Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SWUTC/07/473700-00003-12		

4. Title and Subtitle	5. Report Date
COMPENDIUM OF STUDENT PAPERS: 2007 UNDERGRADUATE TRANSPORTATION SCHOLARS PROGRAM	August 2007
	6. Performing Organization Code
7. Author(s) Matthew Ciarkowski, Nathan Fluker, Jason Richter and Marc Sandhu, Authors, and H. Gene Hawkins, Editor	8. Performing Organization Report No. Report 473700-00003-12
9. Performing Organization Name and Address Texas Transportation Institute Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTRS99-G-0007
12. Sponsoring Agency Name and Address Southwest Region University Transportation Center Texas Transportation Institute Texas A&M University System College Station, Texas 77843-3135	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

This report is a compilation of research papers written by students participating in the 2007 Undergraduate Transportation Scholars Program. The ten-week summer program, now in its seventeenth year, provides undergraduate students in Civil Engineering the opportunity to learn about transportation engineering through participating 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) analysis of trip generation estimates for mixed-use developments; 2) pedestrian and motorist perception of pedestrian signs in work zones; 3) analysis of driver compliance with work zone speed limits; and 4) nighttime driver needs: an analysis of current guide sign standards and the need for change.

17. Key Words	18. Distribution Statement
Trip Generation Estimates, Mixed-Use Developments, Pedestrian and Motorist Perception, Pedestrian Signs, Work Zones, Driver Compliance, Speed Limits, Nighttime Drive Needs, Guide Sign Standards	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	114	

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COMPENDIUM OF STUDENT PAPERS:

2007 UNDERGRADUATE

TRANSPORTATION SCHOLARS PROGRAM

Participating Students (left to right):
Front Row: Nathan Fluker, Matthew Ciarkowski, Jason Richter and Marc Sandhu
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Program Sponsored by

Transportation Scholars Program
Southwest Region University Transportation Center
Texas Transportation Institute
Texas A&M University System
College Station, TX 77843-3135

and the

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Texas A&M University
College Station, Texas 77843-3136

August 2007

PREFACE

The Southwest Region University Transportation Center (SWUTC), through the Transportation Scholars Program, the Texas Transportation Institute (TTI) and the Zachry Department of Civil Engineering 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 2006, the following six students and their faculty/staff mentors were:

STUDENTS	MENTORS
Mr. Matthew Ciarkowski Texas A&M University, College Station, TX	Mr. Brian S. Bochner
Mr. Nathan Fluker Texas A&M University, College Station, TX	Mrs. Brooke Ullman
Mr. Jason Richter Texas A&M University, College Station, TX	Mrs. Melisa D. Finley
Mr. Marc Sandhu Texas A&M University, College Station, TX	Dr. Paul J. Carlson Mr. Jeffrey D. Miles Mr. Adam M. Pike

Sincere appreciation is extended to the following individuals:

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

The authors recognize that support was provided by a grant from the U. S. Department of Transportation, University Transportation Centers Program to the Southwest Region University Transportation Center.

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DISCLAIMER

Analysis of Trip Generation Estimates for Mixed-Use Developments

Prepared for
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by

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MATTHEW CIARKOWSKI

Matthew Ciarkowski is pursuing a Bachelor of Science degree in Civil Engineering at Texas A&M University. He is expecting to graduate in December 2008 and is still considering the option of graduate school. During his time at Texas A&M, Matthew has been honored with the Dwight Look College of Engineering Distinguished Student Award, National Deans List, R. L. Rothe '41 Scholarship, and three time acceptance of the Concrete Reinforcing Steel Institute Student Scholarship.

Matthew has been involved with Class Councils on campus at Texas A&M and had the opportunity to serve as Maroon Out Director for the 2006 year. He is a member of Phi Eta Sigma National Honor Society and Texas A&M Student Chapter of the Institute of Transportation Engineers. Matthew has previous experience interning at a land development firm and is interested in a career in consulting.

ACKNOWLEDGMENT

The research described in this paper was conducted as part of Project 450037, sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The research activities were conducted in support of the Undergraduate Transportation Scholars Program. The findings and recommendations included in this paper are based on the student's summer activities. They should be considered preliminary and not as representative of the findings and recommendations of the parent project. This paper has not been reviewed or approved by the sponsor. The contents of this paper reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of TxDOT and the FHWA.

SUMMARY

As mixed-use developments become more and more popular, information about trip generation and internal capture data for these sites will be essential for land development and transportation planning purposes. Due to the scarcity of information pertaining to this topic, the Texas Department of Transportation has funded project RMC 5-9032-01 to focus on mixed-use development internal trip capture estimation techniques.

The purpose of this project is to provide additional data points for mixed-use development studies, test the validity of existing trip generation techniques and modify if necessary, and to analyze the relationship between internal trip capture and site development characteristics. In addition, information concerning mode of travel and proximity analysis will be provided. This report focuses on the data analysis of Legacy Town Center and data collected from NCHRP 8-51 research study at Mockingbird Station and Atlantic Station.

This report summarizes findings about trip generation and internal trip capture for compact, urban style mixed-use developments. Preliminary results for mixed-use developments from this study show that the current ITE techniques used for estimating trip generation can be fairly accurate. Analysis showed that satisfactory internal capture rates are possible at the new style mixed-use developments and that there is a possible correlation between individual site characteristics and internal capture rates. Analysis of capture rates for specific land uses proved that specific land uses such as retail, restaurant and residential consistently generate and receive a large amount of internal trips.

Results from this research are beneficial in developing trip generation estimates and internal capture rates; however, more data collection would provide stronger relationships for mixed-use developments and their trip generation characteristics.

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INTRODUCTION

Over the last two decades, mixed-use development sites have experienced a tremendous wave of growth and popularity. The appeal of such sites originates not only from the unique architecture and lifestyle which the developments offer, but also from the convenience provided when multiple land uses are available within mere walking distances. However, this convenience affects not only the residents and patrons, but also has a substantial impact on considerations made by the city, land developers and traffic engineers.

Trip generation analysis provides data on the relationships between trips made and the characteristics of a particular location (*1*). With use of trip generation data, traffic engineers can predict the volume of traffic that will enter and exit a specific site for a given time period. Conventional trip generation data is useful when considering a single free standing site. However, when dealing with a mixed-use development which contains multiple land uses, this approach is not directly applicable. In theory, some of the sites within a mixed-use development interact and exchange some of their trips internally with each other, thus potentially reducing the total number of trips made to and from the development itself. To account for these on-site trips, "internal trip capture" rates must be calculated. Internal trip capture is the percent reduction of trip generation estimates for land uses to account for trips made internally on the site. These rates can be a significant component for the prediction of travel patterns (*1*).

In 1993, Florida Department of Transportation conducted two studies, each with three mixed-use development sites, to determine trip generation and internal capture rates for mixed-use development sites (*2*). The results of this research are still in standard use in the Institute of Transportation Engineers Trip Generation Handbook, even though the data was collected nearly fifteen years ago.

The purpose of this research is to evaluate the accuracy of the currently accepted trip generation characteristics of mixed-use developments using data collected at a representative development. To accomplish this, surveys were conducted at a mixed-use development called Legacy Town Center in Plano, Texas. Surveys included cordon and door counts, as well as on-site interviews. After analysis, the results will either confirm the validity of the currently accepted values, or reveal the need of new methods and data.

PROBLEM DESCRIPTION

Although there have been previous studies pertaining to trip generation and internal trip capture at mixed-use developments, more data and analysis is still necessary. Some of the previous survey locations reflect an older style for mixed-use developments and their data results lack information for essential land uses such as restaurants. These studies provide useful data, however the overall sample size is just not large enough to comfortably rely on. Consequently, this project will provide more data for mixed-use development sites, lead to improved estimation techniques and confirm the validity of those existing. Because data collected from one survey site alone is not enough information to improve estimation techniques, data collected from previous surveys will also be used in the analysis. This project will have a heightened focus on internal trip capture and analyze the relationship between site development characteristics and internal capture rates obtained. Results from this research will be added to previous studies of mixed-use developments to provide additional data points and aid in prediction of trip generation estimates and internal trip capture rates for mixed-use developments.

BACKGROUND INFORMATION

The background information for this project was obtained through a literature review at the beginning of the research project.

Mixed-Use Developments

There is no exact definition of what actually qualifies a mixed-use (also referred to as multi-use) development, rather there are guidelines that the site should meet. Generally a mixed-use site is planned as a single real-estate land development project which contains two or more different and interacting land uses. These trips are considered internal and do not travel on a street system external to the development; rather they are made on the internal roads and walkways of the development (*1*).

Many new mixed-use developments follow the trend of new urbanism. New urbanism identifies walkable, human scaled neighborhoods as the building blocks of sustainable communities and regions (*3*). These areas are characteristically higher density, compact walkable areas formed in blocks. Mixing of uses typically includes residential (townhomes, apartments, or detached homes on small lots), retail (mostly specialty and convenience), restaurants, hotels, office buildings, movie theatres, and any other compatible and complimentary uses. The mixing of uses is market driven and typically unique to each development. By maximizing the degree of interaction between land uses, developments are able keep some of the travel internally and reduce the percentage of traffic on exterior street systems. Subsequently, mixed-use developments generate internal trip capture, thus reducing external trip generation rates.

Trip Generation and Internal Trip Capture

Trip generation information is used when determining site access requirements, assessing needed off-site transit improvements and facilitating zoning changes and land use changes (*1*). Internal trip capture is defined as a percent reduction of trip generation for component land uses to account for trips made internally on site. A reduction of trip generation rates can potentially decrease traffic impact and help reduce external congestion.

Previous Studies

While the concept of internal interaction among complimentary land uses has long been accepted, it was not until the early 1990's that a serious investment was first made to research the six Florida locations. Although these sites met the requirements of a mixed-use development, they unfortunately were designed in a manner that was not as conducive for walking trips as today's new-urbanist developments (*2*). Because land uses were separated into different sections (some requiring driving to cover distances between them), it is likely that these locations experience less interaction and internal trip capture than today's compact new urban style developments.

In 2006 two pilot studies were performed for NCHRP 8-51 at Mockingbird Station in Dallas, Texas and at Atlantic Station in Atlanta, Georgia. The purpose of that project is to improve the methodologies for estimating internal trip capture though continued data collection and analysis of existing data. These sites are similar in compactness and land use types to Legacy Town Center. However, they have differing percentages of land uses. It is important to realize that each development's mix of on-site land uses, overall size and location will affect the internal trip making results (*1*). Although each site is different, trends can be observed that lead to general conclusions.

Surveys

Travel characteristics of most land uses vary by time of day and often by day of week. Periods of peak street traffic are most frequently analyzed because at this period the site experiences the largest overall amount of traffic. As a result, the times of day that surveys are conducted are important (*1*). The ideal times for conducting surveys are during the morning and afternoon peak periods. In the windows of 6-10A and 3-7P, the peak hours of street traffic will usually occur. When conducting Traffic Impact Analyses (TIA) or Traffic Impact Studies (TIS) it is important to have data from the peak hour when traffic flow volumes will reach a maximum. Under ideal conditions surveys should be collected for an entire week. However, due to time and funding restraints, surveys are generally performed Tuesday through Thursday because they represent typical weekdays and the most consistent data values (*1*).

METHODOLOGY

Choosing an Appropriate Site

The first step in fulfilling the purpose of this research study was to identify an appropriate mixed-use development site for data collection. The site must provide potential for interaction between on-site land uses and preferably have some of the qualifying characteristics of mixed-use developments. When choosing the site it is important to find a location that is well established economically and socially. The site should not be brand new and still in its infancy; neither should it be aged and in its final stages. Lastly, it is necessary that the site be attractive, popular both aesthetically and socially. A site that meets these standards should represent a mixed-use development style that will likely be modeled in the future.

Conducting the Survey

After the site location is determined, there is still much preparation required before the surveys can actually be conducted. The research team must become familiar with the overall layout of the site and determine where data should be collected for each survey type. It is important to realize that in most cases money will be a constraint that keeps the research team from obtaining all data desired.

For a mixed-use development, the cordon is considered the outer perimeter of the entire site. During the survey, cordon counts are taken to account for the total number of vehicles and individual persons who enter and exit the perimeter of the development per 15 minute period. Cordon counts are used in calculating the peak hour of travel and aid in the generation of mode tables. Similarly, inbound and outbound door counts are made at specific building entrances to capture the total number of people who enter and exit per 15 minute period. These doors are then segmented into general land uses and will be used when factoring the interviews. Along with door counts, there are interviewers present to find specifically where that person is heading, where they were before, and their mode of travel for each of those trips. This provides two trip links and is valuable for determining trip generation characteristics. Samples of the survey forms used at Legacy Town Center can be found in the appendix.

Data Reduction Process

The first priority is to develop trip generation characteristics for the survey site. These characteristics should then be compared to previous studies completed for NCHRP 8-51 at Mockingbird Station and Atlantic Station. ITE trip generation estimates will then be produced for each of these three sites using the ITE Trip Generation Manual and individual development units for each location. These results will then be compared and analyzed.

In addition to the analysis of the trip generation estimates, summary data for the survey site will be necessary. Statistics about percent distribution of internal trips, internal trip capture by land use, mode tables, and proximity analysis will all be beneficial to interpreting the data obtained.

DATA COLLECTION

Prior to my involvement with this research project, Legacy Town Center was chosen as the survey site for which this study is concerned. Legacy is a relatively new, but well established, mixed-use development located in Plano, Texas. A general site overview of Legacy Town Center is shown in Figure 1 below.

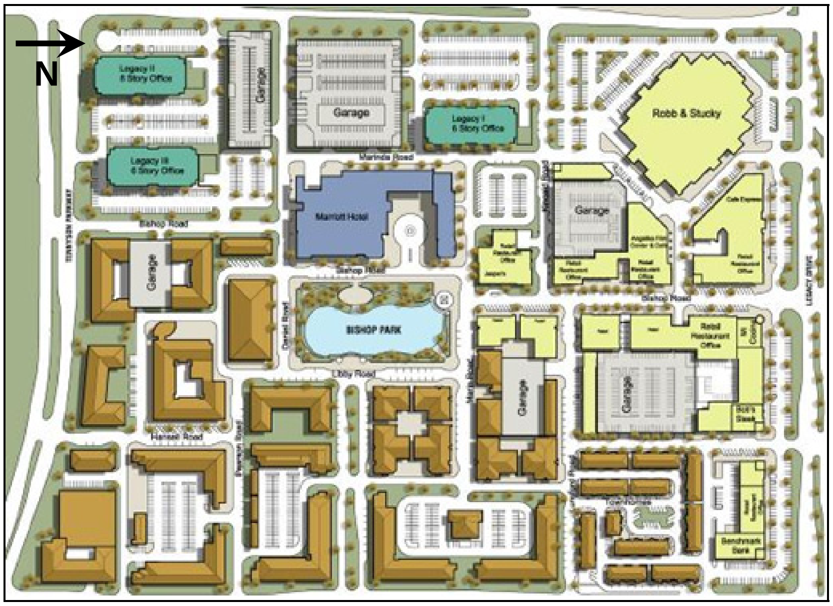

Figure 1: Legacy Town Center

Legacy Town Center represents an attractive and functional style characteristic of what most future mixed-use developments will resemble. It features 1698 dwelling units, both residential apartments and town homes, some of which are located above retail. There are three multi-story office buildings covering 575,000 square feet. A Marriott Hotel is centrally located on-site with 404 rooms available, and accommodations to house large conferences. There is approximately 313,000 square feet of retail space on-site including several convenience based businesses, a movie theater, specialty clothing and furniture stores and restaurants (*4*). Many dining options are available including an ice-cream shop, bakery, lunch café, as well as many other restaurant options. The site is arranged so that all land uses are relatively grouped together, however, the size and arrangement of the site still favors internal travel, walking is convenient for most trips.

Development units for Legacy Town Center are shown in Table 1 below.

Table 1: Legacy Town Center Development Units

Land Use	Total Units	Occupied Units	Largest
Office	310764 Sq. ft	310764 Sq. ft	153230 Sq. ft
Specialty Retail	189669 Sq. ft	189669 Sq. ft	93000 Sq. ft
Convenience Retail	3158 Sq. ft	3158 Sq. ft	1688 Sq. ft
Quality Restaurant	29451 Sq. ft	29451 Sq. ft	9135 Sq. ft
High Turnover Restaurant	25581 Sq. ft	25581 Sq. ft	6000 Sq. ft
Fast Food Restaurant	7296 Sq. ft	7296 Sq. ft	2736 Sq. ft
Drinking Place	6990 Sq. ft	6990 Sq. ft	6990 Sq. ft
Residential	1361 DU	1361 DU	499 DU
Medical	3440 Sq. ft	3440 Sq. ft	3440 Sq. ft
Cinema	27125 Sq. ft - 1019 Seats	27125 Sq. ft - 1019 Seats	27125 Sq. ft - 1019 Seats
Hotel	404 DU	400 DU	404 DU

DATA ANALYSIS & RESULTS

Peak Hour

Cordon and door counts are manually entered into Excel databases where they can then be worked into a form where they provide useful information. After input, door counts do not directly output any significant results, however, the cordon counts do. As previously mentioned, cordon counts provide the number of person trips to and from the site per time period. This provides information for the researcher to identify the peak hour of travel and the modes of access to the site. The cordon counts from Legacy Town Center revealed that the peak hour of morning travel was 7:30 – 8:30A with 1598 total person trips. For the evening period the peak hour was 6:00 – 7:00P with 2461 overall person trips. However, for the study at Legacy Town Center, only the hours between 7:00-9:00A in the morning and 4:00-6:00P in the evening are of concern for their respective peak hours of travel due to the specifications of the research sponsor. Therefore, the evening street peak hour of travel at Legacy was from 5:00 – 6:00P with 2309 total person trips. Figure 2 and Figure 3 shown below illustrate the amount of person trips per hour at Legacy Town Center.

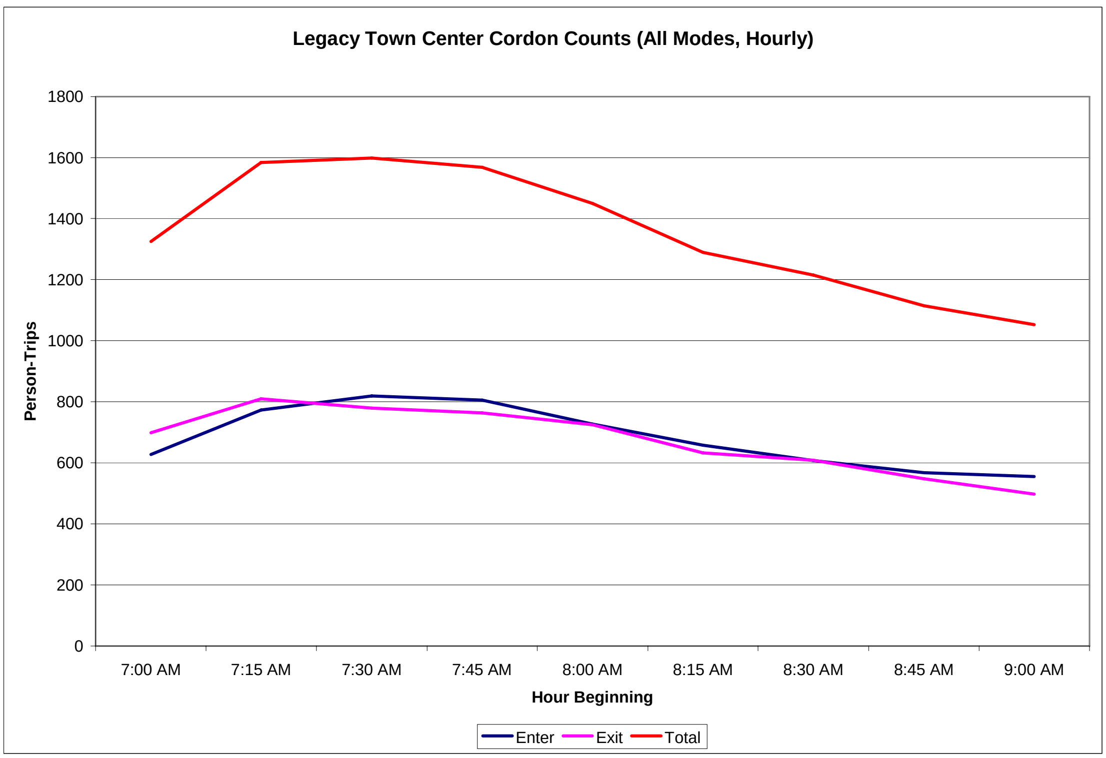

Figure 2: Peak Hour of Travel AM

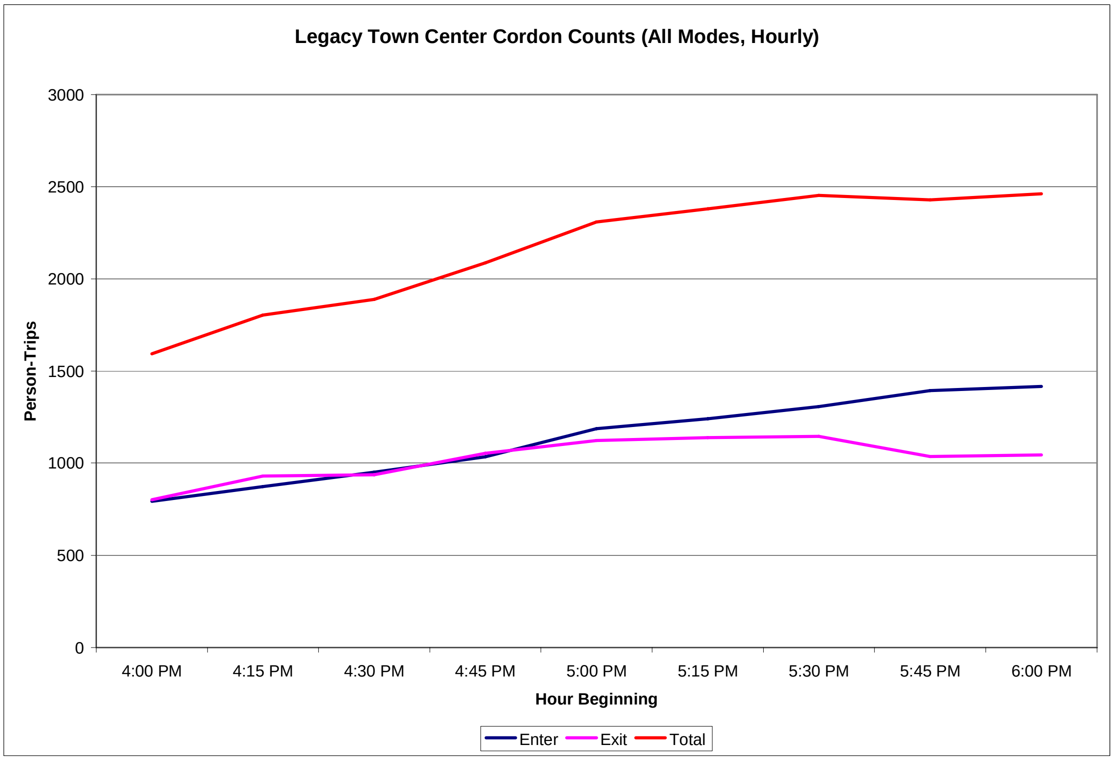

Figure 3: Peak Hour of Travel PM

Interview Analysis

Initially, all interview responses are entered into an overall database that resembles the format of the original survey form. The interviews are then carefully examined to make sure that all make sense. If a problem arises, depending on the quality of the interview and the specific issue in question, some can be easily edited and other interviews must be completely discarded. The database is then filtered by time and land use restraints to produce a table which shows the number of interviewed trips to and from specific land uses for each time period.

