldwell	Passenger	1176	1075	299	184
	Heavy	109	107	NA	NA
Snook	Passenger	892	329	490	186
Milano	Passenger	401	197	NA	NA
	Heavy	124	69	NA	NA

Data Reduction

The purpose for data reduction is to remove misleading data recorded on each counter before performing data formatting and analysis. Data reduction attempts to ensure that the speed data analyzed are representative of vehicles that travel through the test site on a consistent basis. The first step in data reduction is to download the raw data into spreadsheets. A sample of raw data collected at a test site is shown below in Table 3**.** The counter collects the date, time, quality, classification, and speed of a vehicle timestamp. Occasionally, timestamps are not quality data. These timestamps must first be removed from the raw data. The entry in Table 3 of FFFF represents a quality timestamp. Any other combinations of letters for timestamp quality verification are eliminated. Timestamps that were eventually reduced and disregarded for data analysis are italicized in Table 3. Then, the headway, or amount of time between successive vehicles is considered during data reduction. A trailing vehicle with less than six seconds of headway from a leading vehicle was removed from the collected data. Next, all Class 1 vehicle, or motorcycles were removed from the data. Speed was also considered during data reduction. If a vehicle was traveling below 50 mph at the control point, or accelerated more than 10 mph between the Control Point and Counter 2 (see Figure 3), then that vehicle was removed from the data set. These qualifiers help remove vehicles that were noticeably accelerating or decelerating before arriving at the study site. Last, if a vehicle was traveling 20 mph below the posted speed limit, then that vehicle was eliminated from the raw data. The data were then ready to be formatted and analyzed after data reduction. The finished product of data reduction for raw counter data is shown in Table 4. Assume that Table 3 represents hypothetical raw data from the control point counter. Timestamp 4:56:16 is reduced because its vehicle speed is less than 50 mph. Timestamp 4:59:02 is disregarded because the timestamp was not a quality data point. The 4:59:06 timestamp is eliminated because only four seconds separate it and the 4:59:02 timestamp. This case is a violation of headway requirements.

Table 3. Raw Counter Data

Date	Time	Timestamp Quality	Vehicle Classification	Speed
19/07/04	4:51:14	FFFF	2	55
19/07/04	4:56:16	FFFF	2	34
19/07/04	4:58:44	FFFF	5	70
19/07/04	4:59:02	00EE	2	68
19/07/04	4:59:06	FFFF	2	66

Table 4. Reduced Counter Data

Date	Time	Timestamp Quality	Vehicle Classification	Speed
19/07/04	4:41:09	FFFF	9	63
19/07/04	4:48:19	FFFF	8	66
19/07/04	4:49:47	FFFF	3	73
19/07/04	4:51:14	FFFF	2	55
19/07/04	4:58:44	FFFF	2	70

Data Formatting and Analysis

The data for each counter can be compared against each other after data reduction. Speed profiles were developed for individual vehicles based on the comparison of timestamp and vehicle speed. Headway served as a secondary measure for tracking vehicles through a test site. The last step before data analysis could begin was to arrange the matched vehicles into trucks and passenger vehicles for daytime and nighttime periods.

Once the data were arranged, data analysis was conducted on the data to determine mean speeds, 85th percentile speeds, and percentage of vehicles exceeding the speed limit. Data analyzed had similar time periods for each site in the before and after data. Statistical analysis was not performed on the mean speed and 85th percentile speeds. The Z-test of proportions was performed on the speed data. The Z-test of proportions was used to analyze the differences in rates of vehicles exceeding the 70/65 mph and 55 mph speed limit in the before and after condition based on counter position. The statistical analysis was performed at a confidence level of 95%. Microsoft Excel was used to conduct the Z-test of proportions.

RESULTS

The before and after data collected at each site were evaluated to determine if the red border Speed Limit sign caused drivers to reduce speed in proximity of the sign and if more drivers complied with the 55 mph speed limit. Measures of effectiveness for the red border Speed Limit sign included mean speed, 85th percentile speed, and percentages of vehicles exceeding the speed limit. The results are presented in two formats. The mean and 85th percentile speeds for each site are viewed simultaneously while the percentages of vehicles exceeding a certain speed are prepared separately for each site.

Mean and 85th Percentile Speeds

Changes in the before and after mean and 85th percentile speeds help determine the impact of the red border Speed Limit sign. Statistical analysis was not performed on the difference of mean or 85th percentile speeds. The most important location for decreases in speed is downstream of, or after, the Speed Limit sign. Table 5 and Table 6 organize the mean and 85th percentiles speeds downstream of the Speed Limit sign only at all three sites. Figures 4 through 6 illustrate the mean and 85th percentile speeds for different vehicles and time of day. A review of the tables and the figures show that mean speeds and 85th percentile speeds decreased for nearly all of the vehicle types and light conditions after the implementation of the red border Speed Limit sign.

Table 5. Mean Speed and 85th Percentile Speed Comparisons for Heavy Vehicles Downstream of Speed Limit Sign

Site	Time	Study	Mean Speed	85th Percentile
Caldwell	Day	Before	61.02	67.8
		After	59.25	66
Milano	Day	Before	64.95	70.4
		After	65.07	70

Table 6. Mean Speed and 85th Percentile Speeds for Passenger Vehicles Downstream of Speed Limit Sign

Site	Time	Study	Mean Speed	85th Percentile
Caldwell	Day	Before	63.14	71
		After	62.27	69
	Night	Before	60.17	67
		After	58.31	65
Snook	Day	Before	65.48	72
		After	65.01	72
	Night	Before	60.63	68
		After	60.19	67
Milano	Day	Before	65.54	73
		After	65.39	72.6

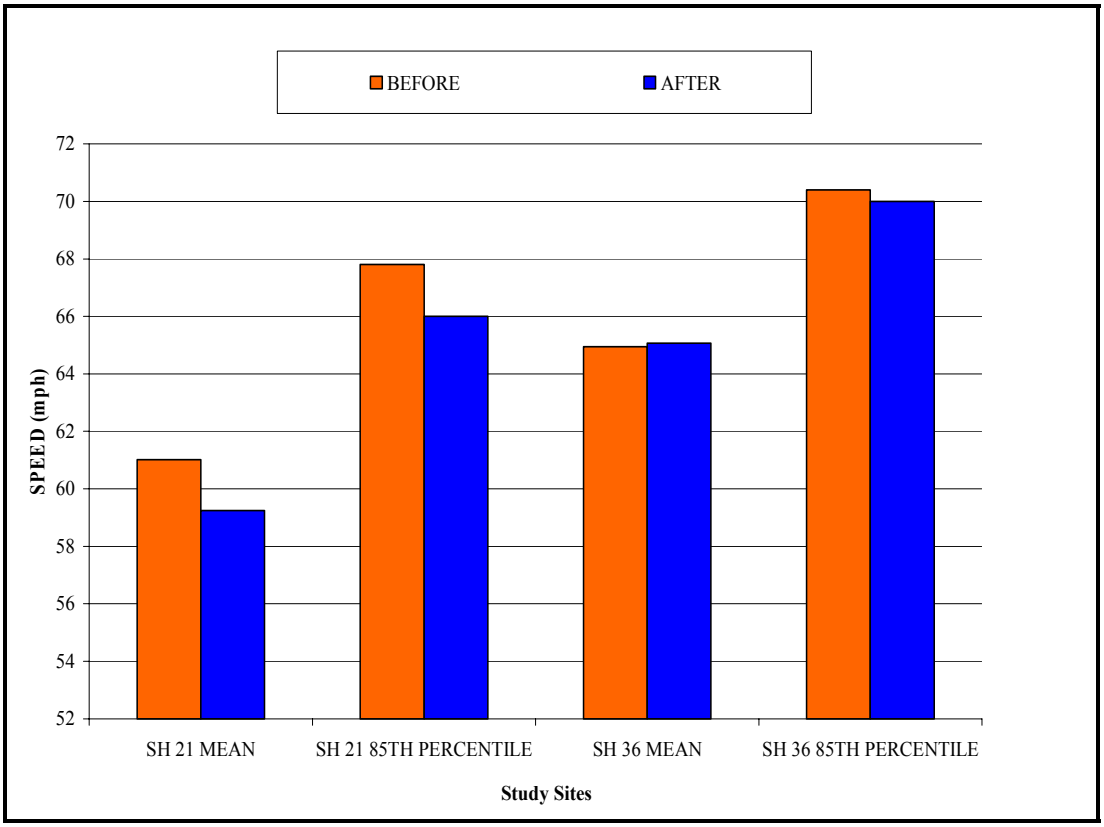

Figure 4. Heavy Vehicles – Daytime – Downstream of Speed Limit Sign

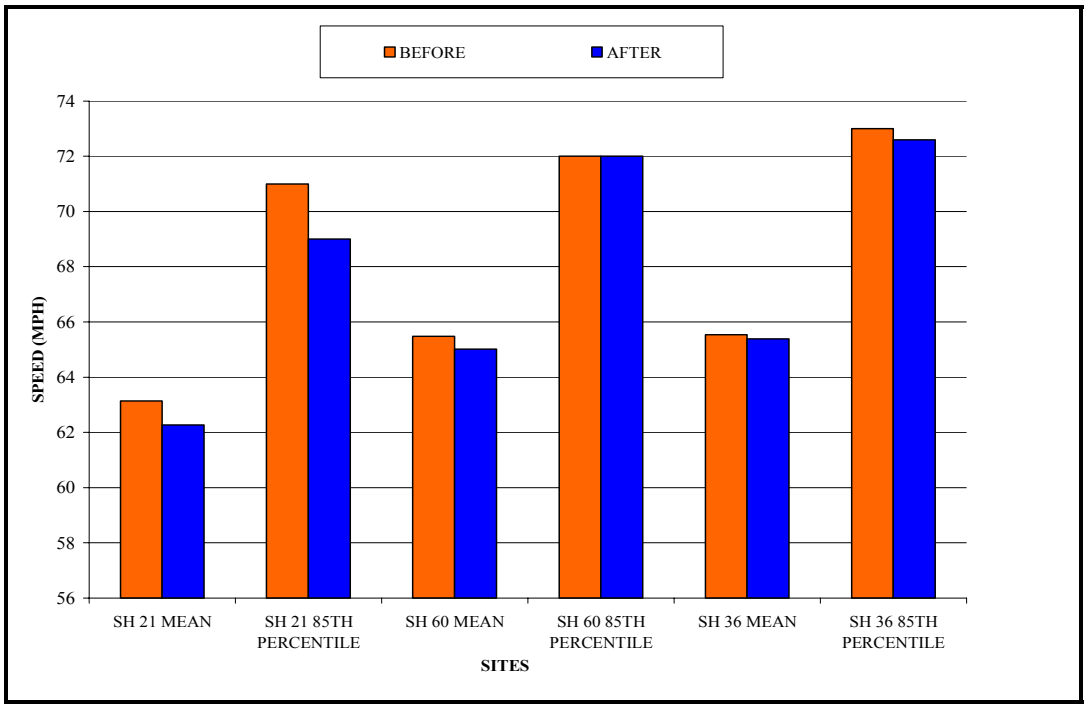

Figure 5. Passenger Vehicles – Daytime – Downstream of Speed Limit Sign

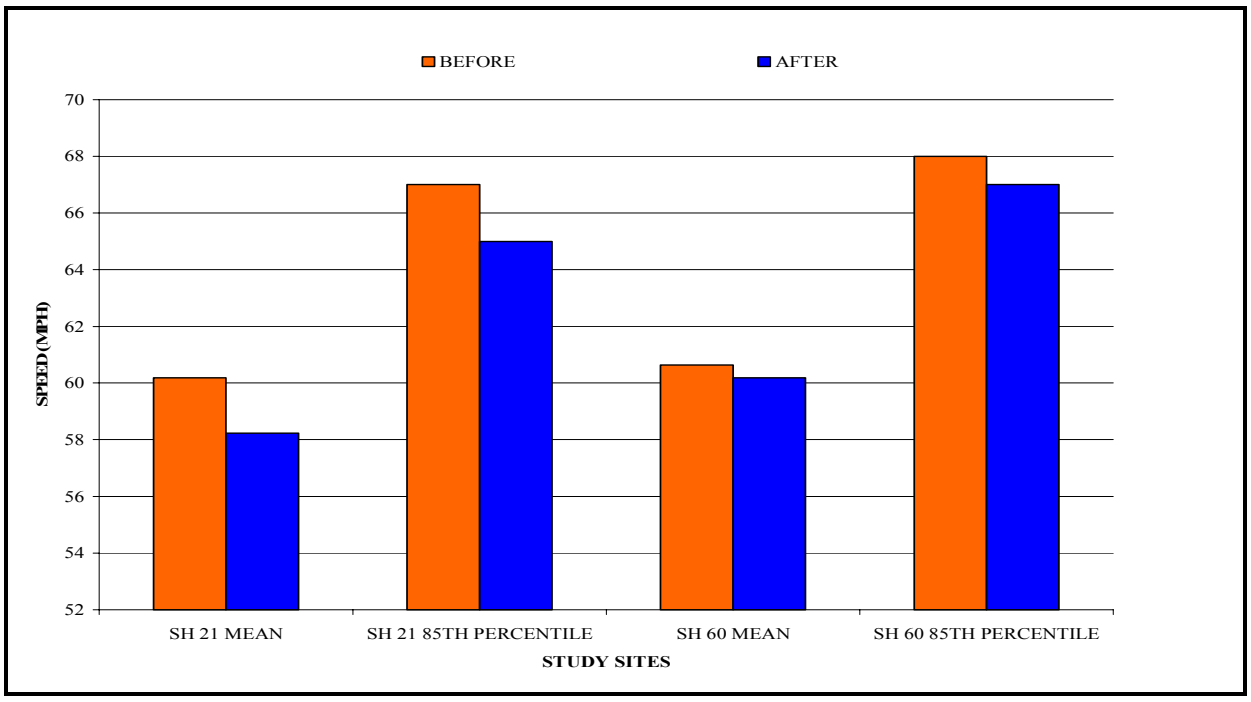

Figure 6. Passenger Vehicles – Nighttime – Downstream of Speed Limit Sign

Percent Exceeding Speed Limit

The percent exceeding speeds of 70 mph, 65 mph, 60 mph, and 55 mph was figured, and the difference in these percentages for the before and after studies was tested for significant changes. The advantage of

evaluating each speed is to see if the vehicles although are decelerating to the 55 mph reduced speed limit, or determine if the vehicles are slowing down but not reducing speed to the 55 mph speed limit. Each site is viewed individually for this phase of the evaluation. Tables 7 through 10 list the change in percent exceeding speeds of the range mentioned above for each study site. The change in percent is the difference of the after and before percentage of vehicles exceeding 70 mph, 65 mph, 60 mph, 55 mph. Figures 7 through 13 graphically portray the information in Tables 7 through 9 demonstrates how vehicles slowed down and what percentage of vehicles complied with the speed limit after the implementation of the red border speed limit sign.

Table 7. Percent Change in Speed for Before and After Study – Passenger Vehicles SH21 – Caldwell

Condition	Counter	Change in % Over 70 mph	Change in % Over 65 mph	Change in % Over 60 mph	Change in % Over 55 mph
Passenger Day	1	16.1%	7.9%	2.2%	-0.4%
	2	19.1%	10.8%	2.2%	-0.2%
	4	4.0%	6.7%	6.8%	2.6%
	5	-3.7% *	-3.3%	-4.1% *	-2.9%
Passenger Night	1	3.6%	16.3%	-4.0%	-1.6%
	2	6.3%	4.8%	1.1%	0.3%
	4	-0.2%	4.8%	7.7%	-2.3%
	5	-5.30% *	-5.9%	-4.8%	-13.8% *

*** = statistically significant differences.**

CONCLUSIONS

The impact of the red border Speed Limit sign in this research along with the results of the previous study support the hypothesis that the red border Speed Limit sign could improve the traffic operational characteristics associated with reduced Speed Limit signs. The future testing of the red border Speed Limit sign on U.S. Highway 79 near Franklin, Texas will further validate or discredit the findings of this research. To enable further evaluation, the red border Speed Limit signs will stay in place at the study sites for a few more months. More after data will be collected in the following months at Franklin and at the sites in this study to test the long term impacts of the red border Speed Limit sign.