Expansion Factors

Due to the difference between actual people counted leaving doors, and the number of interviews obtained, the interviews must be multiplied by an expansion factor to get a value referred to as factored trips. If the factoring step was not completed, the interviews would not accurately represent the trips actually made from the door counts. The expansion factor is made up of an interview factor and a development unit factor. The interview factor is different for each land use, and is found by taking the number of door counts for each land use and dividing it by the total trip interviews for the corresponding use. The development units factor for each individual land use is the ratio of the development units occupied to the development units that were actually counted. To obtain factored trips, the initial trip values are multiplied by both of these expansion factors. When considering trip generation, the only significant trips are those made to different land uses. Because of this, all like to like interchanges are made to be zero.

These factored trips are the basis for the analyses which led to this study's findings. Percent distribution of internal trips tables are produced for both origins and destinations. These values in these tables represent the percentages of trips being made. They tell where percentages of trips are going and where they are coming from. These values provide information for the internal trip capture and internal trip capture by land use pair.

Trip Generation Estimates

A significant portion of this project involves producing ITE trip generation estimates for Legacy Town Center, Mockingbird Station and Atlantic Station and comparing them with each site's actual surveyed data. This will show the validity of the current trip generation estimation method and show where improvements may be needed.

ITE Trip Generation Handbook

The ITE Trip Generation report provides an easy way to estimate the number of vehicle trips generated by a proposed development. The trip generation data pages are each designed for a specific land use. Each with many variations for time and other variables makes it likely to find a page that can match most land use conditions. Compiled with information from more than 4250 trip generation studies, the ITE Trip Generation report is the most comprehensive and widely accepted trip estimation source of its kind.

The steps outlined below document the procedure that should be followed when estimating mixed-use trip generation. Initially, all of the on-site land uses must be classified into which ITE land use code each most accurately fits. The size of these land uses must be documented by the most appropriate independent variable. Independent variables can range from square feet, dwelling units, seats etc. depending on what the land use is. Because internal capture rates vary by time of day, the period that the estimate is for must be clearly identified. The independent variables (development units) for each land use are then substituted into best fit regression equation to calculate the independent variable of average vehicle trip ends. A directional distribution is provided to estimate what percentage of the vehicle trips are entering or exiting the land use for the specified time period. These estimates represent the baseline trip generation values for the development. At this point, these baseline estimates are reduced by the calculated internal capture rates for each development. These values then represent the adjusted trip generation estimates for the mixed-use development. The accuracy of these estimates is based off of the sample size available for each specific land use and time period. As the number of studies increases, so does the chance of an accurate estimate (*1*, *5*).

Trip Generation Estimates for Surveyed Sites

Trip generation estimates were prepared for the surveyed sites using the ITE Trip Generation Handbook and the process mentioned above. Because these sites are mixed-use developments, each of the overall estimates must be reduced to take internal capture into consideration. Figure 4 shown below shows the relationship between the ITE Trip Generation estimates and the surveyed data.

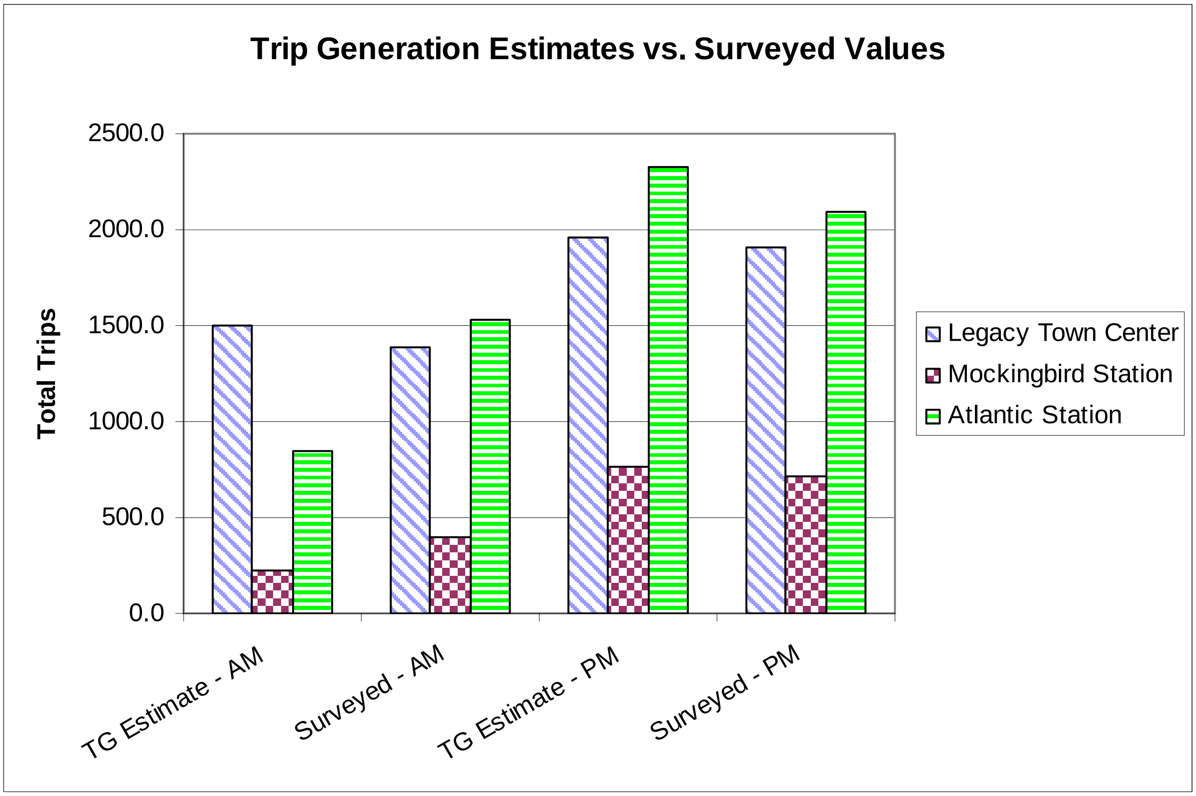

Figure 4: Comparison of Trip Generation Estimates and Surveyed Values

Overall the trip generation estimates for both time periods show favorable comparisons between estimated trips values and trip values surveyed at all three locations.

For each time period, the surveyed values at Legacy Town Center are less than the trip generation estimates, even though it is only by a marginal amount. Contrary to this, at both Mockingbird and Atlantic stations the AM estimates are lower than surveyed while the PM estimates are higher than surveyed.

In the AM period, Legacy Town Center had the most accurate estimate of 1503 trips with only an 8% error while the other two locations revealed poor estimates with error percentages reaching 45%. At both Mockingbird and Atlantic Stations, there are reasons to attribute some underestimation, but not to the degree found. In Atlantic Station there was a Publix Grocery Store located on site that was a higher trip generator during this time period than typical retail which may have contributed to the disparity. In Mockingbird Station, there were probably some walk through trips from the DART transit center. Many patrons of the DART rail station entered the cordon and proceeded through Mockingbird Station to the exit to the Premier development north of Mockingbird Station. These people were counted for the survey, but not accounted for by the trip generation estimate. Also, busy coffee shops were located in both survey sites which may have contributed to the high AM survey count. These coffee shops were in a position where they could easily attract trips from either internal or external sources. Because there is no specific land use code for high end coffee shops in the ITE Trip Generation report, these locations were treated simply as a fast food restaurant. It would not be hard to believe that these overproducing shops could easily far exceed the trip generation of the restaurant and lead to and underestimate. Regardless of the specific cause, it can clearly been seen that there were heavier than anticipated AM conditions.

In the PM period the trip generation estimates for all three locations were extremely close to the surveyed trips. Legacy Town Center had the lowest percent error at 3% while Mockingbird had a 6% error and Atlantic topped out with only 11%. For all estimates that are close to the surveyed values, this means that the overall activity represents what would be typical if the land uses were free standing, taking into effect the internal trip capture rates of each.

The overall ITE Trip Generation Summary table as well as the ITE Trip Generation tables for all three locations can be found in the appendix.

Internal Trips

Land Uses as "Origin" and "Destination"

When classifying internal trip capture rates, they will either fall into the category of "Origin" which corresponds with outbound trips, or "Destination" which subsequently corresponds with inbound trips. Regardless, these values are always classified as percentages.

If a land use has 25% internal capture as an origin, this effectively means that of all the trips leaving an on-site land use, 25% of the trips leaving will end on-site, while the other 75% of the trips will go external. Similarly, if a land use has 30% internal capture as a destination, this means that of all the trips coming into that land use, 30% of them will be from another on-site land use, while the other 70% will be coming in from external.

Surveyed Sites

Typical internal trip capture rates are in the ballpark of 20-30% but in the locations studied, rates higher than this have been reached (*1*, *5*). Figure 5 below shows the capture rates for all land uses combined at all three locations as both origin and destination for each time period.

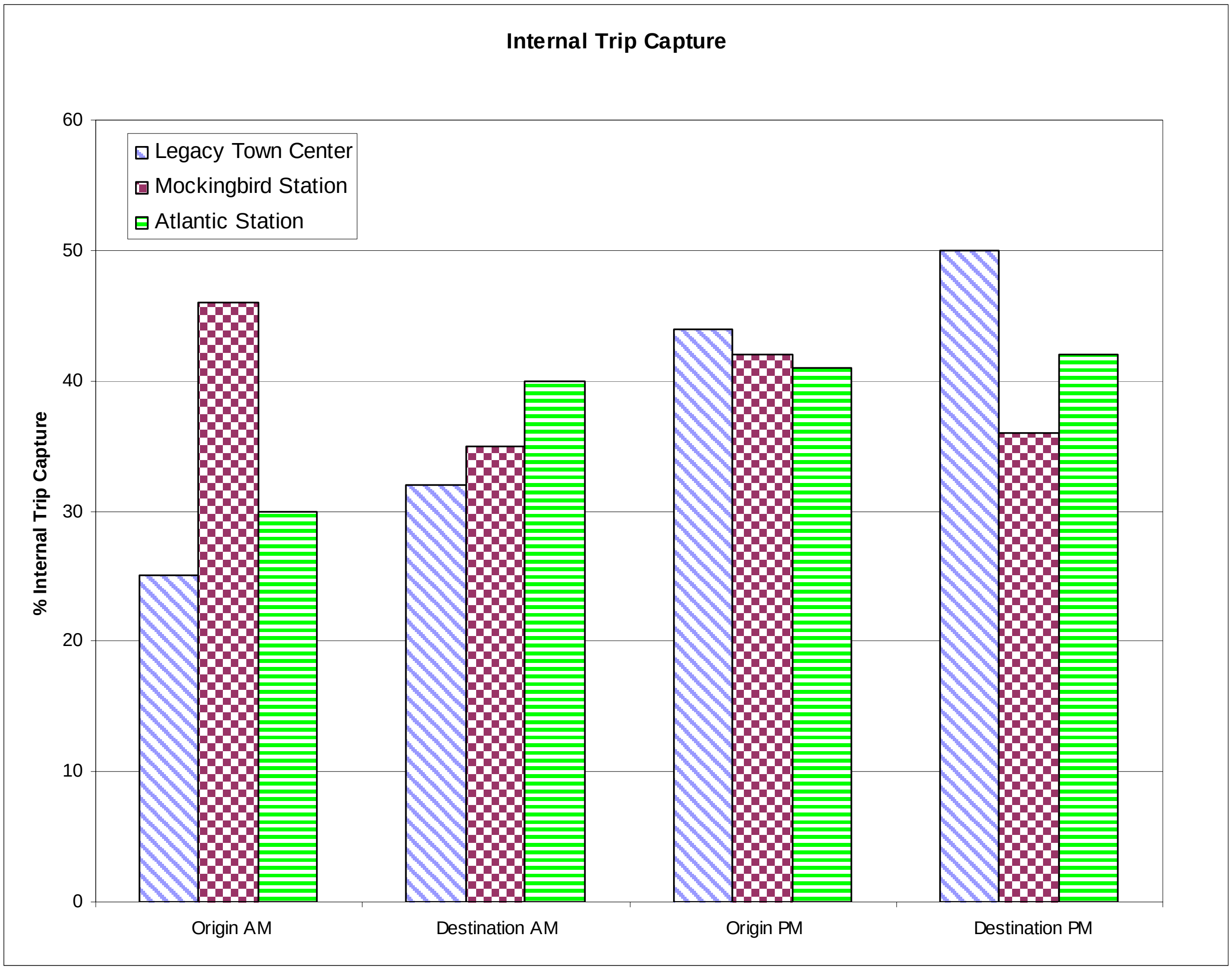

Figure 5: Internal Trip Capture Rates for Surveyed Sites

In general these sites have particularly high internal trip capture rates compared to the data collected in the Florida studies. The AM rates at Legacy Town Center of 25% as origin and 32% as destination are slightly lower than those at Mockingbird and Atlantic stations. This again can be attributed to the fact that locations greatly exceeded their trip generation estimates for the AM time period due to the factors previously mentioned. However, for the afternoon time period Legacy Town Center features the highest capture rates of all three surveyed sites for both origin and destination. With a 44% capture rate as origin, Legacy barely edged out both of the station sites at 41 and 42%. But, as a destination Legacy was able to reach an unprecedented 50% internal capture rate beating out Atlantic Station by 8%.

These internal trip capture rates reached are surprisingly high and show the potential that mixed use developments can reach as far as internal trip capture. After seeing their success it is important to examine the sites to look for similarities or trends that lead to the higher than normal rates. All three of the sites accurately fit the description of a mixed-use development. All are compact areas with interactive land uses that a generally walkable. All of the sites had most of the main land uses such as residential, retail, office and other, but there was a different mix and balance of these land uses at each location. These are the general framework points of a mixed-use development that make them successful in the first place. All three sites provided easy accessibility although they all provided it somewhat differently. All of the three locations were easily accessible to an external highway system, this does not aid in explaining their high internal capture, but it does contribute to their overall high traffic flow.

All three sites had access to mass transit, but in different quantities. Both Legacy Town Center and Atlantic Station had bus stops in their proximity served by buses that made stops a few times per hour. At Atlantic this route ran near the residential area and at Legacy it merely stopped on the perimeter of the site. At both locations transit did not offer a substantial amount of service. Due to the fact that Mockingbird Station serves as a DART (Dallas Area Rapid Transit) stop, transit plays a significant role in its site access. Lastly, the setting of each location is important to take into consideration. Legacy Town Center was located in a more suburban area while Atlantic and Mockingbird Stations were located in midtown areas. If a development is in a midtown area, it could have more trips generated simply because of the ease of access to the site. Similarly, if accessing the site required driving externally, the probability of that trip being made is less.

Internal Capture by Land Use Pair

It was established above that mixed-use developments are capable of significant internal trip capture rates as either origins or destinations. To help explain this, the percent of internal capture by individual land uses and combinations of land uses must be taken into consideration. Figure 6 and Figure 7 below show the percent distribution of internal trips for both inbound and outbound trips at Legacy Town Center:

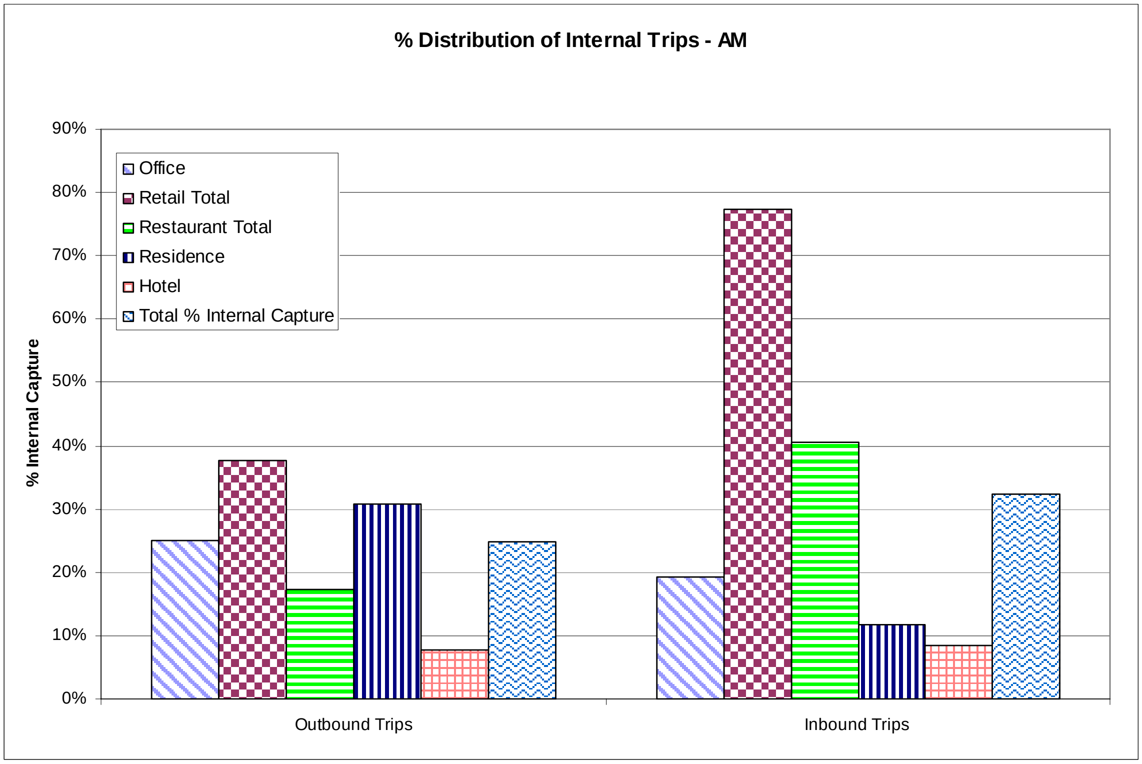

Figure 6: Percent Distribution of Internal Trips - AM

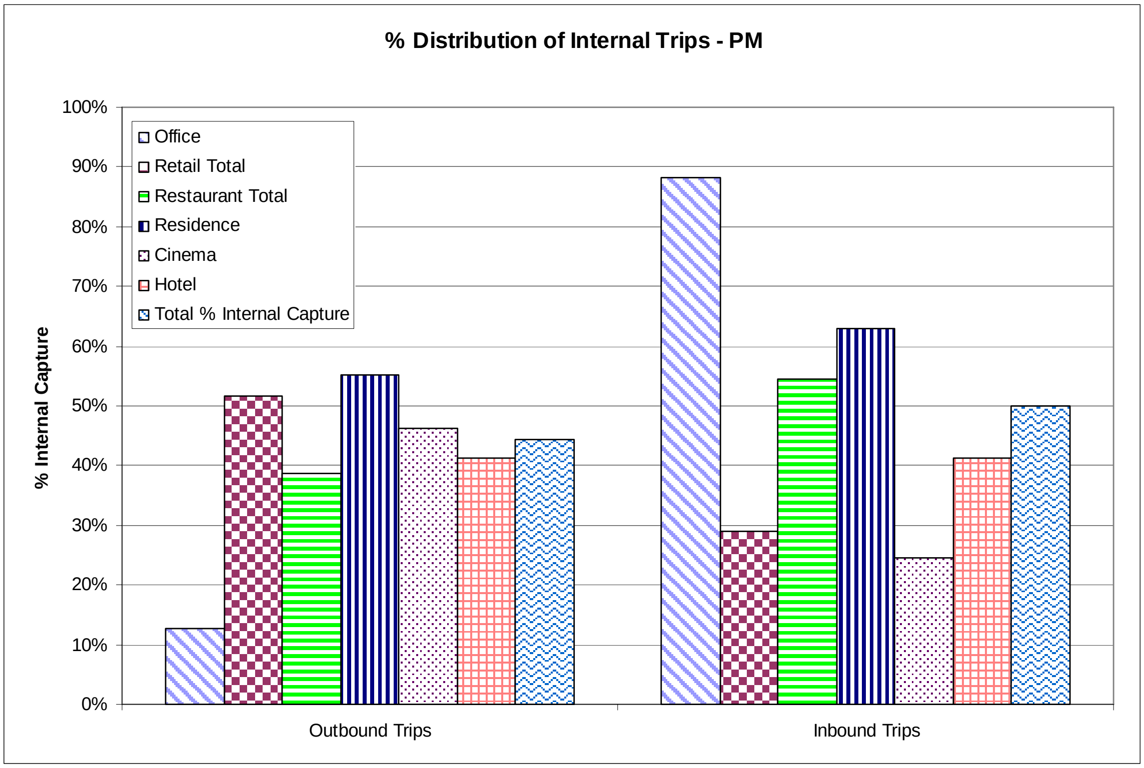

Figure 7: Percent Distribution of Internal Trips - PM

Examination of the figures above and the actual percent distributions of each specific land use show that retail, restaurant and residence are the land uses that generate and receive a large portion of all internal activity at Legacy Town Center for both time periods. Even though this is something that may be expected, it is supported by the data collected. For the AM period this is supported because the only land uses that the office interacts with are restaurant and residential. For both AM inbound and outbound trips, residential and restaurant land uses interact with the most land uses. For the afternoon period, nearly every land use's highest internal trip capture rates are going to restaurant, with retail and residential having high percentages as well. For PM inbound trips, retail and restaurant attracted the most internal trips while residential was the main recipient of those trips. All of this combined with residential's consistently high internal trip capture rates support the idea that restaurant, residential and retail are effective in promoting internal trip capture. These conclusions are supported by the land use interaction graphs shown in Figures 8 - 11 below.

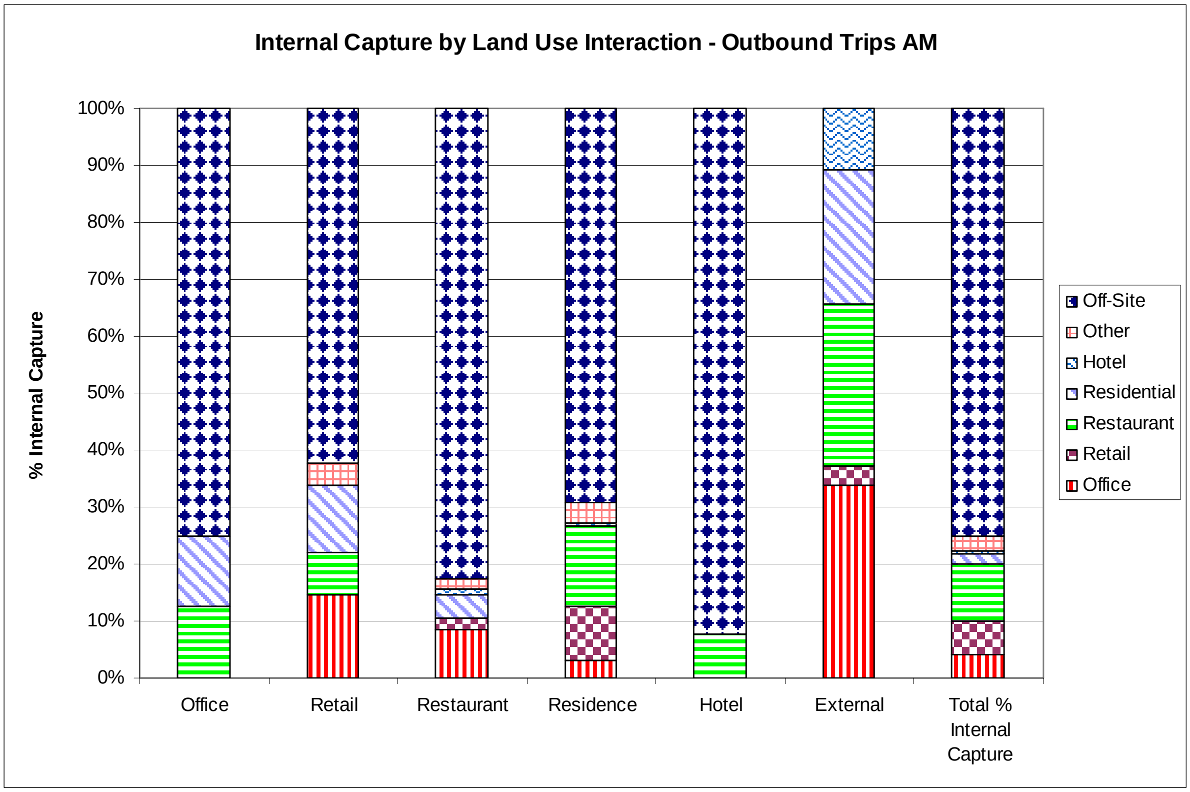

Figure 8: Internal Capture by Land Use Interaction - Outbound Trips AM

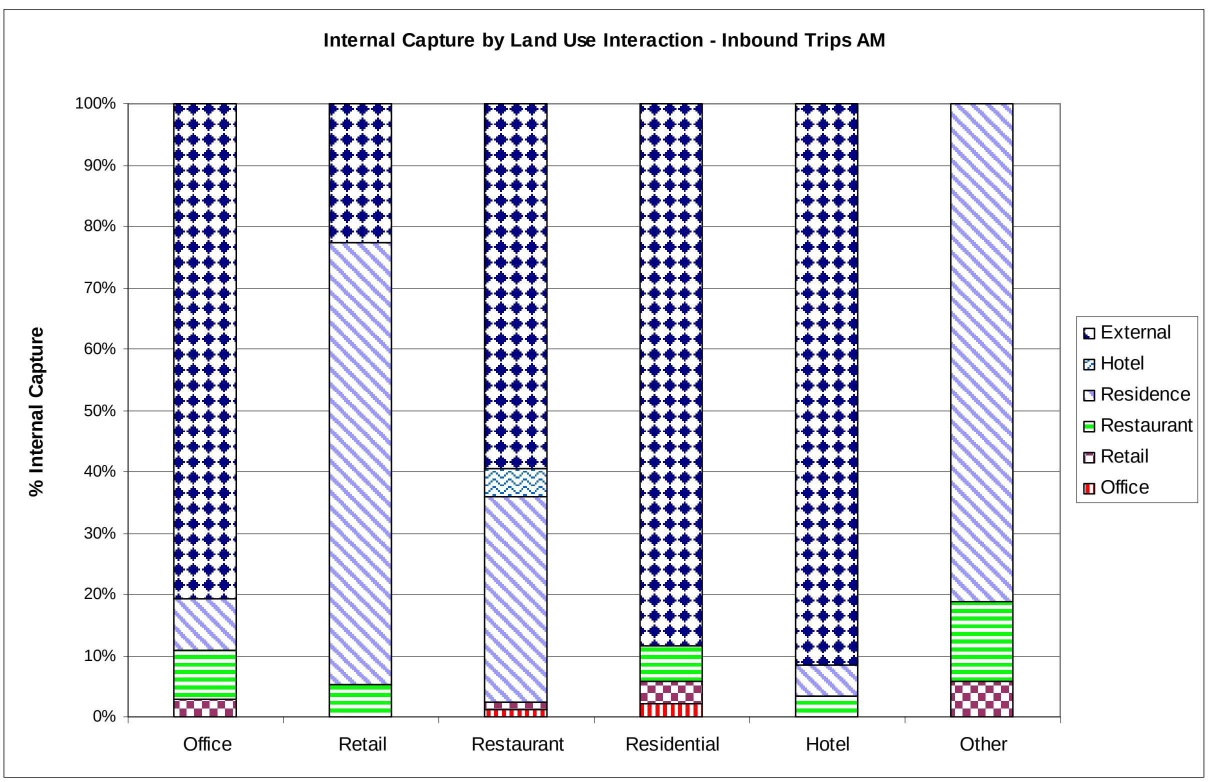

Figure 9: Internal Capture by Land Use Interaction - Inbound Trips AM

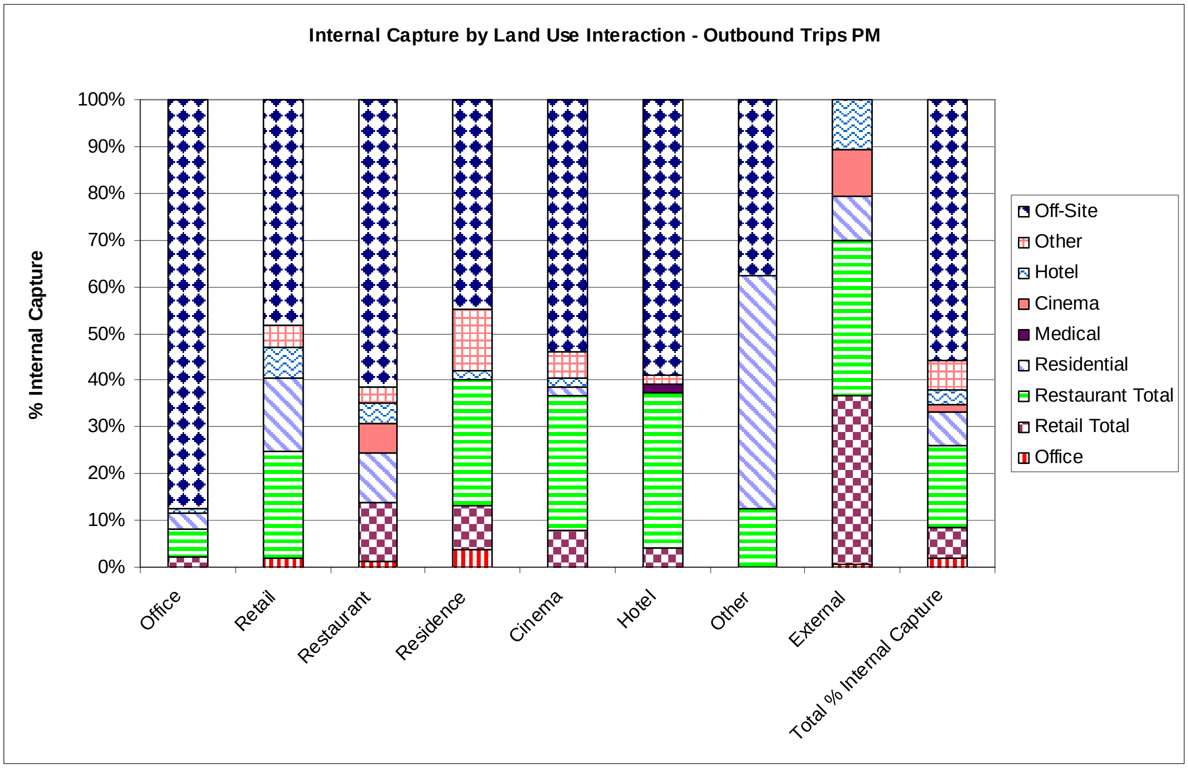

Figure 10: Internal Capture by Land Use Interaction - Outbound Trips PM

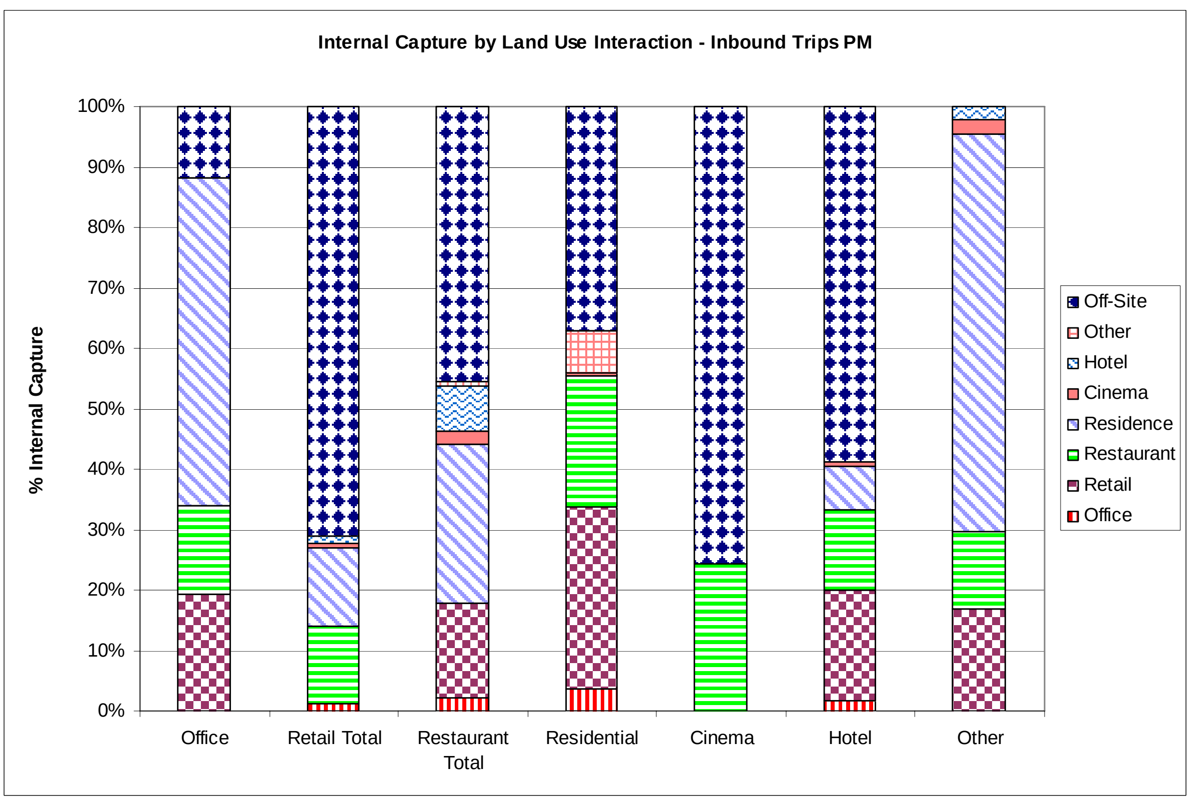

Figure 11: Internal Capture by Land Use Interaction - Inbound Trips PM

In addition to these findings, there are several other more general conclusions that can be reached. Analysis of all three study sites shows low AM inbound trip capture rates for the office and lower outbound capture rates for residential. This shows that not very many people both live and work inside of these developments. In the AM period, all available retail is dominated by convenience. The availability of convenience retail boosts its inbound trip capture to 88% and provides a 38% outbound capture rate. This shows that the availability of convenience retail will create a significant amount of activity in the morning as people leave for work.

Balancing Graphs

When dealing with multiple mixed-use developments with varying land use distributions, there is a hypothesis that a balancing relationship will be necessary. To test this theory, balancing graphs were made for land use interactions to look for a relationship between the varying make-ups of each site.

The graphs plotted the percentage of internal trip capture against the ratio of origin to destination development units. Figure 12 below shows what the balancing graphs should generally resemble.

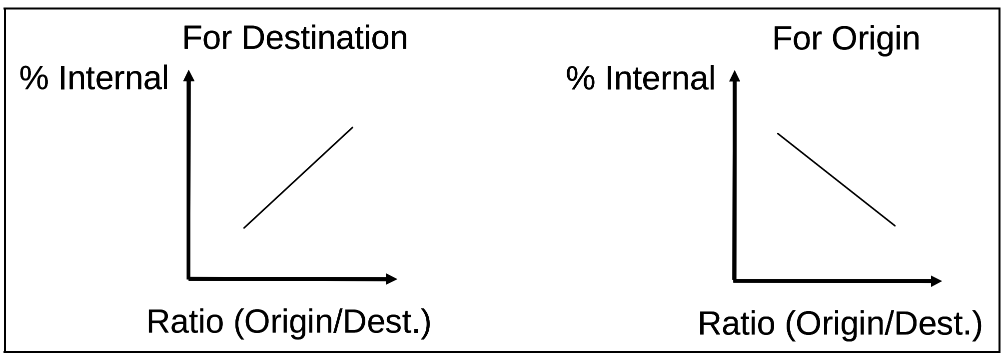

Figure 12: General Balancing Graphs

Ideally for the "For Destination" balancing graph, as the amount of origin development unit increases, the percent internal trips that the destination can accept increases until the origin becomes too large and overloads the destination. The destination subsequently becomes the constraint. Similarly, for the "For Origin" balancing graph, as the origin increases the destination remains constant the percent internal capture for origin will decrease because the destination can not hold all of the trips that the origin can send. Again, the destination becomes the constraint. The slopes of the lines should follow the general trend as shown in Figure 12 above. A minimal slope would show that the balancing process for the sites is not needed, and if the slope were severe, it would support the balancing graph theory.

Several land use interchanges were selected and evaluated with this process. To be selected the land uses must have data points from all six locations with a varying range of percentages (not close to the same value). Figure 13 below is a sample balancing graph produced with data from Legacy Town Center, Mockingbird Station, Atlantic Station and the three Florida sites surveyed.

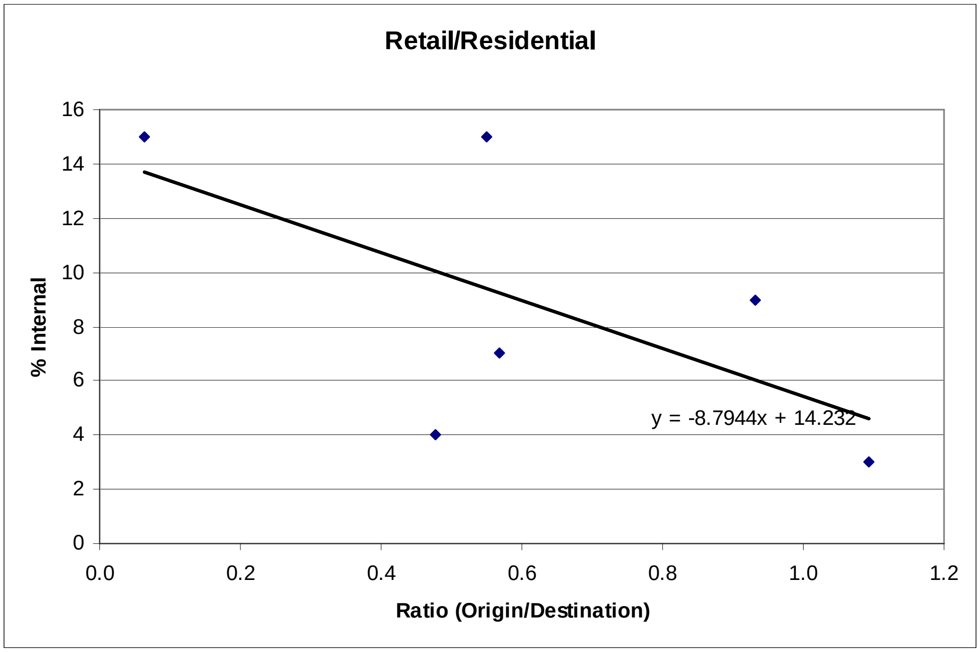

Figure 13: Sample Balancing Graph

From the land use combinations tested, no significant linear trends or patterns occurred. Most followed the appropriate slope direction but slope values ranged from very mild to severe. There is a need for more site studies to provide additional data points. No substantial conclusions can be reached on the balancing process until this data is available.