The details of the previous TTI study are provided in Appendix A. The past TTI study concluded that the mean speed of heavy vehicles and passenger vehicles decreased with statistical significance downstream of the red border Speed Limit sign. The past study also stated that a statistically significant decrease in the percentage of vehicles exceeding the reduced, 55 mph Speed Limit only occurred for passenger vehicles during the day.

Table 8. Percent Change in Speed for Before and After Study – Heavy Vehicles SH21 – Caldwell

Condition	Counter	Change in % Over 70 mph	Change in % Over 65 mph	Change in % Over 60 mph	Change in % Over 55 mph
Heavy Vehicles Day	1	1.30%	10.3%	-2.1%	2.7%
	2	3.20%	17.6%	10.9%	3.7%
	4	-4.50%	1.4%	0.0%	8.0%
	5	-9.10% *	-9.8%	-16.8% *	-2.3%

*** = statistically significant differences.**

Table 9. Percent Change in Speed for Before and After Study – SH 60 - Snook

Condition	Counter	Change in % Over 70 mph	Change in % Over 65 mph	Change in % Over 60 mph	Change in % Over 55 mph
Passenger Day	1	5.7%	2.1%	0.4%	-0.5%
	2	-1.9%	-3.9%	-2.6%	-0.8%
	3	2.5%	2.0%	-1.4%	-2.2%
	4	-2.8%	-5.1%	-3.9%	-2.8% *
	5	-0.3%	-3.8%	-3.9%	-3.3% *
Passenger Night	1	15.6%	10.6%	3.3%	-0.9%
	2	-3.3%	3.3%	4.1%	0.5%
	3	-3.1%	1.3%	2.2%	1.9%
	4	-2.9%	-3.8%	-0.1%	2.0%
	5	-3.9%	-3.7%	0.3%	2.3%

*** = statistically significant differences.**

The current research observed mean speeds and 85th percentile speeds. The mean speeds of passenger vehicles during the day and night decreased at each study site. Mean speed reductions ranged from 0.15 mph to 0.87 mph. Heavy vehicles experienced similar results with decreases of 1.77 mph during the day and 4.85 mph at night. The 85th percentile speeds decreased also with the smallest reduction being no change and the largest decrease at 2 mph. Heavy vehicles decreased in 85th percentile speeds also. The range in deductions spanned from 0.4 mph to 5 mph. Based on the differences in mean and 85th percentile speeds, the red border Speed Limit sign caused a slight improvement in the conspicuity of the sign.

Table 10. Percent Change in Speed for Before and After Study – SH 36 - Milano

Condition	Counter	Change in % Over 70 mph	Change in % Over 65 mph	Change in % Over 60 mph	Change in % Over 55 mph
Passenger Day	1	16.1%	12.6%	5.2%	0.7%
	2	1.4%	8.6%	7.1%	3.2%
	3	0.5%	3.4%	4.8%	2.0%
	4	-1.2%	0.2%	0.6%	2.4%
	5	-1.6%	0.1%	1.6%	-0.1%
Heavy Vehicles Day	1	21.9%	20.3%	5.0%	0.2%
	2	8.0%	31.3%	20.3%	1.9%
	3	13.2%	23.1%	15.7%	0.3%
	4	7.6%	30.1%	21.0%	4.5%
	5	2.9%	23.3%	15.8%	8.4%

The results for the statistical analysis of reduced speeds over a range of speeds will confirm the conclusion based on the mean and 85th percentile speeds. All significant results were deemed so from the statistical analysis performed on the before and after speed data. The difference between the before and after data can be statistically significant but not grounds for implementing the red border Speed Limit sign on an application basis. Figure 13 shows, from left to right, the red border Speed Limit signs for Caldwell, Snook, and Milano.

State Highway 21 – Caldwell

Passenger vehicles and heavy vehicles during the day and night were affected by the red border Speed Limit sign. This reduction in percent exceeding the speeds proved to be significant downstream of the Speed Limit sign for several cases. The change in percent exceeding 70 mph decreased significantly for passenger vehicles during the day and night and dropped 9.1% for heavy vehicles during the day. Also, a significantly lower percentage of passenger vehicles were exceeding 60 mph. The percentage of heavy vehicles exceeding 60 mph dropped considerably during the day and night (16.8%, 43.8%). According to the statistical analysis, the red border Speed Limit sign had a positive affect on traffic conditions.

State Highway 60 – Snook

Statistical analysis was performed on passenger vehicles during the day and night only at Snook. Data collection in the after phase only accounted for seventeen trucks during the day and fifteen trucks at night. The low volumes eliminated heavy vehicles from analysis. The decrease in passenger vehicles exceeding 55 mph at the 55 mph Speed Limit sign and downstream of the Speed Limit sign was significant with decreases of 2.8% and 3.3%. State Highway 60 outside of Snook does not have a shoulder. This condition might cause drivers to typically drive slower, especially at night. This characteristic could have been the cause for the red border Speed Limit sign not significantly affecting passenger vehicles at night.