Mode Tables

Understanding information provided about mode of travel provides the link between person trips and vehicle trips and is essential to the fundamentals of trip generation.

The cordon counts provide information about the mode of travel for trips that are entering Legacy Town Center. As would be expected, nearly all trips entering Legacy are motorized with 90-95% of the trips being made by personal vehicle in each time period. In addition to the personal vehicle, trips were made mainly by delivery or service trucks, hotel shuttles, and a limited number of walking trips. In general, almost all trips entering or leaving the development were motorized. This is supported by Table 2 shown below.

Table 2: Mode Split of Access to Site

Mode	Peak Period			
	AM		PM	
	In	Out	In	Out
Personal Vehicle	92%	90%	94%	95%
Delivery/Service Truck	4%	3%	2%	2%
Shuttle	1%	4%	1%	0%
Walk	3%	3%	3%	2%

An important part of modal analysis is mode split. Mode split classifies the mode of travel percentage of all internal trips. For most mixed-use developments studied, mode split for internal trips is typically dominated by walking trips with values in the upper ninetieth percentile. The mode split ranges found at Legacy Town Center are shown in Figure 14 and Figure 15 below.

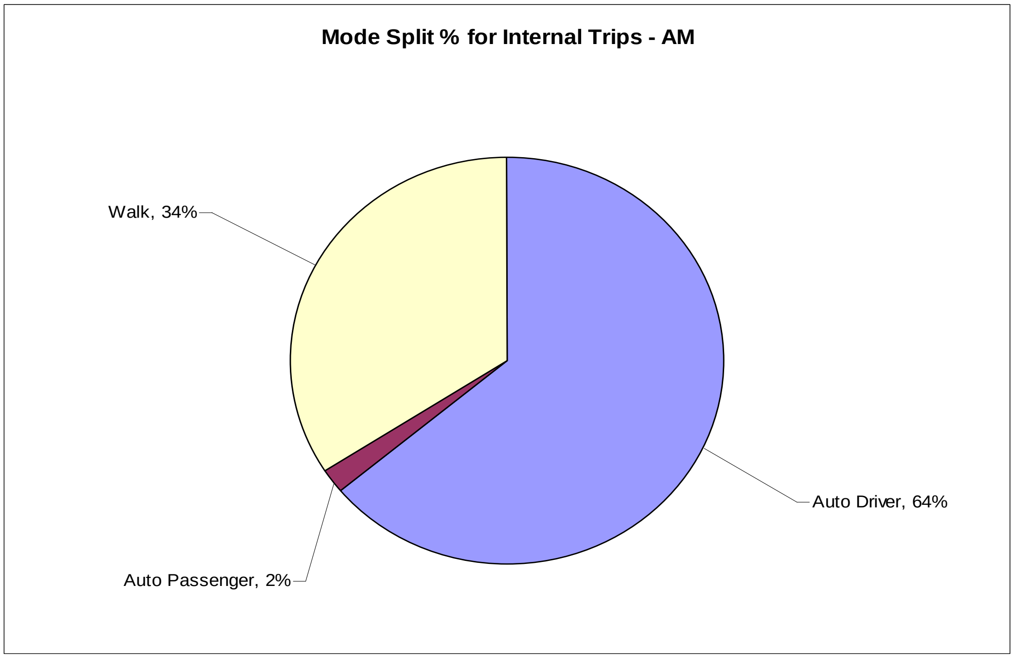

Figure 14: Legacy Town Center Mode Split - AM

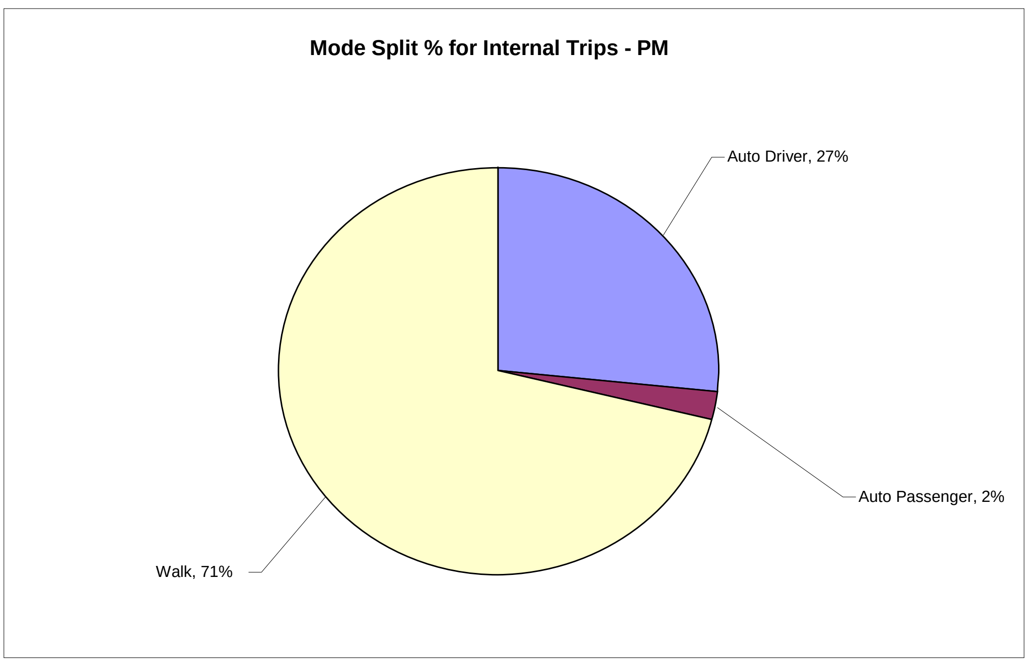

Figure 15: Legacy Town Center Mode Split – PM

The mode split percentages for each individual land use are shown in Table 3 and Table 4 below.

Table 3: Mode Split for internal Trips by Land Use - AM

Land Use (From)	Auto Driver	Auto Passenger	Walk
Office	4%	0%	2%
Retail	6%	0%	4%
Restaurant	10%	1%	7%
Residence	41%	1%	22%
Medical	0%	0%	0%
Cinema	0%	0%	0%
Hotel	4%	0%	0%
Other	0%	0%	0%
Subtotal	64%	2%	34%
Total	100%		

Table 4: Mode Split for Internal Trips by Land Use - PM

Land Use (From)	Auto Driver	Auto Passenger	Walk
Office	4%	0%	2%
Retail	6%	0%	16%
Restaurant	6%	0%	15%
Residence	8%	0%	21%
Medical	0%	0%	0%
Cinema	0%	1%	9%
Hotel	2%	1%	5%
Other	0%	0%	2%
Subtotal	27%	2%	71%
Total	100%		

The mode split percentages for Legacy Town Center are different than those typically found at compact mixed-use developments. In the AM period, motorized traffic dominates the split with 64%. This value may seem higher than expected at first, but when considering that most walking trips are generated by retail and restaurant, and that there is almost none of these land uses available in the morning, the statistic becomes more acceptable. As expected, walking internal trips increase in the afternoon, but do not reach the values expected. This again may seem very high, but after reviewing the site plan this too seems within acceptable limits. All of the main retail and restaurant locations (main trip generators) are located at the north end of Bishop Road and along Legacy Drive at the North Cordon. These locations are easily accessible by walking if the patron is traveling from the northern apartment locations or the town homes, but if someone is interested in reaching these locations from the southern apartment locations, the two southern office buildings or even the centrally located hotel, this trip becomes less and less favorable of walking.

Overall, the mode split at Legacy Town Center is surprisingly favorable of motorized trips in both the AM and PM periods.

Proximity Analysis

Proximity analysis tests the theory that there is a direct relationship between the distance between two land uses or individual doors, and the willingness of someone to make that trip. Intuition tells us that as the distance between two places increases, the likelihood of that trip being made decreases. This has been confirmed at longer distances through development of the gravity model in past research. The gravity model hypothesizes that the number of trips from one area to another is related to the degree of activity (development units) for each area and the distance between areas (*6*). Basically, the gravity model says that the number of trips between zone A and zone B is proportional to the size of each and the inverse of some power of distance. Analysis of this ratio shows that as distance between zones increases, the number of trips made will decrease.

To test the theory of proximity analysis, Legacy Town Center must first be divided up into door code zones. Door code zones are segmented sections of Legacy Town Center. Each door will be assigned to a larger zone for easier analysis. This is done because it is not practical to find the trip lengths to and from each of the hundreds of doors on site. Dividing Legacy Town Center into door code zones will aid in the proximity analysis and help in developing trip length distribution. Depending on the activity or land use of the area, the door code zones were split up into different sizes. After the door code zones were divided, each was assigned a centroidal point either in the middle of the zone, or towards an area of increased activity. The 15 door code zones and their centroidal points are shown in Figure 16 below.

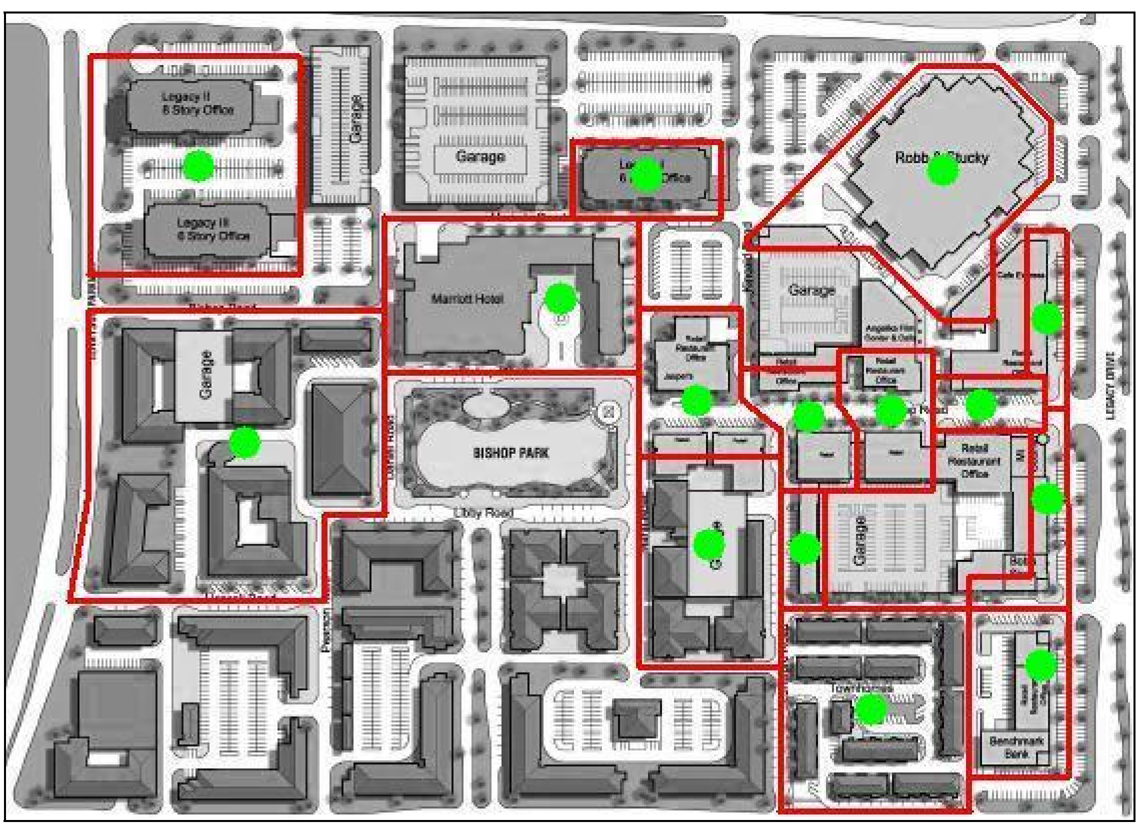

Figure 16: Legacy Town Center Door Code Zones

The distances between these points were determined then put into a database and rounded to the nearest 100 foot increment.

To visualize trip length distribution, a graph is constructed with data points from the available interchanges for each distance and the percent of internal trips made at each distance. The available interchanges will be the percent of the total trips that one specific trip length makes up. The percent of internal trips will be the percentage of times that a trip of that length was made at Legacy Town Center. Trend lines are then fit to these data points and the proximity analysis can be performed. Figure 17 below shows the proximity analysis graph for Legacy Town Center.

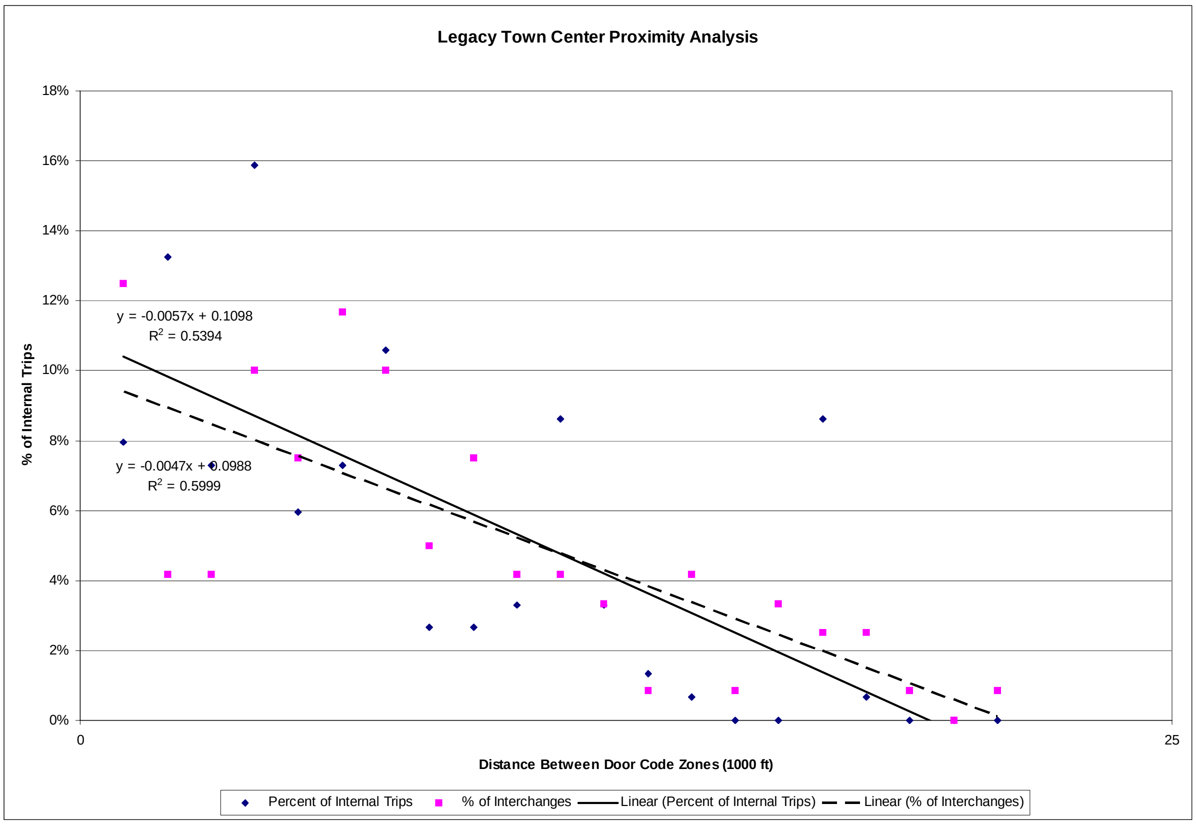

Figure 17: Legacy Town Center Proximity Analysis

The proximity analysis graph shows that the two trend lines shown are nearly identical. The lines have small slopes. Because the lines are almost flat, this shows that distance between land uses at Legacy Town Center has limited impact on where or whether the trip is made.

Figure 18 shown below shows the proximity analysis of percent of trips made internally for all three surveyed sites.

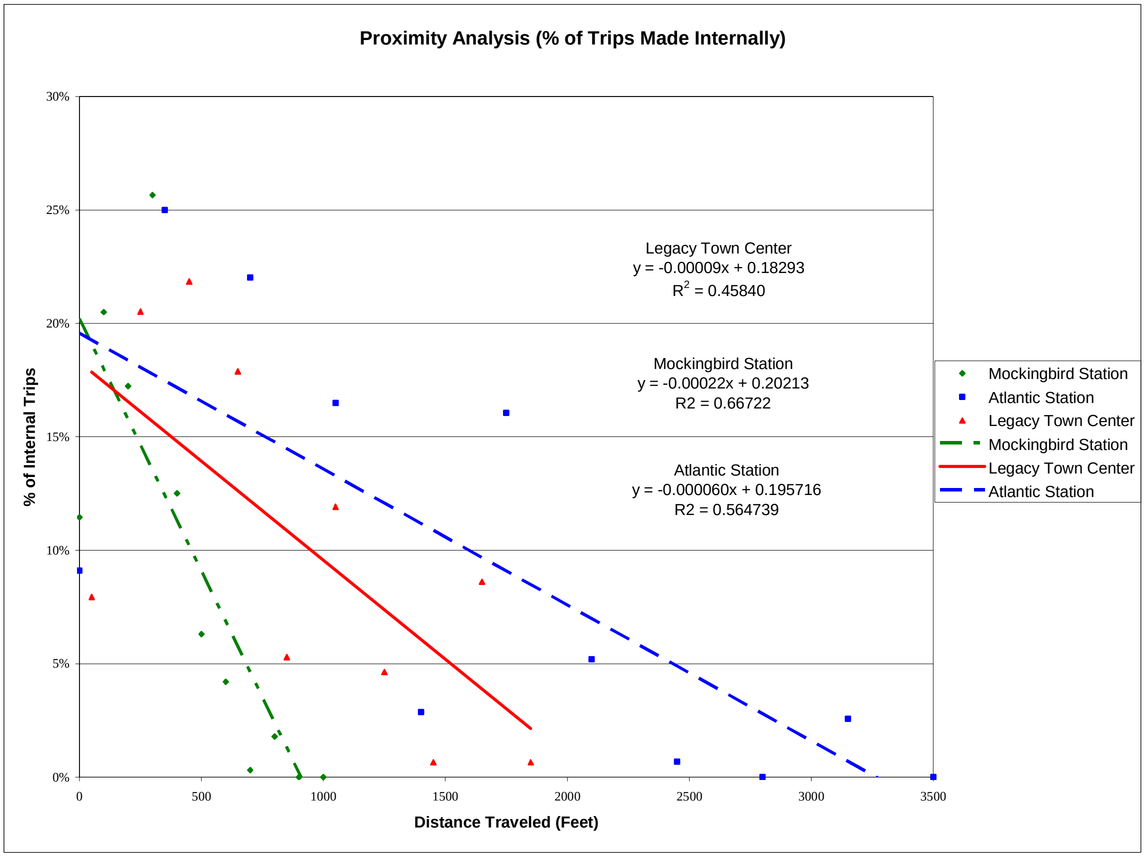

Figure 18: Proximity Analysis for All Three Surveyed Sites

The Legacy Town Center trip length distribution does not appear to be similar to those produced with proximity analysis at Mockingbird and Atlantic stations. It is difficult to pull any strong conclusions from this data set based on only three sample surveys.

Even though there are no significant relationships that can be developed between the three test sites, there is still some useful information from the proximity analysis. The general slope of the trend lines and the fact that the slope of the internal trips trend line is above slope of the available interchanges line both support the general theory behind proximity analysis. The hypothesis that an increase in distance between door code zones will lead to a will lead to a lower proportion of trips made is true at all three locations, even though at Legacy Town Center the impact was minimal.

CONCLUSIONS

After analysis of Legacy Town Center, Mockingbird Station and Atlantic Station, there are several conclusions that can be reached.

- Comparison of ITE Trip Generation Estimates to actual surveyed data points was surprisingly precise.
- The total site peak period internal capture rates achieved at all three locations had fairly high rates with a minimum of 25% and a maximum of 50%.

- New trends for mixed-use developments are effective in promoting internal trip capture.
- Restaurant, retail and residential land uses are most effective in generating and receiving internal trips.
- Internal trip capture by individual land use suggested that few people both live and work on-site.
- Although it would seem logical that the percent of internal trips for developments with differing percentages of land uses would be related to the ratio of development units for the sites, the data did not confirm.
- Mode split of access to site shows that the primary mode of access to site is motorized, with personal vehicle being the primary mode of travel. This is true at all three surveyed sites, even though Mockingbird Station is developed around a DART station.
- Legacy Town Center mode split for internal travel favored motorized travel significantly more than at the other developments. This is most likely due to the size of the development and segmentation of land uses.
- The highly transit oriented Mockingbird Station development did not have any significant differences in data than Legacy Town Center or Atlantic Station.
- Proximity analysis at Legacy Town Center supports the hypothesis that an increase in distance will cause a lower proportion of internal trips.

RECOMMENDATIONS

As mixed-use developments continue to grow in popularity, there will no doubt be a strong demand for trip generation and internal trip capture information. With a sample size of only three sites, it is hard see what trends are justifiable and what is merely a coincidence. The overall recommendation from the project is to collect more samples to refine this process and improve accuracy.