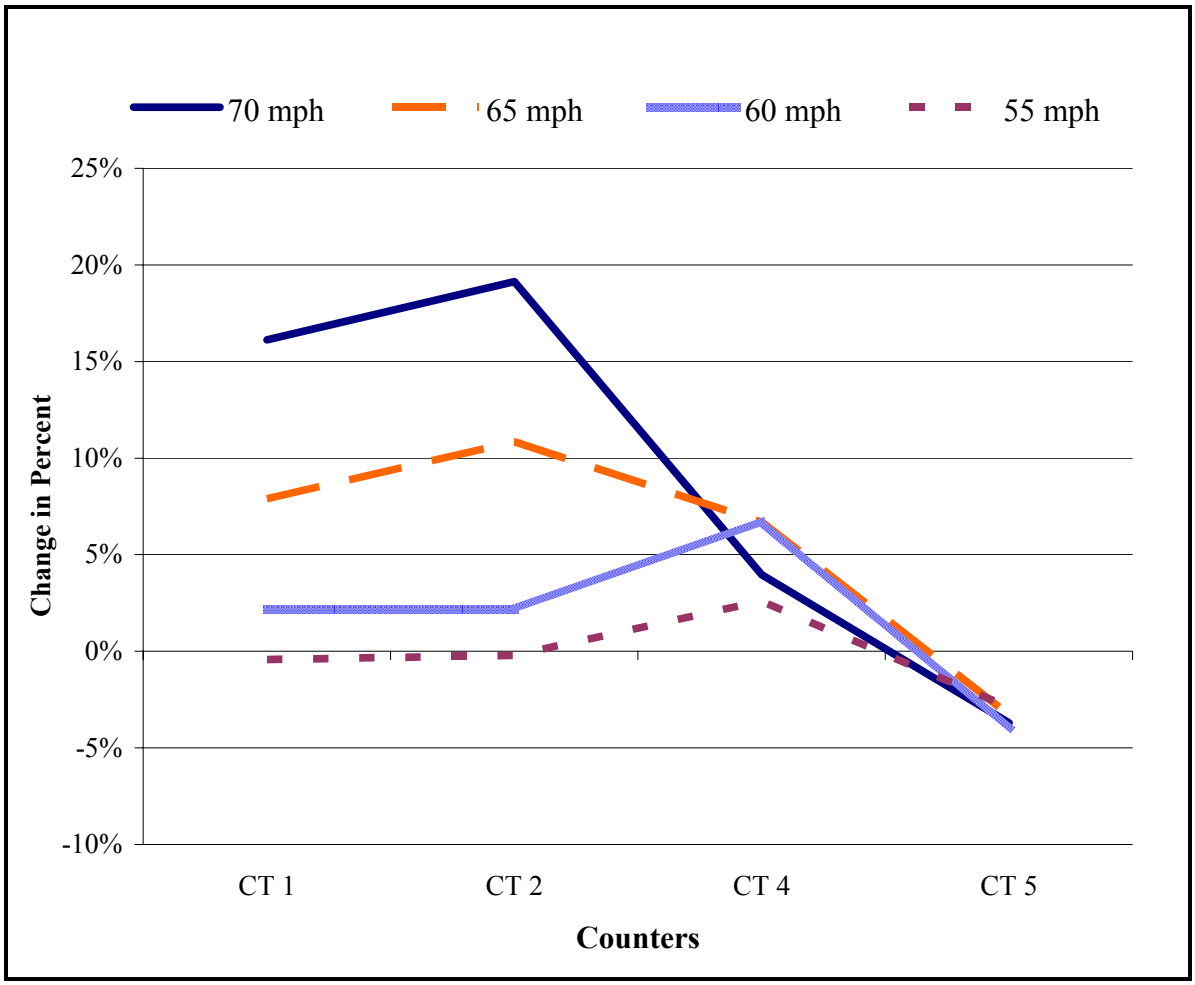

Figure 7. SH 21 Passenger Vehicles Daytime Before and After Change in Percent Exceeding Speed

State Highway 36 – Milano

The Milano study site was perceived as an extremely promising site because of its design and roadside features. The study at this site was impacted considerably during daytime and nighttime data collection because of wet weather and data collection equipment malfunction. Enough data were collected during the day to make tentative conclusions on passenger and heavy vehicles. The results from the statistical analysis showed no signs of significant changes in the percentage of passenger or heavy vehicles exceeding 70 mph, 65 mph, 60 mph, and 55 mph.

RECOMMENDATIONS

The research conducted on State Highway 21 near Caldwell, State Highway 60 outside of Snook, and at State Highway 36 approaching Milano provided insight on the possibilities of the red border Speed Limit sign. Because of the lack of traffic volumes in some instances, data collected at the future test site, U.S. Highway 79 near Franklin, and the long term data collection at the sites for this study will provide important data for determining the effect of the red border Speed Limit sign. Future researchers might consider whether increasing the width of the red border for locations with larger signs is appropriate. Milano and Caldwell had larger signs than Snook, but the same width of border was used at each location. Based on the results from this study, the width of border may not be crucial. The red border Speed Limit sign performed the best statistically at Caldwell.

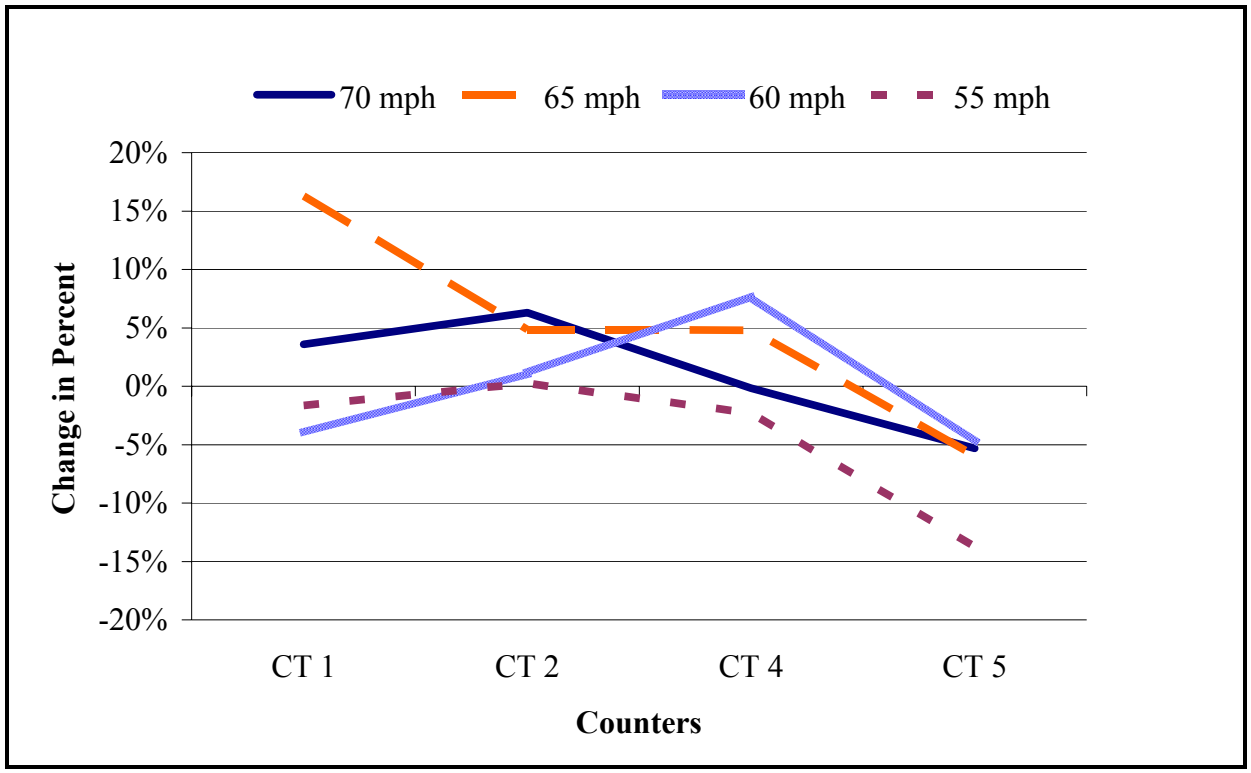

Figure 8. SH 21 Passenger Vehicles Nighttime Before and After Change in Percent Exceeding Speed

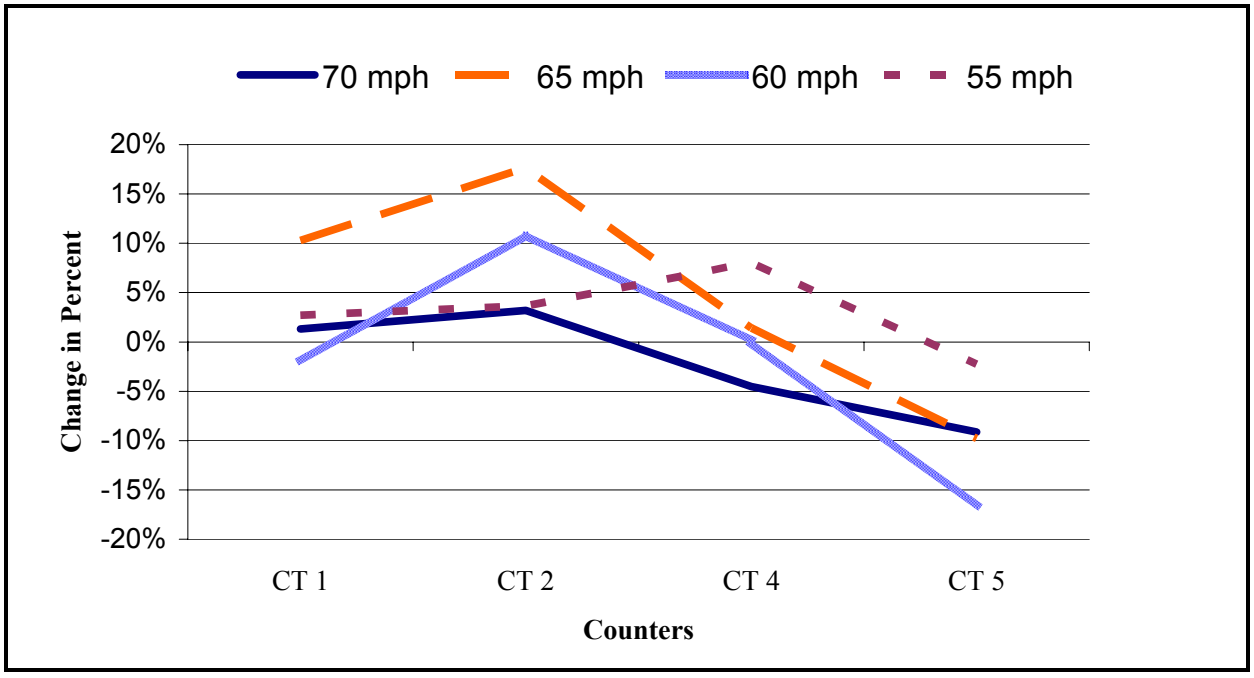

Figure 9. Heavy Vehicles Daytime Before and After Change in Percent Exceeding Speed

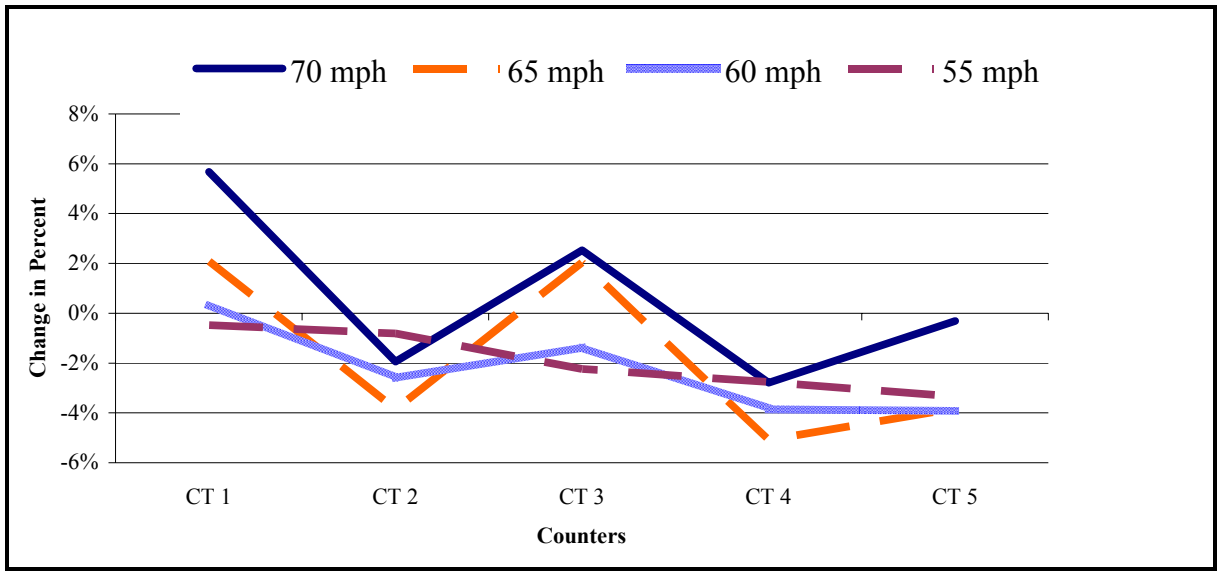

Figure 10. SH 60 – Passenger Vehicles Daytime Before and After Change in % Exceeding Speed