REFERENCES

1. Trip Generation Handbook, 2nd Edition. Institute of Transportation Engineers (ITE), June 2004.
2. *Quarterly Progress Report to the National Cooperative Highway Research Program (NCHRP) Project 8-51Enhancing Internal Trip Capture Estimation For Mixed Use Developments*. Texas Transportation Institute. March 31, 2007.
3. "Learn About New Urbanism, Creating Enduring Neighborhoods." Congress for the New Urbanism. 12 June 2007. http://www.cnu.org/Intro_to_new_urbanism
4. "Shops at Legacy Site Plan." Trammell Crow Company. April 2007.
5. Institute of Transportation Engineers (ITE). *Trip Generation, 7th Edition*. Washington DC, 2004.
6. Transportation Planning Handbook, 2nd Edition. Institute of Transportation Engineers (ITE), 1999.

APPENDIX

Table A1: Sample Cordon Count Form

Minutes after hour	Direction	Personal Vehicles				Motorcycles		Delivery/Service Trucks		Walk		Hotel Shuttle		Bike
		Occupants				Riders		Occupants		DART	Other	No.	Occupants	
		1	2	3	4+	1	2	1	2+					
:00 to :15	In													
	Out													
:15 to :30	In													
	Out													
:30 to :45	In													
	Out													
:45 to :00	In													
	Out													

Table A2: Sample Door Count Form

Minutes after hour	Direction	Place/Location						
		Starbucks	UPS Store	Coldstone	Martini Park	Robb & Stucky	Mi Cocina	Bobs Steak House
:00 to :15	In							
	Out							
:15 to :30	In							
	Out							
:30 to :45	In							
	Out							
:45 to :00	In							
	Out							

Table A3: Sample Interview Form

Building Entrance	Time	Where are you headed?		How are you going to get there?	If trip within Legacy Town Center: Would you be making this trip if you had to travel outside Legacy Town Center?	Where did you come from before you came to [name place being exited]		How did you travel from there?	What time did you arrive there?	How did you initially travel to Legacy Town Center Today?	
		1. Within Legacy Town Center 2. Outside Legacy Town Center	1. Office 2. Retail 3. Restaurant 4. Residential 5. Medical Office 6. Cinema 7. Hotel/Motel 8. Other (Specify) Specify business/building	1. Auto Driver 2. Auto Passenger 3. Taxi 4. Bus 5. Walk 6. Bicycle	1. Yes 2. No	1. Within Legacy Town Center 2. Outside Legacy Town Center	1. Office 2. Retail 3. Restaurant 4. Residential 5. Medical Office 6. Cinema 7. Hotel/Motel 8. Other (Specify) Specify business/building	1. Auto Driver 2. Auto Passenger 3. Taxi 4. Bus 5. Walk 6. Bicycle		1. Auto Driver 2. Auto Passenger 3. Taxi 4. Bus 5. Walk 6. Bicycle 7. Live On-Site 8. Staying in On-Site Hotel	If not as driver, did you have an auto available for your trip here? 1. Yes 2. No

Table A4: Percent Distribution of Internal Trip Origins for Destination Land Uses

Percent Distribution of Internal Trip Origins for Destination Land Uses (Inbound Trips) - AM

Destination Land Use (To)	Origin Land Use (From)																		
	Office	Specialty Retail	Convenience Retail	Retail Unspecified	Retail Total	Quality Restaurant	HT Restaurant	FF Restaurant	Drinking Place	Unspecified Restaurant	Restaurant Total	Residential	Medical	Cinema	Hotel	Other	External	Total % Internal Capture	Total
Office	0%	0%	3%	0%	3%	0%	2%	6%	0%	0%	8%	8%	0%	0%	0%	0%	81%	19%	100%
Specialty Retail	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%	16%	49%	0%	0%	0%	0%	35%	65%	100%
Convenience Retail	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	82%	0%	0%	0%	0%	18%	82%	100%
Unspecified Retail	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%	100%
Retail Total	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	5%	72%	0%	0%	0%	0%	23%	77%	100%
Quality Restaurant	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
High Turnover Restaurant	0%	0%	3%	0%	3%	0%	0%	0%	0%	0%	0%	41%	0%	0%	0%	0%	55%	45%	100%
Fast Food Restaurant	1%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	32%	0%	0%	6%	0%	60%	40%	100%
Drinking Place	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Unspecified Restaurant	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Restaurant Total	1%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%	33%	0%	0%	5%	0%	59%	41%	100%
Residential	2%	1%	2%	0%	4%	0%	0%	6%	0%	0%	6%	0%	0%	0%	0%	0%	88%	12%	100%
Medical	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cinema	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hotel	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	3%	5%	0%	0%	0%	0%	92%	8%	100%
Other	0%	0%	6%	0%	6%	0%	13%	0%	0%	0%	13%	81%	0%	0%	0%	0%	0%	100%	100%
Total	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			

Percent Distribution of Internal Trip Origins for Destination Land Uses (Inbound Trips) - PM

Destination Land Use (To)	Origin Land Use (From)																		
	Office	Specialty Retail	Convenience Retail	Retail Unspecified	Retail Total	Quality Restaurant	HT Restaurant	FF Restaurant	Drinking Place	Unspecified Restaurant	Restaurant Total	Residential	Medical	Cinema	Hotel	Other	External	Total % Internal Capture	Total
Office	0%	19%	0%	0%	19%	0%	0%	15%	0%	0%	15%	54%	0%	0%	0%	0%	12%	88%	100%
Specialty Retail	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%	2%	5%	0%	1%	0%	0%	92%	8%	100%
Convenience Retail	6%	0%	0%	0%	0%	15%	20%	0%	0%	0%	34%	36%	0%	0%	0%	0%	24%	76%	100%
Unspecified Retail	0%	0%	0%	0%	0%	0%	21%	0%	38%	0%	59%	19%	0%	3%	18%	0%	0%	100%	100%
Retail Total	1%	0%	0%	0%	0%	3%	7%	0%	3%	0%	13%	13%	0%	1%	1%	0%	71%	29%	100%
Quality Restaurant	0%	37%	13%	0%	51%	0%	0%	0%	0%	0%	0%	17%	0%	3%	13%	0%	16%	84%	100%
High Turnover Restaurant	1%	18%	5%	0%	22%	0%	0%	0%	0%	0%	0%	37%	0%	5%	10%	0%	24%	76%	100%
Fast Food Restaurant	6%	4%	2%	0%	7%	0%	0%	0%	0%	0%	0%	33%	0%	2%	4%	2%	47%	53%	100%
Drinking Place	0%	0%	3%	0%	3%	0%	0%	0%	0%	0%	0%	7%	0%	0%	0%	0%	90%	10%	100%
Unspecified Restaurant	0%	27%	0%	0%	27%	0%	0%	0%	0%	0%	0%	37%	0%	0%	36%	0%	0%	100%	100%
Restaurant Total	2%	12%	4%	0%	16%	0%	0%	0%	0%	0%	0%	26%	0%	2%	7%	1%	46%	54%	100%
Residential	4%	18%	12%	0%	30%	9%	0%	12%	0%	0%	22%	0%	0%	0%	0%	7%	37%	63%	100%
Medical	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	100%	100%
Cinema	0%	0%	0%	0%	0%	0%	22%	3%	0%	0%	24%	0%	0%	0%	0%	0%	76%	24%	100%
Hotel	2%	16%	3%	0%	18%	0%	4%	2%	7%	0%	13%	7%	0%	1%	0%	0%	59%	41%	100%
Other	0%	13%	4%	0%	17%	0%	0%	13%	0%	0%	13%	66%	0%	2%	2%	0%	0%	100%	100%
Total	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A			

Table A5: Percent Distribution of Internal Trip Destinations for Origin Land Uses

Percent Distribution of Internal Trip Destinations for Origin Land Uses (Outbound Trips) - AM

Destination Land Use (To)	Origin Land Use (From)																	
	Office	Specialty Retail	Convenience Retail	Retail Unspecified	Retail Total	Quality Restaurant	HT Restaurant	FF Restaurant	Drinking Place	Unspecified Restaurant	Restaurant Total	Residential	Medical	Cinema	Hotel	Other	External	Total % Internal Capture
Office	0%	0%	20%	0%	15%	N/A	17%	7%	N/A	N/A	9%	3%	N/A	N/A	0%	N/A	34%	4%
Specialty Retail	0%	0%	0%	0%	0%	N/A	0%	2%	N/A	N/A	2%	2%	N/A	N/A	0%	N/A	2%	2%
Convenience Retail	0%	0%	0%	0%	0%	N/A	0%	0%	N/A	N/A	0%	7%	N/A	N/A	0%	N/A	2%	4%
Unspecified Retail	0%	0%	0%	0%	0%	N/A	0%	0%	N/A	N/A	0%	1%	N/A	N/A	0%	N/A	0%	0%
Retail Total	0%	0%	0%	0%	0%	N/A	0%	2%	N/A	N/A	2%	9%	N/A	N/A	0%	N/A	3%	6%
Quality Restaurant	0%	0%	0%	0%	0%	N/A	0%	0%	N/A	N/A	0%	0%	N/A	N/A	0%	N/A	0%	0%
High Turnover Restaurant	0%	0%	5%	0%	4%	N/A	0%	0%	N/A	N/A	0%	3%	N/A	N/A	0%	N/A	5%	2%
Fast Food Restaurant	13%	0%	0%	100%	4%	N/A	0%	0%	N/A	N/A	0%	11%	N/A	N/A	8%	N/A	24%	8%
Drinking Place	0%	0%	0%	0%	0%	N/A	0%	0%	N/A	N/A	0%	0%	N/A	N/A	0%	N/A	0%	0%
Unspecified Restaurant	0%	0%	0%	0%	0%	N/A	0%	0%	N/A	N/A	0%	0%	N/A	N/A	0%	N/A	0%	0%
Restaurant Total	13%	0%	5%	100%	7%	N/A	0%	0%	N/A	N/A	0%	14%	N/A	N/A	8%	N/A	28%	10%
Residential	13%	20%	10%	0%	12%	N/A	0%	5%	N/A	N/A	4%	0%	N/A	N/A	0%	N/A	24%	2%
Medical	0%	0%	0%	0%	0%	N/A	0%	0%	N/A	N/A	0%	0%	N/A	N/A	0%	N/A	0%	0%
Cinema	0%	0%	0%	0%	0%	N/A	0%	0%	N/A	N/A	0%	0%	N/A	N/A	0%	N/A	0%	0%
Hotel	0%	0%	0%	0%	0%	N/A	0%	1%	N/A	N/A	1%	1%	N/A	N/A	0%	N/A	11%	1%
Other	0%	0%	5%	0%	4%	N/A	11%	0%	N/A	N/A	2%	4%	N/A	N/A	0%	N/A	0%	3%
External	75%	80%	60%	0%	62%	N/A	72%	85%	N/A	N/A	83%	69%	N/A	N/A	92%	N/A	0%	75%
Total	100%	100%	100%	100%	100%	N/A	100%	100%	N/A	N/A	100%	100%	N/A	N/A	100%	N/A	100%	100%

Percent Distribution of Internal Trip Destinations for Origin Land Uses (Outbound Trips) - PM

Destination Land Use (To)	Origin Land Use (From)																	
	Office	Specialty Retail	Convenience Retail	Retail Unspecified	Retail Total	Quality Restaurant	HT Restaurant	FF Restaurant	Drinking Place	Unspecified Restaurant	Restaurant Total	Residential	Medical	Cinema	Hotel	Other	External	Total % Internal Capture
Office	0%	2%	0%	0%	2%	0%	0%	4%	0%	N/A	1%	4%	N/A	0%	0%	0%	1%	2%
Specialty Retail	0%	0%	0%	0%	0%	0%	6%	0%	0%	N/A	1%	3%	N/A	6%	0%	0%	34%	1%
Convenience Retail	2%	0%	0%	0%	0%	22%	19%	0%	0%	N/A	7%	6%	N/A	0%	0%	0%	3%	4%
Unspecified Retail	0%	0%	0%	0%	0%	0%	6%	0%	9%	N/A	4%	1%	N/A	2%	4%	0%	0%	2%
Retail Total	2%	0%	0%	0%	0%	22%	31%	0%	9%	N/A	12%	9%	N/A	8%	4%	0%	36%	7%
Quality Restaurant	0%	7%	11%	0%	8%	0%	0%	0%	0%	N/A	0%	2%	N/A	4%	6%	0%	1%	3%
High Turnover Restaurant	1%	10%	11%	0%	10%	0%	0%	0%	0%	N/A	0%	11%	N/A	17%	14%	0%	5%	7%
Fast Food Restaurant	5%	2%	5%	0%	3%	0%	0%	0%	0%	N/A	0%	10%	N/A	8%	6%	13%	10%	5%
Drinking Place	0%	0%	5%	0%	1%	0%	0%	0%	0%	N/A	0%	2%	N/A	0%	0%	0%	16%	1%
Unspecified Restaurant	0%	2%	0%	0%	2%	0%	0%	0%	0%	N/A	0%	2%	N/A	0%	8%	0%	0%	2%
Restaurant Total	6%	21%	32%	0%	23%	0%	0%	0%	0%	N/A	0%	27%	N/A	29%	33%	13%	33%	18%
Residential	3%	12%	32%	0%	15%	33%	0%	17%	0%	N/A	11%	0%	N/A	2%	0%	50%	9%	7%
Medical	0%	0%	0%	0%	0%	0%	0%	0%	0%	N/A	0%	0%	N/A	0%	2%	0%	0%	0%
Cinema	0%	0%	0%	0%	0%	0%	25%	2%	0%	N/A	6%	0%	N/A	0%	0%	0%	10%	1%
Hotel	1%	7%	5%	0%	7%	0%	6%	2%	9%	N/A	5%	2%	N/A	2%	0%	0%	11%	3%
Other	0%	5%	5%	0%	5%	0%	0%	9%	0%	N/A	3%	13%	N/A	6%	2%	0%	0%	6%
External	87%	52%	26%	100%	48%	44%	38%	67%	82%	N/A	61%	45%	N/A	54%	59%	38%	0%	56%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	N/A	100%	100%	N/A	100%	100%	100%	100%	100%

Table A6: Distribution of Internal Trip Origins for Destination Land Uses

Distribution of Internal Trip Origins for Destination Land Uses (Inbound Trips) - AM

Origin Land Use (From)	Destination Land Use (To)																		
	Office	Specialty Retail	Convenience Retail	Retail Unspecified	Retail Total	Quality Restaurant	HT Restaurant	FF Restaurant	Drinking Place	Unspecified Restaurant	Restaurant Total	Residential	Medical	Cinema	Hotel	Other	External	Total Internal Capture	Total
Office	0.0	0.0	17.0	0.0	17.0	0.0	14.0	33.5	0.0	0.0	47.5	50.1	0.0	0.0	0.0	0.0	482.3	114.6	596.9
Specialty Retail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2	0.0	0.0	11.2	33.4	0.0	0.0	0.0	0.0	23.7	44.6	68.3
Convenience Retail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	108.7	0.0	0.0	0.0	0.0	23.3	108.7	132.0
Unspecified Retail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0.0	0.0	0.0	0.0	0.0	8.4	8.4
Retail Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2	0.0	0.0	11.2	150.4	0.0	0.0	0.0	0.0	47.0	161.6	208.6
Quality Restaurant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
High Turnover Restaurant	0.0	0.0	4.3	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	50.1	0.0	0.0	0.0	0.0	67.2	54.4	121.6
Fast Food Restaurant	8.2	0.0	0.0	4.3	4.3	0.0	0.0	0.0	0.0	0.0	0.0	175.5	0.0	0.0	30.8	0.0	334.1	218.8	552.9
Drinking Place	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unspecified Restaurant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Restaurant Total	8.2	0.0	4.3	4.3	8.6	0.0	0.0	0.0	0.0	0.0	0.0	225.7	0.0	0.0	30.8	0.0	401.3	273.2	674.6
Residential	8.2	5.4	8.5	0.0	13.9	0.0	0.0	22.3	0.0	0.0	22.3	0.0	0.0	0.0	0.0	0.0	336.2	44.5	380.6
Medical	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cinema	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hotel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	5.6	8.4	0.0	0.0	0.0	0.0	153.0	13.9	166.9
Other	0.0	0.0	4.3	0.0	4.3	0.0	9.3	0.0	0.0	0.0	9.3	58.5	0.0	0.0	0.0	0.0	0.0	72.1	72.1
Total	66.0	27.0	85.0	4.3	116.3	0.0	84.0	469.0	0.0	0.0	553.0	1596.3	0.0	0.0	400.0	0.0	1419.8	2731.6	4151.4

Distribution of Internal Trip Origins for Destination Land Uses (Inbound Trips) - PM

Origin Land Use (From)	Destination Land Use (To)																		
	Office	Specialty Retail	Convenience Retail	Retail Unspecified	Retail Total	Quality Restaurant	HT Restaurant	FF Restaurant	Drinking Place	Unspecified Restaurant	Restaurant Total	Residential	Medical	Cinema	Hotel	Other	External	Total Internal Capture	Total
Office	0.0	17.4	0.0	0.0	17.4	0.0	0.0	13.1	0.0	0.0	13.1	48.7	0.0	0.0	0.0	0.0	10.6	79.1	89.8
Specialty Retail	0.0	0.0	0.0	0.0	0.0	0.0	13.4	0.0	0.0	0.0	13.4	36.5	0.0	6.2	0.0	0.0	623.4	56.1	679.5
Convenience Retail	11.8	0.0	0.0	0.0	0.0	30.0	40.1	0.0	0.0	0.0	70.1	73.0	0.0	0.0	0.0	0.0	50.0	154.9	204.9
Unspecified Retail	0.0	0.0	0.0	0.0	0.0	0.0	13.4	0.0	24.6	0.0	37.9	12.2	0.0	2.1	11.8	0.0	0.0	64.0	64.0
Retail Total	11.8	0.0	0.0	0.0	0.0	30.0	66.8	0.0	24.6	0.0	121.4	121.6	0.0	8.3	11.8	0.0	673.4	275.0	948.3
Quality Restaurant	0.0	52.1	18.6	0.0	70.7	0.0	0.0	0.0	0.0	0.0	0.0	24.3	0.0	4.2	17.7	0.0	23.1	116.9	139.9
High Turnover Restaurant	5.9	69.4	18.6	0.0	88.0	0.0	0.0	0.0	0.0	0.0	0.0	146.0	0.0	18.7	41.3	0.0	94.2	299.9	394.1
Fast Food Restaurant	23.5	17.4	9.3	0.0	26.7	0.0	0.0	0.0	0.0	0.0	0.0	133.8	0.0	8.3	17.7	8.3	191.5	218.3	409.8
Drinking Place	0.0	0.0	9.3	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	24.3	0.0	0.0	0.0	0.0	305.8	33.6	339.4
Unspecified Restaurant	0.0	17.4	0.0	0.0	17.4	0.0	0.0	0.0	0.0	0.0	0.0	24.3	0.0	0.0	23.6	0.0	0.0	65.3	65.3
Restaurant Total	29.4	156.2	55.8	0.0	212.0	0.0	0.0	0.0	0.0	0.0	0.0	352.8	0.0	31.2	100.3	8.3	614.5	734.0	1348.5
Residential	17.6	86.8	55.8	0.0	142.6	45.1	0.0	59.0	0.0	0.0	104.0	0.0	0.0	2.1	0.0	33.4	176.2	299.7	475.9
Medical	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	5.9	5.9
Cinema	0.0	0.0	0.0	0.0	0.0	0.0	53.5	6.6	0.0	0.0	60.0	0.0	0.0	0.0	0.0	0.0	185.4	60.0	245.4
Hotel	5.9	52.1	9.3	0.0	61.4	0.0	13.4	6.6	24.6	0.0	44.5	24.3	0.0	2.1	0.0	0.0	197.4	138.2	335.5
Other	0.0	34.7	9.3	0.0	44.0	0.0	0.0	32.8	0.0	0.0	32.8	170.3	0.0	6.2	5.9	0.0	0.0	259.2	259.2
Total	511.5	729.0	176.7	17.1	922.8	135.2	213.8	353.8	270.4	0.0	973.2	1301.6	0.0	108.0	301.0	66.7	1857.5	4184.8	6042.3

Table A7: Distribution of Internal Trip Destinations for Origin Land Uses

Distribution of Internal Trip Destinations for Origin Land Uses (Outbound Trips) - AM