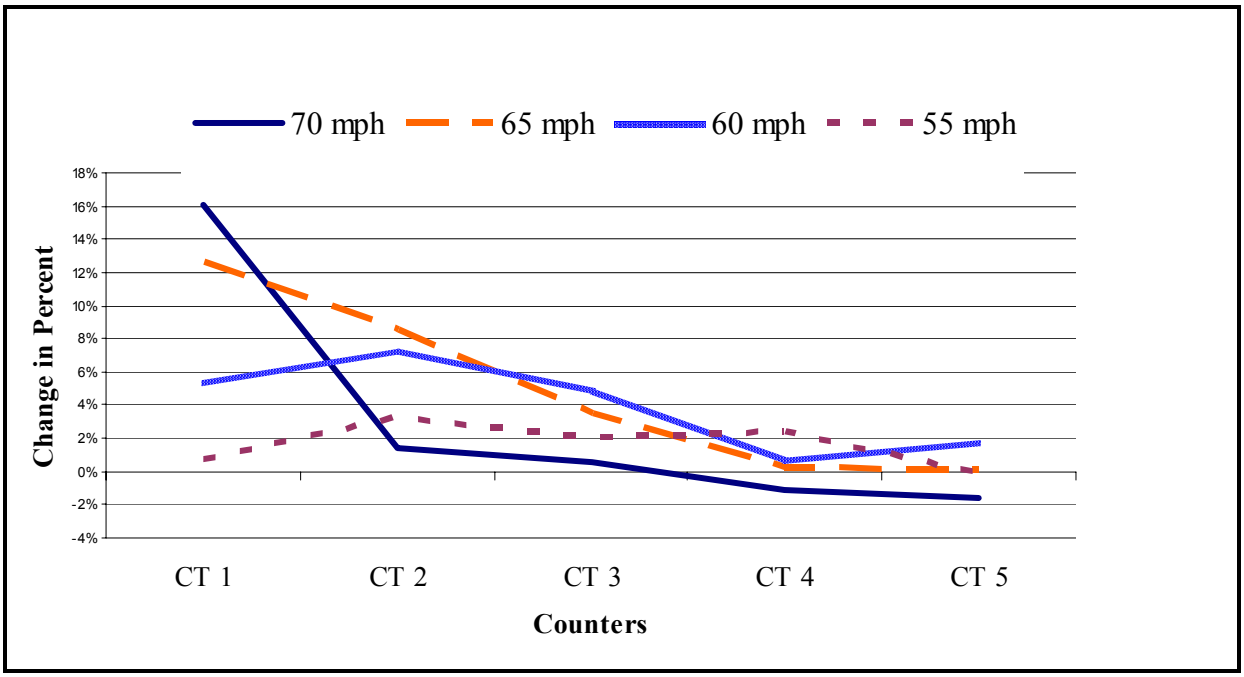

Figure 11. SH 36 – Passenger Vehicles Daytime Before and After Change in Percent Exceeding Speed

Local transportation officials have expressed that the red border Speed Limit sign made them more aware of the reduced speed limit. An effort to poll the communities where the red border Speed Limit signs were tested would supplement the speed data with the local citizens' thoughts on the sign.

The significant safety concerns associated with reduced speed zones increases the importance of improving the conspicuity of the Speed Limit sign. Every effort should be made to determine if the red border Speed Limit sign is the answer to the safety issue.

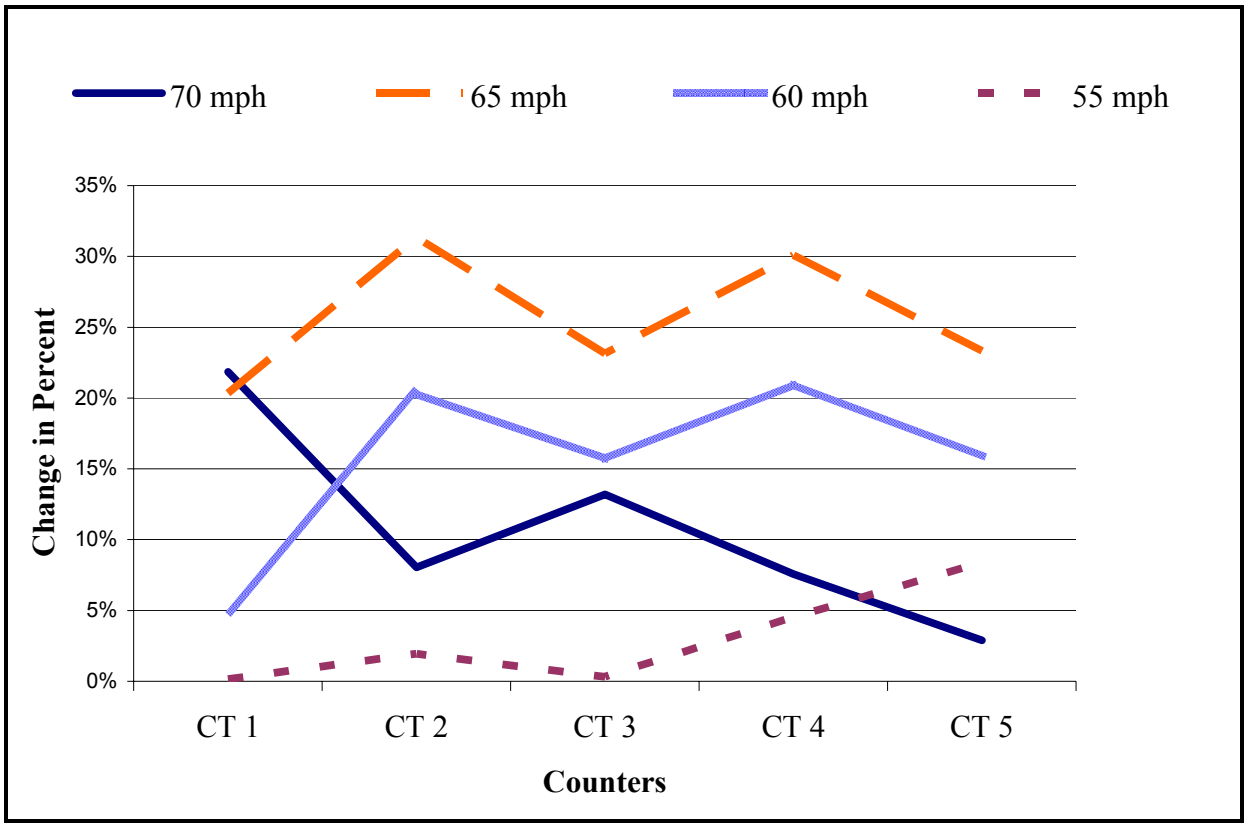

Figure 12. SH 36 – Heavy Vehicles Daytime Before and After Change in Percent Exceeding Speed

Figure 13. Red Border Speed Limit Signs from Caldwell, Snook, and Milano

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APPENDIX A: TTI PAST STUDY RESULTS

Table A1. State Highway 7 Results, Daytime Passenger Vehicles.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (7500 ft upstream from sign)	Mean Speed (mph)	1209	67.9	67.4	-0.5	NO
	85th Speed (mph)	1209	73.0	73.0	0.0	NO
	Std. Dev. (mph)	1209	6.7	6.0	-0.7	NO
2000 ft upstream of the sign (where sign is visible)	Mean Speed (mph)*	926	67.5	66.4	-1.1	YES
	85th Speed (mph)	926	73.0	73.0	0.0	NO
	Std. Dev. (mph)	926	6.0	6.3	0.2	NO
600 ft upstream of the sign (where sign is legible)	Mean Speed (mph)*	1007	65.7	64.8	-0.9	YES
	85th Speed (mph)	1007	71.0	71.0	0.0	NO
	Std. Dev. (mph)	1007	6.0	6.3	0.3	NO
	% Exceeding 55 mph	1007	95.0	92.8	-2.2	NO
At 55 treatment sign	Mean Speed (mph)*	799	64.5	62.6	-1.9	YES
	85th Speed (mph)	799	71.0	69.0	-2.0	NO
	Std. Dev. (mph)	799	6.1	6.6	0.5	NO
	% Exceeding 55 mph	799	93.4	84.4	-9.0	YES
500 ft downstream of sign	Mean Speed (mph)*	728	62.5	60.5	-2.0	YES
	85th Speed (mph)	728	70.0	68.0	-2.0	NO
	Std. Dev. (mph)	728	6.6	7.4	0.7	NO
	% Exceeding 55 mph	728	85.0	71.3	-13.7	YES

*Control point speed included in the analysis as a covariate

Table A2. State Highway 7 Results, Nighttime Passenger Vehicles.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (7500 ft upstream from sign)	Mean Speed (mph)	268	65.8	66.6	0.9	NO
	85th Speed (mph)	268	73.0	73.0	0.0	NO
	Std. Dev. (mph)	268	6.8	7.7	0.9	NO
2000 ft upstream of the sign (where sign is visible)	Mean Speed (mph)*	262	63.5	63.0	-0.5	NO
	85th Speed (mph)	262	70.2	70.0	-0.2	NO
	Std. Dev. (mph)	262	7.0	7.3	0.3	NO
600 ft upstream of the sign (where sign is legible)	Mean Speed (mph)*	260	62.3	61.3	-1.0	YES
	85th Speed (mph)	260	69.5	68.0	-1.5	NO
	Std. Dev. (mph)	260	6.9	7.0	0.2	NO
	Percent Exceeding 55 mph	260	80.0	77.1	-2.9	NO
At 55 treatment sign	Mean Speed (mph)*	251	60.3	59.3	-1.0	NO
	85th Speed (mph)	251	67.7	66.0	-1.7	NO
	Std. Dev. (mph)	251	7.7	7.1	-0.6	NO
	Percent Exceeding 55 mph	251	69.8	62.2	-7.6	NO
500 ft downstream of sign	Mean Speed (mph)*	246	58.3	57.5	-0.8	YES
	85th Speed (mph)	246	66.0	64.8	-1.2	NO
	Std. Dev. (mph)	246	7.2	7.4	0.2	NO
	Percent Exceeding 55 mph	246	62.0	50.0	-12.0	NO

*Control point speed included in the analysis as a covariate

Table A3. State Highway 7 Results, Daytime Heavy Trucks.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (7500 ft upstream from sign)	Mean Speed (mph)	180	67.1	65.7	-1.4	NO
	85th Speed (mph)	180	71.0	71.0	0.0	NO
	Std. Dev. (mph)	180	4.5	5.5	1.0	NO
2000 ft upstream of the sign (where sign is visible)	Mean Speed (mph)*	132	66.4	64.7	-1.7	NO
	85th Speed (mph)	132	70.0	70.0	0.0	NO
	Std. Dev. (mph)	132	4.7	5.1	0.4	NO
600 ft upstream of the sign (where sign is legible)	Mean Speed (mph)*	145	64.7	63.6	-1.2	NO
	85th Speed (mph)	145	70.0	68.0	-2.0	NO
	Std. Dev. (mph)	145	5.4	4.8	-0.6	NO
	Percent Exceeding 55 mph	145	99.0	95.6	-3.4	NO
At 55 treatment sign	Mean Speed (mph)*	114	63.2	62.1	-1.1	NO
	85th Speed (mph)	114	68.0	68.0	0.0	NO
	Std. Dev. (mph)	114	4.8	5.2	0.4	NO
	Percent Exceeding 55 mph	114	93.8	90.7	-3.1	NO
500 ft downstream of sign	Mean Speed (mph)*	83	62.5	58.6	-3.9	YES
	85th Speed (mph)	83	68.0	63.5	-4.6	NO
	Std. Dev. (mph)	83	5.4	4.0	-1.4	NO
	Percent Exceeding 55 mph	83	88.0	76.5	-11.5	NO

*Control point speed included in the analysis as a covariate

Table A4. State Highway 7 Results, Nighttime Heavy Trucks.

Location	Measure of Effectiveness	Overall Sample Size	Before	After	After-Before	Significant @ 95% Confidence?
Control Point (7500 ft upstream from sign)	Mean Speed (mph)	80	64.7	65.4	0.7	NO
	85th Speed (mph)	80	68.0	70.0	2.0	NO
	Std. Dev. (mph)	80	4.8	3.6	-1.2	NO
2000 ft upstream of the sign (where sign is visible)	Mean Speed (mph)*	71	62.8	63.0	0.3	NO
	85th Speed (mph)	71	66.3	67.4	1.2	NO
	Std. Dev. (mph)	71	3.9	4.1	0.2	NO
600 ft upstream of the sign (where sign is legible)	Mean Speed (mph)*	70	62.2	61.6	-0.6	NO
	85th Speed (mph)	70	66.0	65.0	-1.0	NO
	Std. Dev. (mph)	70	4.4	3.9	-0.5	NO
	Percent Exceeding 55 mph	70	92.0	100.0	8.0	NO
At 55 treatment sign	Mean Speed (mph)*	46	61.1	60.3	-0.8	NO
	85th Speed (mph)	46	65.3	64.2	-1.1	NO
	Std. Dev. (mph)	46	4.5	4.6	0.1	NO
	Percent Exceeding 55 mph	46	84.0	76.4	-7.6	NO
500 ft downstream of sign	Mean Speed (mph)*	61	59.7	59.0	-0.7	NO
	85th Speed (mph)	61	65.3	63.9	-1.4	NO
	Std. Dev. (mph)	61	5.5	4.7	-0.8	NO
	Percent Exceeding 55 mph	61	69.0	67.9	-1.1	NO

*Control point speed included in the analysis as a covariate

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