Destination Land Use (To)	Origin Land Use (From)																	
	Office	Specialty Retail	Convenience Retail	Retail Unspecified	Retail Total	Quality Restaurant	HT Restaurant	FF Restaurant	Drinking Place	Unspecified Restaurant	Restaurant Total	Residential	Medical	Cinema	Hotel	Other	External	Total Internal Capture
Office	0.0	0.0	17.0	0.0	17.0	0.0	14.0	33.5	0.0	0.0	47.5	50.1	0.0	0.0	0.0	0.0	482.3	114.6
Specialty Retail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2	0.0	0.0	11.2	33.4	0.0	0.0	0.0	0.0	23.7	44.6
Convenience Retail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	108.7	0.0	0.0	0.0	0.0	23.3	108.7
Unspecified Retail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0.0	0.0	0.0	0.0	0.0	8.4
Retail Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2	0.0	0.0	11.2	150.4	0.0	0.0	0.0	0.0	47.0	161.6
Quality Restaurant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
High Turnover Restaurant	0.0	0.0	4.3	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	50.1	0.0	0.0	0.0	0.0	67.2	54.4
Fast Food Restaurant	8.2	0.0	0.0	4.3	4.3	0.0	0.0	0.0	0.0	0.0	0.0	175.5	0.0	0.0	30.8	0.0	334.1	218.8
Drinking Place	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unspecified Restaurant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Restaurant Total	8.2	0.0	4.3	4.3	8.6	0.0	0.0	0.0	0.0	0.0	0.0	225.7	0.0	0.0	30.8	0.0	401.3	273.2
Residential	8.2	5.4	8.5	0.0	13.9	0.0	0.0	22.3	0.0	0.0	22.3	0.0	0.0	0.0	0.0	0.0	336.2	44.5
Medical	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cinema	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hotel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	5.6	8.4	0.0	0.0	0.0	0.0	153.0	13.9
Other	0.0	0.0	4.3	0.0	4.3	0.0	9.3	0.0	0.0	0.0	9.3	58.5	0.0	0.0	0.0	0.0	0.0	72.1
External	49.5	21.6	51.0	0.0	72.6	0.0	60.7	396.4	0.0	0.0	457.1	1103.2	0.0	0.0	369.2	0.0	0.0	2051.6
Total	66.0	27.0	85.0	4.3	116.3	0.0	84.0	469.0	0.0	0.0	553.0	1596.3	0.0	0.0	400.0	0.0	1419.8	2731.6

Distribution of Internal Trip Destinations for Origin Land Uses (Outbound Trips) - PM

Destination Land Use (To)	Origin Land Use (From)																	
	Office	Specialty Retail	Convenience Retail	Retail Unspecified	Retail Total	Quality Restaurant	HT Restaurant	FF Restaurant	Drinking Place	Unspecified Restaurant	Restaurant Total	Residential	Medical	Cinema	Hotel	Other	External	Total Internal Capture
Office	0.0	17.4	0.0	0.0	17.4	0.0	0.0	13.1	0.0	0.0	13.1	48.7	0.0	0.0	0.0	0.0	10.6	79.1
Specialty Retail	0.0	0.0	0.0	0.0	0.0	0.0	13.4	0.0	0.0	0.0	13.4	36.5	0.0	6.2	0.0	0.0	623.4	56.1
Convenience Retail	11.8	0.0	0.0	0.0	0.0	30.0	40.1	0.0	0.0	0.0	70.1	73.0	0.0	0.0	0.0	0.0	50.0	154.9
Unspecified Retail	0.0	0.0	0.0	0.0	0.0	0.0	13.4	0.0	24.6	0.0	37.9	12.2	0.0	2.1	11.8	0.0	0.0	64.0
Retail Total	11.8	0.0	0.0	0.0	0.0	30.0	66.8	0.0	24.6	0.0	121.4	121.6	0.0	8.3	11.8	0.0	673.4	275.0
Quality Restaurant	0.0	52.1	18.6	0.0	70.7	0.0	0.0	0.0	0.0	0.0	0.0	24.3	0.0	4.2	17.7	0.0	23.1	116.9
High Turnover Restaurant	5.9	69.4	18.6	0.0	88.0	0.0	0.0	0.0	0.0	0.0	0.0	146.0	0.0	18.7	41.3	0.0	94.2	299.9
Fast Food Restaurant	23.5	17.4	9.3	0.0	26.7	0.0	0.0	0.0	0.0	0.0	0.0	133.8	0.0	8.3	17.7	8.3	191.5	218.3
Drinking Place	0.0	0.0	9.3	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	24.3	0.0	0.0	0.0	0.0	305.8	33.6
Unspecified Restaurant	0.0	17.4	0.0	0.0	17.4	0.0	0.0	0.0	0.0	0.0	0.0	24.3	0.0	0.0	23.6	0.0	0.0	65.3
Restaurant Total	29.4	156.2	55.8	0.0	212.0	0.0	0.0	0.0	0.0	0.0	0.0	352.8	0.0	31.2	100.3	8.3	614.5	734.0
Residential	17.6	86.8	55.8	0.0	142.6	45.1	0.0	59.0	0.0	0.0	104.0	0.0	0.0	2.1	0.0	33.4	176.2	299.7
Medical	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	5.9
Cinema	0.0	0.0	0.0	0.0	0.0	0.0	53.5	6.6	0.0	0.0	60.0	0.0	0.0	0.0	0.0	0.0	185.4	60.0
Hotel	5.9	52.1	9.3	0.0	61.4	0.0	13.4	6.6	24.6	0.0	44.5	24.3	0.0	2.1	0.0	0.0	197.4	138.2
Other	0.0	34.7	9.3	0.0	44.0	0.0	0.0	32.8	0.0	0.0	32.8	170.3	0.0	6.2	5.9	0.0	0.0	259.2
External	446.8	381.9	46.5	17.1	445.4	60.1	80.2	235.9	221.3	0.0	597.4	583.9	0.0	58.2	177.1	25.0	0.0	2333.7
Total	511.5	729.0	176.7	17.1	922.8	135.2	213.8	353.8	270.4	0.0	973.2	1301.6	0.0	108.0	301.0	66.7	1857.5	4184.8

Table A8: ITE Trip Generation Summary

	AM Peak Period														
	ITE Trip Generation Raw			Internal Trip Capture		ITE Trip Generation Adjusted			Surveyed			% Error			
Development	Total Trips	Entering	Exiting	Inbound	Outbound	Total Trips	Entering	Exiting	Total Trips	Entering	Exiting	Total Trips	Entering	Exiting
Legacy Town Center	2108	1111	997	32%	25%	1503.2	755.5	747.8	1386	741	645	8%	2%	16%
Mockinbird Station	371	240	130	35%	46%	226.2	156.0	70.2	397	270	127	43%	42%	45%
Atlantic Station	1331	862	469	40%	30%	845.5	517.2	328.3	1533	1008	525	45%	49%	37%

	PM Peak Period													
	ITE Trip Generation Raw			Internal Trip Capture		ITE Trip Generation Adjusted			Surveyed			% Error		
Development	Total Trips	Entering	Exiting	Inbound	Outbound	Total Trips	Entering	Exiting	Total Trips	Entering	Exiting	Total Trips	Entering	Exiting
Legacy Town Center	3647	1460	2187	50%	44%	1954.7	730.0	1224.7	1907	947	960	3%	23%	28%
Mockinbird Station	1259	575	685	36%	42%	765.3	368.0	397.3	719	366	353	6%	1%	13%
Atlantic Station	3982	1787	2195	42%	41%	2331.5	1036.5	1295.1	2093	1037	1056	11%	0%	23%

Table A9: ITE Trip Generation Estimate - Legacy Town Center AM

Land Use	Developer	Building Name	Developed	Occupied	Units	% Occupied	Total Trips	% Entering	% Exiting	Trips Entering	Trips Exiting
Office	Carr America	Legacy Town Center One	153,766	153,230	S.F.	100%	263.9	88%	12%	232.2	31.7
	Carr America	Legacy Town Center Two	207,076	53,415	S.F.	26%	113.6	88%	12%	99.9	13.6
	Carr America	Legacy Town Center Three	153,866	38,394	S.F.	25%	87.2	88%	12%	76.7	10.5
	Shops at Legacy	Building D	35,033	35,033	S.F.	100%	81.0	88%	12%	71.3	9.7
	Shops at Legacy	Building E	10,805	10,805	S.F.	100%	31.6	88%	12%	27.8	3.8
	Shops at Legacy	Building G	19,887	19,887	S.F.	100%	51.5	88%	12%	45.3	6.2
Retail	Shops at Legacy	Building A	3,022	0	S.F.	0%	0.0	48%	52%	0.0	0.0
	Shops at Legacy	Building B	19,779	0	S.F.	0%	0.0	48%	52%	0.0	0.0
	Shops at Legacy	Building C	21,975	0	S.F.	0%	0.0	48%	52%	0.0	0.0
	Shops at Legacy	Building D	18,931	0	S.F.	0%	0.0	48%	52%	0.0	0.0
	Shops at Legacy	Building E	21,523	0	S.F.	0%	0.0	48%	52%	0.0	0.0
	Shops at Legacy	Building G	1,490	0	S.F.	0%	0.0	48%	52%	0.0	0.0
	Post Properties	Murphy Lofts	5,993	0	S.F.	0%	0.0	48%	52%	0.0	0.0
	Shops at Legacy	Building D	3,158	3,158	S.F.	100%	259.1	51%	49%	132.1	126.9
Restaurant	Shops at Legacy	Quality Restaurants	29,451	0	S.F.	0%	0.0	82%	18%	0.0	0.0
	Shops at Legacy	High-Turnover Restaurants	25,581	3,102	S.F.	12%	35.7	52%	48%	18.6	17.2
	Shops at Legacy	Fast Food Restaurants	6,184	3,448	S.F.	56%	251.8	52%	48%	130.9	120.9
	Post Properties	Coldstone Creamery	1,112	0	S.F.	0%	0.0	52%	48%	0.0	0.0
	Shops at Legacy	Drinking Place	6,990	0	S.F.	0%	0.0	0%	0%	0.0	0.0
Cinema	Angelika Cinema	Angelika Cinema	1,019	0	Seats	0%	0.0	0%	0%	0.0	0.0
Residential	Post Properties	Post Properties	384	362	DU	94%	181.1	20%	80%	36.2	144.9
	Lincoln Properties	Buildings A,B,C,D	312	297	DU	95%	149.3	20%	80%	29.9	119.4
	Lincoln Properties	Building E	106	74	DU	70%	40.0	20%	80%	8.0	32.0
	Lincoln Properties	Building F	66	46	DU	70%	26.3	20%	80%	5.3	21.0
	Lincoln Properties	Building G (Acqua)	64	23	DU	36%	15.0	20%	80%	3.0	12.0
	Lincoln Properties	Lakeside Apartments	517	499	DU	97%	248.2	20%	80%	49.6	198.6
	Townhomes	Townhomes	63	60	DU	95%	34.3	17%	83%	5.8	28.5
Hotel	Marriott Hotel	Marriott Hotel	404	344	Rooms	85%	238.5	58%	42%	138.3	100.2
Medical	Shops at Legacy	MRI Central	3,440	3,440	S.F.	100%	0.0	0%	0%	0.0	0.0
Bank	Shops at Legacy	Benchmark Bank	7,062	0	S.F.	0%	0.0	51%	49%	0.0	0.0
						TOTAL	**2108**			**1111**	**997**

Table A10: ITE Trip Generation Estimate - Legacy Town Center PM

Land Use	Developer	Building Name	Developed	Occupied	Units	% Occupied	Total Trips	% Entering	% Exiting	Trips Entering	Trips Exiting
Office	Carr America	Legacy Town Center One	153,766	153,230	S.F.	100%	250.4	17%	83%	42.6	207.9
	Carr America	Legacy Town Center Two	207,076	53,415	S.F.	26%	138.6	17%	83%	23.6	115.1
	Carr America	Legacy Town Center Three	153,866	38,394	S.F.	25%	121.8	17%	83%	20.7	101.1
	Shops at Legacy	Building D	35,033	35,033	S.F.	100%	118.0	17%	83%	20.1	98.0
	Shops at Legacy	Building E	10,805	10,805	S.F.	100%	90.9	17%	83%	15.5	75.5
	Shops at Legacy	Building G	19,887	19,887	S.F.	100%	101.1	17%	83%	17.2	83.9
Retail	Shops at Legacy	Building A	3,022	3,022	S.F.	100%	28.7	44%	56%	12.6	16.1
	Shops at Legacy	Building B	19,779	19,779	S.F.	100%	68.9	44%	56%	30.3	38.6
	Shops at Legacy	Building C	21,975	16,713	S.F.	76%	61.6	44%	56%	27.1	34.5
	Shops at Legacy	Building D	18,931	18,931	S.F.	100%	66.9	44%	56%	29.4	37.5
	Shops at Legacy	Building E	21,523	17,891	S.F.	83%	64.4	44%	56%	28.3	36.1
	Shops at Legacy	Building G	1,490	1,490	S.F.	100%	25.1	44%	56%	11.0	14.0
	Post Properties	Murphy Lofts	5,993	5,993	S.F.	100%	35.9	44%	56%	15.8	20.1
	Shops at Legacy	Building D	3,158	3,158	S.F.	100%	196.4	49%	51%	96.3	100.2
Restaurant	Shops at Legacy	Quality Restaurants	29,451	29,451	S.F.	100%	220.6	67%	33%	147.8	72.8
	Shops at Legacy	High-Turnover Restaurants	25,581	25,581	S.F.	100%	279.3	61%	39%	170.4	108.9
	Shops at Legacy	Fast Food Restaurants	6,184	6,184	S.F.	100%	161.7	51%	49%	82.5	79.2
	Post Properties	Coldstone Creamery	1,112	1,112	S.F.	100%	29.1	51%	49%	14.8	14.2
	Shops at Legacy	Drinking Place	6,990	6,990	S.F.	100%	79.3	66%	34%	52.3	27.0
Cinema	Angelika Cinema	Angelika Cinema	1,019	1,019	Seats	100%	71.3	39%	61%	27.8	43.5
Residential	Post Properties	Post Properties	384	362	DU	94%	216.8	65%	35%	140.9	75.9
	Lincoln Properties	Buildings A,B,C,D	312	297	DU	95%	181.0	20%	80%	36.2	144.8
	Lincoln Properties	Building E	106	74	DU	70%	58.4	20%	80%	11.7	46.7
	Lincoln Properties	Building F	66	46	DU	70%	43.0	20%	80%	8.6	34.4
	Lincoln Properties	Building G (Acqua)	64	23	DU	36%	30.3	20%	80%	6.1	24.2
	Lincoln Properties	Lakeside Apartments	517	499	DU	97%	292.1	20%	80%	58.4	233.7
	Townhomes	Townhomes	63	60	DU	95%	39.5	67%	33%	26.5	13.0
Hotel	Marriott Hotel	Marriott Hotel	404	344	Rooms	85%	234.8	49%	51%	115.1	119.8
Medical	Shops at Legacy	MRI Central	3,440	3,440	S.F.	100%	17.8	50%	50%	8.9	8.9
Bank	Shops at Legacy	Benchmark Bank	7,062	7,062	S.F.	100%	323.0	50%	50%	161.5	161.5
						TOTAL	**3647**			**1460**	**2187**

Table A11: ITE Trip Generation Estimate - Mockingbird Station

Land Use	Building Name	Development Units	Occupied Units	Units	% Occupied	Total Trips	% Entering	% Exiting	Trips Entering	Trips Exiting
Office	--	146,553	117,896	S.F.	80%	214.0	88%	12%	188.3	25.7
Retail	--	199,789	0	S.F.	0%	0.0	0%	0%	0.0	0.0
Restaurant	Quality Restaurants	20,759	0	S.F.	0%	0.0	Not Provided	Not Provided	0.0	0.0
	High Turnover Restaurants	5,760	0	S.F.	0%	0.0	52%	48%	0.0	0.0
	Fast Food Restaurants	2,364	1,182	S.F.	50%	51.9	60%	40%	31.1	20.7
Cinema	Angelika Cinema	8	0	Screens	0%	0.0	0%	0%	0.0	0.0
Residential	Efficiencies	10	10	DU	100%	8.6	20%	80%	1.7	6.9
	1 Bedroom	177	160	DU	90%	82.1	20%	80%	16.4	65.7
	2 Bedroom	24	21	DU	88%	14.0	20%	80%	2.8	11.2
					TOTAL	371			240	130

Land Use	Building Name	Development Units	Occupied Units	Units	% Occupied	Total Trips	% Entering	% Exiting	Trips Entering	Trips Exiting
Office	--	146,553	17,494	S.F.	12%	98.4	17%	83%	16.7	81.7
Retail	--	199,789	177,921	S.F.	89%	448.5	44%	56%	197.3	251.2
Restaurant	--	20,759	20,759	S.F.	100%	155.5	67%	33%	104.2	51.3
	--	5,760	5,760	S.F.	100%	62.9	61%	39%	38.4	24.5
	--	2,364	2,364	S.F.	100%	61.8	51%	49%	31.5	30.3
Cinema	Angelika Cinema	8	8	Screens	100%	161.8	40%	60%	64.7	97.1
Residential	Efficiencies	10	10	DU	100%	23.2	65%	35%	15.0	8.1
	1 Bedroom	177	160	DU	90%	105.7	65%	35%	68.7	37.0
	2 Bedroom	24	21	DU	88%	29.2	65%	35%	19.0	10.2
					TOTAL	1147			556	591

Table A12: ITE Trip Generation Estimates - Atlantic Station

Land Use	Developer / Building Name	Development Units	Occupied Units	Units	% Occupied	Total Trips	% Entering	% Exiting	Trips Entering	Trips Exiting
Office	Wachovia	559,680	542,890	S.F.	97%	726.0	88%	12%	638.9	87.1
	Tahitian Noni - Corp. Office	7,672	7,672	S.F.	100%	24.0	88%	12%	21.2	2.9
	The Joint - Chiropractor	1,440	1,440	S.F.	100%	6.3	88%	12%	5.6	0.8
	Piedmont Physicians	4,349	4,349	S.F.	100%	15.3	88%	12%	13.4	1.8
Retail	Atlantic Station Shopping Center	437723	30301	S.F.	7%	76.5	61%	39%	46.6	29.8
Restaurant	Quality Restaurants	15325	0	S.F.	0%	0	Not Provided	Not Provided	0.0	0.0
	High Turnover Restaurants	43041	0	S.F.	0%	0	52%	48%	0.0	0.0
	Fast Food Restaurants	2188	1625	S.F.	74%	71.3	60%	40%	42.8	28.5
	Drinking Places	4091	0	S.F.	0%	0	0%	0%	0.0	0.0
Cinema	Regal Cinema	16	0	Screens	0%	0	0%	0%	0.0	0.0
Residential	Park District Apartments	231	206	DU	89%	104.5	20%	80%	20.9	83.6
	Art Foundry - Condos	347	347	DU	100%	139.7	17%	83%	23.7	115.9
	Breezer Townhomes	56	55	DU	98%	31.9	17%	83%	5.4	26.5
	Condos	380	190	DU	50%	86.3	17%	83%	14.7	71.6
Hotel	--	101	101	Rooms	100%	49.0	58%	42%	28.4	20.6
					TOTAL	1331			862	469

Land Use	Developer / Building Name	Development Units	Occupied Units	Units	% Occupied	Total Trips	% Entering	% Exiting	Trips Entering	Trips Exiting
Office	Wachovia	559,680	542,890	S.F.	97%	686.8	17%	83%	116.8	570.1
	Tahitian Noni - Corp. Office	7,672	7,672	S.F.	100%	87.4	17%	83%	14.9	72.5
	The Joint - Chiropractor	1,440	1,440	S.F.	100%	80.4	17%	83%	13.7	66.8
	Piedmont Physicians	4,349	4,349	S.F.	100%	83.7	17%	83%	14.2	69.5
Retail	Atlantic Station Shopping Center	437723	437723	S.F.	100%	1658.8	48%	52%	796.2	862.6
Restaurant	Quality Restaurants	15325	15325	S.F.	100%	114.8	67%	33%	76.9	37.9
	High Turnover Restaurants	43041	43041	S.F.	100%	470.0	61%	39%	286.7	183.3
	Fast Food Restaurants	2188	2118	S.F.	97%	45.9	50%	50%	22.9	22.9
	Drinking Places	4091	4091	S.F.	100%	46.4	66%	34%	30.6	15.8
Cinema	Regal Cinema	16	16	Screens	100%	218.24	45%	55%	98.2	120.0
Residential	Park District Apartments	231	206	DU	89%	130.7	65%	35%	85.0	45.8
	Art Foundry - Condos	347	347	DU	100%	166.7	67%	33%	111.7	55.0
	Breezer Townhomes	56	55	DU	98%	36.8	67%	33%	24.6	12.1
	Condos	380	190	DU	50%	101.8	67%	33%	68.2	33.6
Hotel	--	101	101	Rooms	100%	54.0	49%	51%	26.4	27.5
					TOTAL	3982			1787	2195

Pedestrian and Motorist Perception of Pedestrian Signs in Work Zones

Prepared for
Undergraduate Transportation Scholars Program

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August 10, 2007

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ACKNOWLEDGMENT

The research described in this paper was conducted as part of Project 0-5237, sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The research activities were conducted in support of the Undergraduate Transportation Scholars Program. The findings and recommendations included in this paper are based on the student's summer activities. They should be considered preliminary and not as representative of the findings and recommendations of the parent project. This paper has not been reviewed or approved by the sponsor. The contents of this paper reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of TxDOT and the FHWA.

SUMMARY

Pedestrian injuries and deaths have become a recurring problem, especially in work zones. It is possible that confusing signs or a disregarding of the signs by pedestrians is causing these casualties.

Little research exists on pedestrian and motorist perception of pedestrian signs in work zones. As such, no one is sure how users perceive these signs. The purpose of this research is to understand how users perceive these signs, and to help determine what type of sign is the best to use in a pedestrian area work zone. The study focuses on eight signs in particular.

The study involves surveys given across the state of Texas, and an analysis of the results of the surveys. Six hundred and sixty-eight people took this survey, and all of their opinions, insight, and understanding of these signs are what make up this research. The researcher took their answers to the questions over the eight different signs and interpreted, analyzed, and evaluated the results. From this, he was able to make some conclusions as to which signs are acceptable, and which signs are not. In addition, the researcher analyzed several design variations

separately, in an attempt to find out what different elements of a sign effectively communicate to users the intended message.

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INTRODUCTION

Nearly everyone utilizes walking as a form of transportation on any given day. However, pedestrians are seldom aware that they are required to follow all laws and traffic regulations, just like motorists. Individuals should be conscious of the chance of being involved in accidents as pedestrians just as they are when they are driving. In 2003, 11% of all traffic accident fatalities were pedestrians. With this number totaling 4,749, on average, one pedestrian died every two hours (*1*). In addition, there were 70,000 pedestrian injuries recorded, which averages out to one every eight minutes (*2*). From 2001-2005, 15% of all deaths in work zone crashes were pedestrians (*3*).

Most pedestrian signs currently in use are regulatory. Regulatory signs generally have a black legend with a white background, and inform users of traffic laws and regulations (*4*). The other sign form used for pedestrian traffic is the warning sign. Normally, warning signs are diamond shaped, with a yellow background, but temporary traffic control zones display different warning signs for pedestrians. Pedestrian warning signs are more likely to be orange rectangles with a black legend (*5*). Figure 1 and Figure 2, below, are examples of a regulatory sign and a warning sign found in a temporary traffic control zone, respectively.

Figure 1. Regulatory Sign

Figure 2. Warning Sign

Like roadways, pedestrian pathways occasionally close due to construction. These closures are normally marked with signs telling pedestrians not to walk through the closed off section. Generally, there are signs available to offer other routes. Some believe that many of these signs may be confusing pedestrians. For example, in Figure 1, there is an arrow notifying the user to cross the street here, but some might take the arrow to mean that the sidewalk on the other side of the street is closed. In addition, it is also possible that pedestrians understand the signs, but choose not to obey them.

Therefore, there is a potential that pedestrians will either walk through the work zone, or continue up the sidewalk and then cross the street illegally**.** Pedestrians face the chance of injury or death by any number of potentially hazardous vehicles, including those in traffic or machines working the construction site. This is not even to mention the damage that could be done to said machinery or vehicles if the driver were to swerve and miss the pedestrian, only to hit an obstacle. Likewise, there is concern that drivers see the pedestrian signs, and mistake them for a road sign. This might cause unnecessary lane changes, turns, or general confusion. There is not much research on this particular subject of pedestrian signs in work zones, and no one is sure how people perceive these signs. It is possible that a lack of understanding or even a lack of respect for these signs has caused inefficient commuting, injuries, and pedestrian fatalities.

Background

This research is part of a much larger project, Development of Guidelines for Handling Pedestrians in Temporary Traffic Control Areas (Project # 0-5237), that the Texas Department of Transportation (TxDOT) is doing. The purpose of the project is to provide improved guidelines and traffic control standard sheets regarding the handling of pedestrians in work zones, and to make sure these guidelines meet the requirements of the Americans with Disabilities Act (ADA).

Project 5237 consists of six tasks. Previously, members of the TTI research team: reviewed the current operational practices regarding work zone traffic control for pedestrians, conducted focus groups to determine information needs, and identified innovative technologies and strategies to improve work zone pedestrian traffic control. Currently they are on the fourth task, evaluating the technologies and strategies.

This research is part of the fourth task, evaluating innovative technologies and strategies. More specifically, it is part of subtask 4.2, field evaluation of innovative technologies and traffic control. Other studies involve the innovative devices used for those with disabilities in accordance with the ADA, but this particular research approaches the topic of pedestrian sign perception in work zones by normal pedestrian traffic.

When sidewalks are closed, users need to know the most efficient and safe way of traveling to their destinations, and the signs that tell them this should be very clear; however, drivers do not need to be confused. It is imperative that the signs are designed in such a way that it is obvious to drivers that the signs do not pertain to them, so drivers do not make unnecessary lane changes, or turn at the wrong place. Signs must give pedestrians a clear message through combinations of colors, shapes, and wordings to prompt the desired response and refrain from confusing drivers.

Research Objectives

The main objective of this research was to decide what sign is best for achieving the result of pedestrians taking the proper path, without confusing drivers. Smaller objectives included:

- Understanding how pedestrians perceive pedestrian signs
- Understanding what impact pedestrian signs have on drivers
- Determining if shape and color have an impact on users
- Determining if wording has an impact on users
- Determining if pictures are best for conveying various messages
- Determining if pedestrians are more likely to obey a certain type of sign

RESEARCH TASKS

The following is a list and explanation of the tasks performed during this research.

Literature Review

While the literature review for this research was important, it was not very extensive. Not much research exists on the subject of pedestrian signs in work zones, and thus there was not much literature available. What the researcher did review however was the Texas Manual on Uniform Traffic Control Devices (TMUTCD), the original project proposal, and the surveys used for data collection.

The TMUTCD contains information on the current regulations regarding traffic signs. In addition, it provides a brief description of how to display temporary warning signs concerning pedestrians. One of the main reasons for Project 5237 is this briefness in the TMUTCD on the subject. Knowledge of the overall project is vital to understanding where and how this research fits into the bigger picture. The project proposal provided this.

Data Collection

Previously this spring, members of the TTI research team conducted surveys in Houston, Dallas, Waco, and San Antonio. This summer, members of the TTI team administered a survey in Paris, Texas; simultaneously, the researcher helped administer the last survey in Laredo, Texas. The broad geographical range and varying degrees of urbanized development of these locations are why members of the TTI team chose these six in particular.

Surveys

One hundred and twenty random volunteers at each location completed a survey, with the exception of Paris and Laredo-due to low volunteer turnout. The total number of participants was 668. Half of the participants pretended they were pedestrians, and the other half of the participants pretended they were drivers. Portraying both pedestrian and motorist roles is critical to the value of the surveyed data since part of the goal is to refrain from distracting drivers. Having the role-play of pedestrians and motorists in the survey ensures that each perspective is collected. Administrators of the surveys transcribed all results on paper. A copy of both the driver and pedestrian surveys is in the appendices.

The surveys consisted of three parts. In part one, participants viewed a picture on the laptop, and then pressed a button to hide the picture. The pictures were of pedestrian traffic situations, with a traffic sign visible. After the participants viewed the picture, they answered questions about the clarity of the sign, and told what they might do in that situation. Participants also answered questions about what they would do to improve that particular sign.

In part two, the participants had to compare two different signs. The signs were similar, but differed in perhaps color or shape. Participants answered questions about sign preference and whether the signs had different meanings.

Lastly, in part three, participants picked which example of wording of various phrases was the most desirable. Part three only applies to pedestrians, and thus it was part of the pedestrian survey, not the driver perspective version.

Signs

The eight signs included in this study are in the figure below. The creators of the survey picked these particular eight signs so that this study would cover a broad range of ideas. They are a mixture of colors, shapes, wordings, and symbols, in an attempt to determine which is best to use.

The intended meaning of the signs are all the same; the sidewalk farther ahead is closed, and pedestrians are to cross the street at the location of the sign, because there is not another crosswalk available before the closed sidewalk.

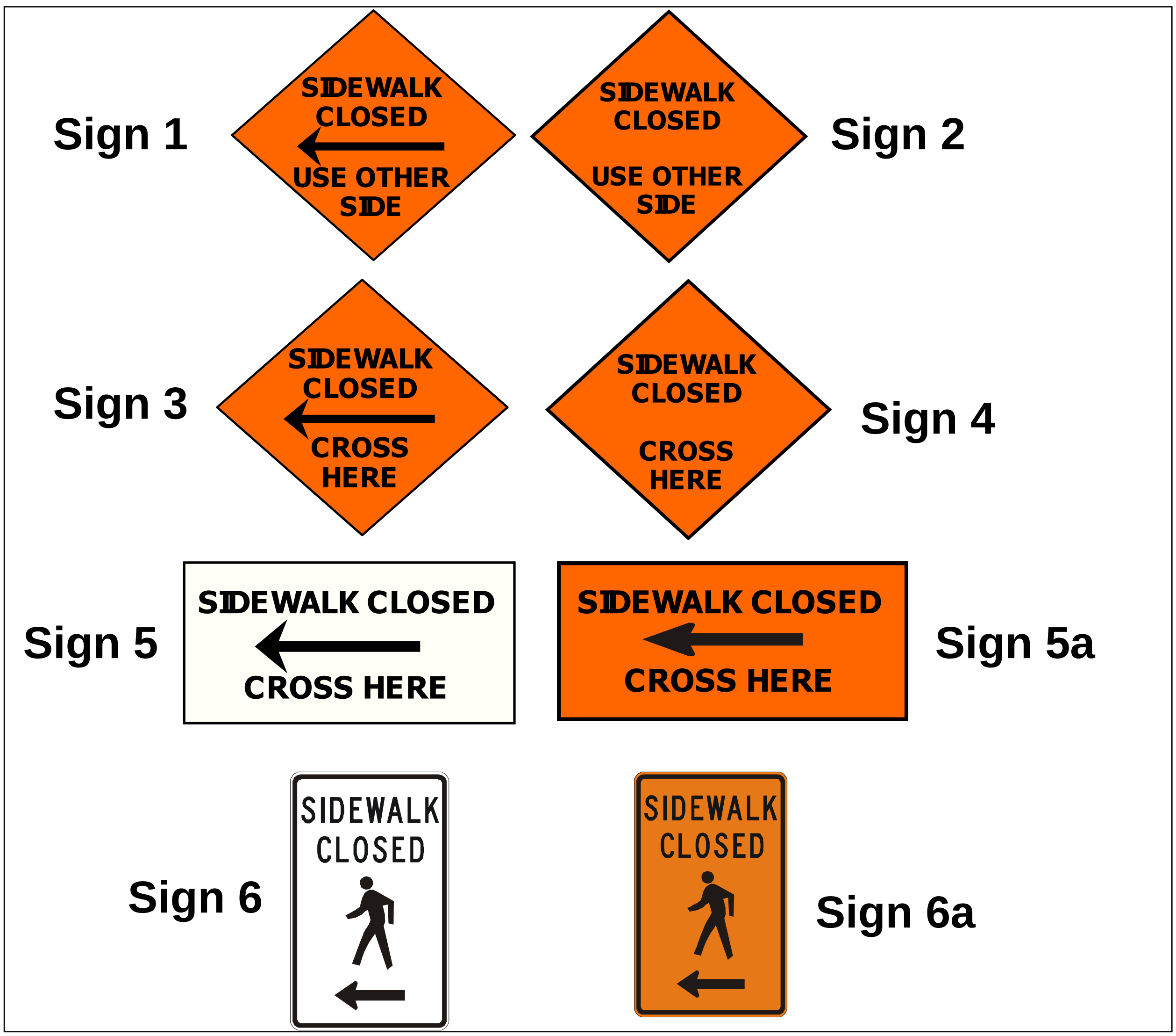

Figure 3. Studied Signs

Demographics

Administrators of the survey were at the Department of Public Safety drivers licensing offices, in each respective town. They gave the survey to volunteers. There was no initial quota of certain demographics, however, administrators attempted to create an even distribution. The results turned out fairly even across age, gender, and education level.

Part three of the pedestrian survey asked two questions regarding how often people walk to their destinations. The questions were, how often do you walk on a sidewalk near a road, and what percent of this time is on or near a work zone? The results are in the graphs below.

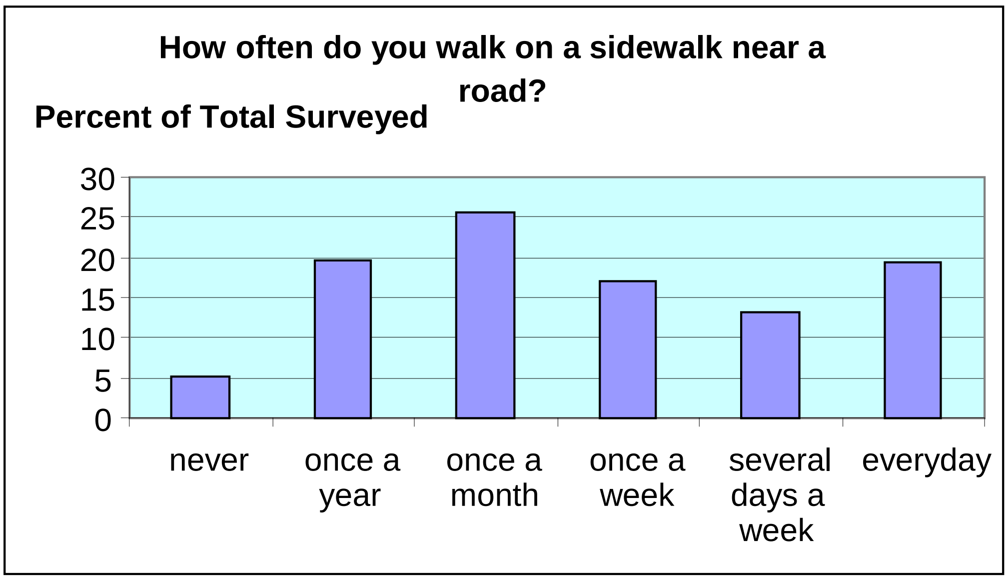

Figure 4. Walking Question Graph I

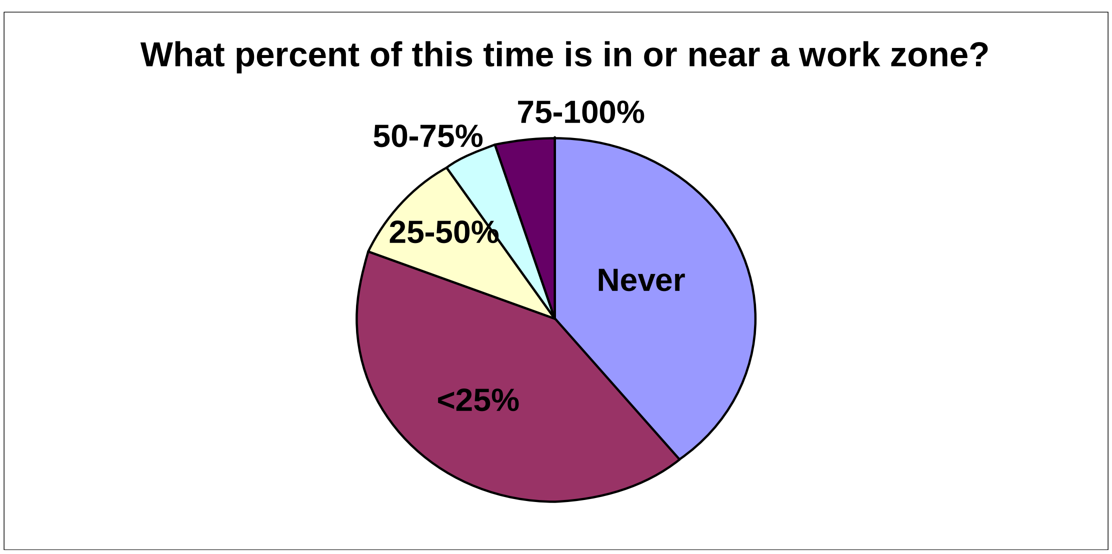

Figure 5. Walking Question Graph II

From these two questions, it is obvious many of the participants had little real world experience with the type of situation in question. This type of user is the "worst case scenario" to design for, but they do exist, so the researcher must keep them in mind.

Data Entry

With all of the surveys put together, there are 668 people's input and insight into the meaning of pedestrian traffic signs. Using Excel, the researcher entered this data into spreadsheets. There are six different kinds of surveys, however. Surveys B1, B2, B3, and B4 are different versions of the pedestrian survey. The driver perspective surveys are numbered 1-D through 6-D. All odd numbered surveys are the same though, and all even numbered surveys are the same, so ultimately this means there are two versions of the driver survey, odd and even.

Six different spreadsheets hold the six different sets of data, from the six versions of the survey. The project spreadsheets sort by any demographic field that the research calls for. It also sorts by specific answers to questions, making it easy to view who answered a specific question a certain way. Thus, answers to questions can be viewed by any category desired, making it easier to spot trends and calculate statistics.

Data Evaluation/Statistical Analysis

After entering the data, the researcher went through each question and divided the answers into different groups. Each question then had its own set of standard answers, and the researcher was able to determine the percentage of participants who said each one.

After this, the researcher conducted statistical analysis on the differences in the data. The statistical analysis involved two types of tests, a confidence interval test, and a Z-test.

A general rule of thumb for signs is if 85% of users understand them, then they are acceptable for use. Traffic engineers often use this number for design purposes. If a sign had results that were less than 85%, the confidence interval test determined if that percentage was statistically different from 85%. The following formula established the boundaries of the confidence interval (*6*):

$$p - 1.96 * \sqrt{\frac{p*(1-p)}{n}} < p_0 < p + 1.96 * \sqrt{\frac{p*(1-p)}{n}}$$

where: p_0 = true percent correct response considering error,
p = sample percent correct response, and
n = total number of respondents.

If 0.85 fell within the boundaries, then the tested percentage was not statistically different from 85%, using a level of significance of α equals 0.05. This means that the researcher is asserting that the result of the test is correct 95% of the time.

The second test was the Bernoulli Model, also called a Z-test. It was for two different data sets, to see if they were statistically different from each other. The formula used was as follows (6):

$$Z = \frac{f_1/n_1 - f_2/n_2}{\sqrt{\frac{f_1 + f_2}{n_1 + n_2}\left(1 - \frac{f_1 + f_2}{n_1 + n_2}\right)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where: f_1 = number of correct responses from alternative 1,
f_2 = number of correct responses from alternative 2,
n_1 = total number of respondents in alternative 1, and
n_2 = total number of respondents in alternative 2.

The null hypothesis is that the percentage of alternative 1 is equal to the percentage of alternative 2. The alternate hypothesis is that they are not equal. Rejection of the null hypothesis occurs if the test statistic, Z, is greater than 1.96. This value again came from using a level of significance of α equal to 0.05. Rejecting of the null hypothesis indicates that there is a statistically significant difference between the two percentages.

Essentially, if the confidence interval test shows that a percentage that is below 85 percent is not statistically different from 85 percent, then the researchers cannot automatically rule that sign out as a viable sign due to the 85 percent rule. If the Z-test shows that a data point is significantly different from the best results in its category, then this means that that particular data point should not be considered to be at the same level of success as the best in that category.

RESULTS

Below are the results of the surveys, divided into sections of comprehension, action, and sign improvements. Following that are sections evaluating design variations.

Comprehension

Pedestrians must be able to quickly look at a sign and understand it, in order for traffic to flow smoothly and efficiently. Motorists must be able to look at the same sign and understand first that it is for pedestrians, and second, they must understand what the pedestrians will be doing. The next sections discuss sign comprehension of both pedestrians and drivers.

Pedestrian Comprehension

One of the main purposes of this research is to find a sign that pedestrians understand. Participants of the pedestrian survey viewed a sign and then indicated what that sign told them to do. The researcher then divided the answers into categories, and decided if the participants actually understood the intended meaning or not. The results are in the graph below.

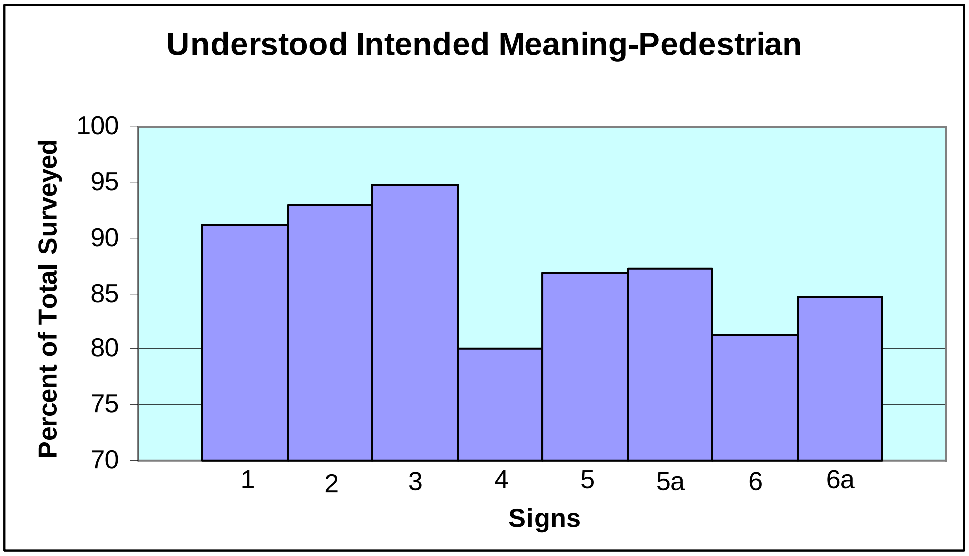

Figure 6. Pedestrian Comprehension Graph

The researcher divided those who did not understand the intended meaning into categories based on how they misunderstood the sign. The categories are participants who thought the sign meant a closed crosswalk, participants who did not know which side the closed sidewalk was on, participants who were unsure of what route to take, and participants who were generally confused. "Generally confused" entails an array of responses by participants that were all incorrect, but did not fit into the first three categories. Participants did not give these responses enough to warrant them their own individual categories, so they are all grouped into "Generally confused."

Signs 1, 2, and 3 ("Use Other Side" with arrow, "Use Other Side" without arrow, and "Cross Here" with arrow) had the best results. Sign 4 had the lowest comprehension level, because participants did not understand the "Cross Here" without arrow combination. Sign 5 and 5a's results are just above 85 percent. These likely have slightly lower results than signs 1, 2, and 3 because signs 5 and 5a were first on the survey. Participants understood the process better as they answered more and more questions, so they may have been unsure of themselves on the first question. Signs 6 and 6a confused participants with the lack of wording. The arrow without words made them think the opposite sidewalk was the closed sidewalk.

For sign 1, over 90 percent of those surveyed with the pedestrian portion of the survey understood the intended meaning. The sign with the best results had a comprehension level of almost 95 percent (sign 3), but according to the Z-test, this difference is not statistically significant. The majority of those confused by this sign, 5 percent, were unsure of what route to take.

Sign 2 produced almost a 93 percent rate of understanding of the intended meaning. This is the second highest level of comprehension in this study. General confusion was the biggest problem for those who did not understand the sign, at 4.7 percent.

Sign 3 has the best understood meaning, at almost 95 percent. However, 2.6 percent of participants did not know which side the closed sidewalk was on, and 2.6 percent said the sign confused them.

Only 80 percent of participants understood the intended meaning of sign 4; however, according to the confidence interval test, this is not significantly different from 85 percent. It was statistically different from the best in this category though. The majority of those who did not understand it, 10 percent, were generally confused. Five percent of participants were unsure of what route to take, and another 5 percent did not know which side the closed sidewalk was on.

Sign 5 has an understood meaning by pedestrians of just under 87 percent. This is not significantly different from the best in this category. People not knowing what was closed was the biggest problem, with nearly 6 percent thinking it meant a closed crosswalk, and another 5.4 percent thinking it was the opposite sidewalk.

Sign 5a has a pedestrian comprehension level of 87.3 percent, and there is no significant difference between this number and the best comprehension level in this study. Five and a half percent of participants misunderstood where the closed sidewalk was.

Sign 6 has an understood meaning that is lower than yet not statistically different from 85 percent, but it is significantly lower than the best sign in this category. Not knowing which side the closed sidewalk is on, at 9.4 percent, and general confusion, at 3.2 percent, were the main problems.

Sign 6a is below but not significantly below 85 percent. It is significantly lower than the best though. An overwhelming majority of those who did not understand the sign misunderstood which side the closed sidewalk was on.

All of these signs have over an 85 percent level of comprehension, or at least they are significantly close to it, meaning that the researcher cannot automatically rule any of them out as viable signs, based on this question. However, signs 4, 6, and 6a are significantly different from sign 3, the best, and so from this question alone, they are not as good. This means that while they are acceptable, the other signs are better. The biggest hindrance to understanding all of these signs was participants not sure of what side the closed sidewalk was on.

Driver Comprehension

Motorist confusion is the last thing that needs to happen because of these signs. Driver comprehension includes both understanding that the sign was for pedestrians, and understanding what the pedestrians were to do. However, the more important data is whether the drivers thought the sign was for them. The researcher ran a Z-test with each sign's driver and pedestrian comprehension levels to see if that sign is better for drivers or pedestrians in particular.

Below is a graph of the sign comprehension level of those who took the driving version of the survey. It displays the results of how many participants understood that the sign was not for them, and that it was for pedestrians. Signs 2, 3, and 4 were not included in the driver survey, so there is no data on driver comprehension for them. The pedestrian and driver surveys tested different elements, and thus did not use all of the same signs.

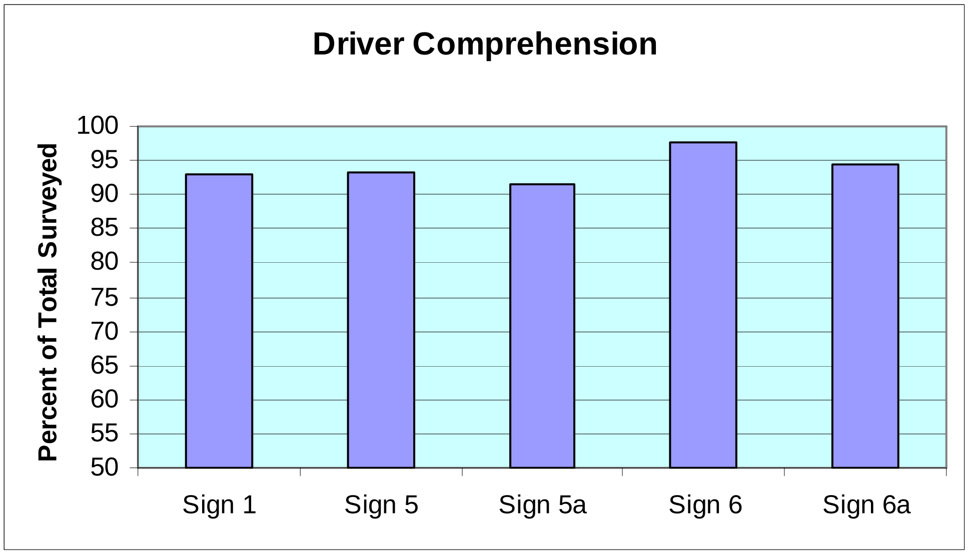

Figure 7. Driver Comprehension Graph

All signs have results over 90 percent, which is well above the acceptable limit of 85 percent. This means that driver confusion is not a problem with any of these signs. However, note that signs 6 and 6a do have the best results, at 97.5 percent and 94.6 percent respectively. Both of these signs have the pedestrian symbol on them, and it is likely that this signals to drivers that the sign definitely is not for them.

Action

The next major question is whether a pedestrian would take the correct action or not after reading the sign. If they did not understand the sign, chances are they would not take the correct action, but it is also possible that they would understand the sign, and then ignore it.

Correct Action

After participants viewed the sign and answered what it meant, they told what action they would take. The researcher reviewed all the answers and decided if each individual participant would take the correct action or not. He then divided the incorrect actions into groups. These groups are participant would walk straight through the closed sidewalk, the participant would walk around the closed sidewalk (in the grass or the street), the participant would find another route (not the correct one or the two already mentioned), or they were confused about the whole situation. A graph of the results is below.

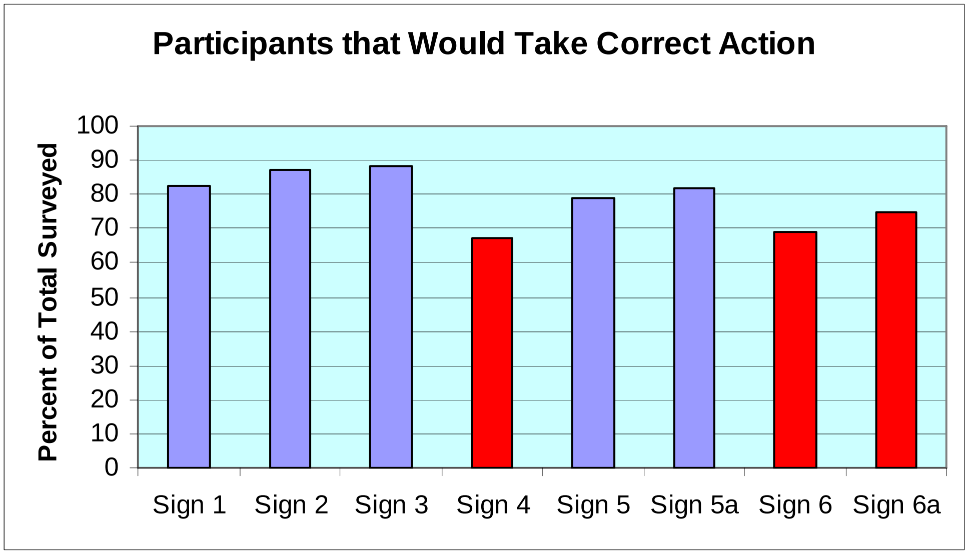

Figure 8. Correct Action Graph

The darker colored bars denote that those particular signs are significantly lower than 85 percent, according to the confidence interval test. This means that well below 85% of participants would take the correct action, which is not acceptable.

For sign 1, less than 85 percent of pedestrians surveyed would take the correct action, but this is not significantly different from 85 percent, according to the confidence interval test. The majority of those who would take the incorrect action, 6.25 percent, would walk straight. The ones who would take the correct action would do so, mostly either because the sign told them to do so, or because of the closed sidewalk. This is true of most of the signs

Sign 2 has the second best results as far as who would take the correct action, at 87 percent. Almost 5.9 percent would find another route, the most of those who would take an incorrect route. Of those who would take the correct action, the main reasons were the closed sidewalk and because the sign told them to do so.

With 88.3 percent, sign 3 has the highest percentage of those that would take the correct action. Most of those who would take the correct action would do so because the sign said. The majority of those that would not, 6.5 percent, would find another route.

Only 67.5 percent would take the correct action after reading sign 4, which is significantly lower than 85 percent. The majority of those that would not, 15 percent, would walk straight. In addition, 7.5 percent said they did not know what they would do.

Seventy-nine percent of participants would take the correct action because of sign 5, which was below 85 percent, but not significantly. There is also not a significant difference between this number and the best results in this category. Most who would not take the correct action would either find another route, 5.6 percent, or walk straight, 9.6 percent. The main reasons for this were ignoring of the sign and thinking the closed sidewalk was on the opposite side of the street.

Most people that would take the correction action would do so because the sign told them to do so or because of the closed sidewalk.

Sign 5a has less than an 85 percent rate of people that would take the correct action, but not significantly less, nor is it significantly less than the best in this category. Other choices people chose besides the correct action were walking straight at 4.8 percent, or finding another route, 9.1 percent. Those that would take the correct action would do so because the sign told them to do so.

Sign 6 has the second lowest percent of those who would take the correct action at 68.75 percent, which is also significantly lower than 85 percent. Most would walk straight through the construction, mainly because they thought the closed sidewalk is on the opposite side. Those who would take the correct action would do so because of the closed sidewalk.

Significantly less than 85 percent of participants would take the correct action because of sign 6a. Most of these, 10.9 percent, would walk straight. Others, 9.6 percent, would take another route. Those who would take the correct action would do so mostly because the sign told them to do so.

Understood Meaning but Ignored Sign

The researcher calculated the percent of participants who would ignore a sign by subtracting the percent that would take the correct action from the percent that understood the sign. This gave the percent of those who understood the sign, but did not take the correct action, and in effect, ignored the sign. This was possible because a negligible amount of participants misunderstood the signs but took the correct action. The results are in the graph below.

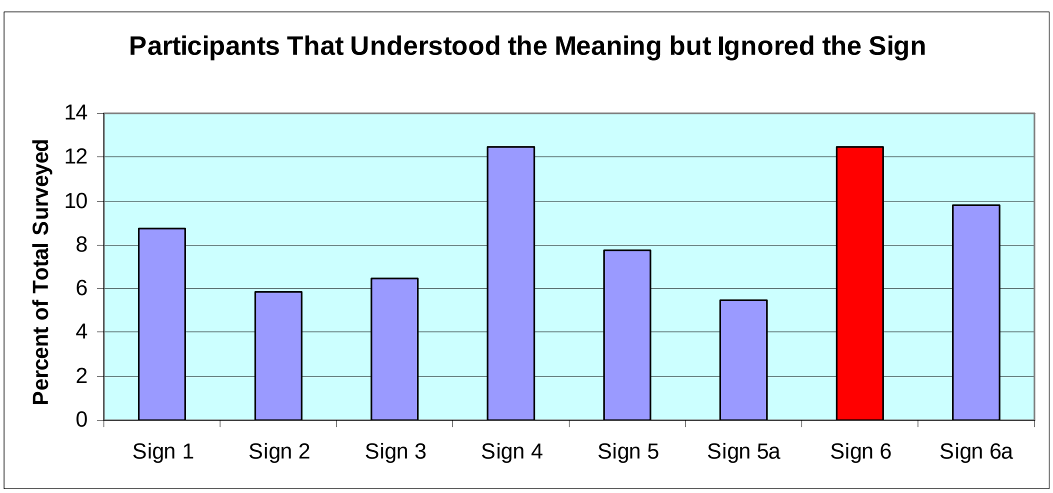

Figure 9. Ignoring of Sign Graph

The darker bar indicates that that sign is significantly different from the best sign, sign 5a. Almost 9 percent of those surveyed would ignore sign 1. This is right in the middle of all the signs. Sign 2 has the second lowest number out of all the signs, at 5.88 percent. Almost 6.5 percent would ignore sign 3. Twelve and a half percent would ignore sign 4. Sign 4 has the same percentage that sign 6 does, but the difference between it and sign 5a is not significant because sign 4 has about one quarter as many total participants. Seven and eight tenths percent would ignore sign 5, 5.45 percent would ignore sign 5a, 12.5 percent would ignore sign 6 (which again is the only one that is significantly different from sign 5a), and 9.81 percent would ignore sign 6a.

It is likely that these results correlate to the level of comprehension of each of these signs. A person may have identified the correct meaning of a sign by guessing, and thus would have not been sure about it. When deciding what action to take, they may have changed their mind, or they may have been so confused they decided to ignore the sign totally and just keep walking straight.

Note that signs 5 and 5a are the same except sign 5a is orange. Many less would ignore sign 5a than sign 5. The same is true of signs 6 and 6a.

Sign Improvements

Participants of the pedestrian survey had a chance to tell what improvements they would make to each sign. Note that both those who understood the meaning and those who did not suggested improvements. Administrators of the surveys did not correct those who misunderstood the signs. In addition, many participants suggested changing the sign placement as an improvement. This type of change is not what this research is studying, but these results are included in the report so that readers can fully understand what the participants said.

The least amount of people would improve sign 1. It had the least results in this category by a significant amount. Of those who want to improve it, most said the sign needs more information, such as why the sidewalk was closed.

Forty-three and a half percent of the participants said that they would improve sign 2. This number is statistically different from both the highest and lowest percentages on this question, putting it right in the middle. Adding an arrow was the most popular improvement, but changing the look of the sign, as far as shape and size, as well as sign placement were also popular.

Almost 38 percent of those surveyed would improve sign 3. Most wanted the sign placement to change, but some wanted the sign to contain more information, like why the sidewalk is closed.

Sign 4 had the highest percentage of those who would improve it, which relates to the fact that it was the least understood. Fifty-one percent of participants said that they would improve this sign. Adding an arrow was by far the most popular improvement.

Thirty-three percent of pedestrians would improve sign 5, which is the second lowest of all the signs; however, there is a significant difference between this sign and the first. Adding more information was the most popular suggestion.

Forty-four percent of the pedestrians surveyed would improve sign 5a, which again, is in the middle of these numbers. Changing the sign placement was the most suggested improvement;

however, this type of change is not what this research is covering. The most popular improvement after this was changing the look of the sign (shape, size, color, etc.), and adding why the sidewalk is closed or where you can walk.

Forty-five percent of those surveyed would improve sign 6. There were many suggestions, but the majority says to add more information, followed closely by adding where you can walk. This suggestion obviously comes from those who did not understand the sign, because it does tell where you can walk. Signs 6 and 6a had the highest percentage of participants say to add where you can walk, presumably because most who said this were confused as to which sidewalk is closed, which was a problem for these signs.

Forty-one percent of people would improve sign 6a. Changing the wording was the most popular way to do this (ex. adding “Use Other Side”). Again, with this sign though, many said to add where you can walk.

Analysis of Design Variations

Part of this study is the evaluation of various wordings and ways to convey messages on signs. These include “Use Other Side” versus “Cross Here,” arrow versus no arrow, words versus symbol, wordings for distance, and new route wording. During this portion of the study, the researcher studied pairs of signs that differed only in the subject matter.

Use Other Side vs. Cross Here

Sign 1 and sign 3 differ only in the phrases “Use Other Side,” and “Cross Here.” The same is true of signs 2 and 4. In part two, signs 2 and 4 were evaluated, and in part three, one question was asked regarding these two phrases.

In comparing signs 1 and 3, three significant differences stand out. First, significantly more people are unsure of what route to take with sign 1. This could be because “Use Other Side” does not specifically state where to cross. To some it only tells them that they eventually need to get to the other side. The second difference that stands out is that significantly less people would improve sign 1. All others were in the 33-51 percent range, but sign 1 had only 21 percent that would improve it. Lastly, sign placement becomes more of an issue with a “Cross Here” sign.

Signs 2 and 4 have huge differences in results. Sign 4 is a difficult sign to understand because the phrase “Cross Here” needs something to specify where “Here” is. It more understandable, and is more preferred with an arrow. Sign 4 has the lowest understood meaning, the lowest percent of those that would take the correct action, the highest percent of those who would ignore the sign, and the highest percent of those who would improve the sign. Sign 2 however is not a bad sign at all. Apparently, pedestrians do not find “Use Other Side” confusing, even without an arrow.

Part two also evaluates signs 2 and 4. The participants essentially split down the middle as far as who prefers which sign, with 50.4 percent preferring sign 2 and 48.6 percent preferring sign 4. However, considering the poor results that sign 4 received in part one, it is possible that many who said they prefer sign 4 actually misunderstand it and do not realize it. In addition to this, nearly 3 percent of those who picked sign 2 said they did so because it “gives more options,” meaning they can cross the street whenever they like, which is of course incorrect. Therefore, subtracting this number from the original percentage decreases the gap between sign 2 and sign 4. This would actually make sign 4 the preferred sign, but again, the difference is so close that participants still would not have an outright favorite.

Part three asks participants which of the following phrases requires them to select a different path (they can pick more than one): “Detour,” “Cross Here,” “Use Other Side,” “Alternate Route,” and “Alternate Path.” Overall, 62 percent of the people picked use other side, while only 43 percent picked cross here. This difference is statistically significant. Figure displays these results.

This data is not conclusive enough to rule out either phrase. What it can rule out is “Cross Here” without an arrow. However, cross here with an arrow, and use other side both with and without an arrow are so close in results that it is difficult to say with any certainty which one is the best.

Arrow vs. No Arrow

The general problem with arrows on these types of signs is that users sometimes think the arrow is pointing to the closed sidewalk. Signs 1 and 2 in parts one and two, as well as signs 3 and 4 in part one only, can be used to evaluate the effectiveness of arrows in pedestrian signs.

When compared to sign 1, almost 5 percent more people would take the correct action as a result of sign 2. This is not a significant difference though. Sign 1’s main problem was that people did not know what route to take, while sign 2’s problem was that it confused people.

Sign 1 had significantly less people say they would improve it. Most who wanted sign 2 improved would add an arrow. The same two signs were evaluated in part two, and 95 percent of participants prefer sign 1 to sign 2. So, whether they understand it better or not, pedestrians definitely feel more comfortable with the arrow on this particular sign.

Signs 3 and 4 demonstrated both the best and the worst in pedestrian comprehension, with 3 being the best and 4 being the worst. “Cross Here” is not good without an arrow. Significantly more people were confused by sign 4, as well as were unsure on what route to take.

All of this evidence points to the fact that arrows are generally acceptable, but the wording and placement must not confuse pedestrians. Overall, people prefer arrows. Sign designers should make it obvious what the arrow is pointing at though, so users are not confused about what is actually closed.

Words vs. Symbol

Signs 6 and 6a both display the pedestrian symbol. Signs 5 and 5a are the closest non-symbol match to these signs. The only difference besides not having a symbol is they have the words

"Cross Here." Part two of the survey evaluates signs 5 and 6, and the researcher will compare these two signs as well as signs 5a and 6a.

In part two, 72 percent of pedestrians and 62 percent of drivers say that signs 5 and 6 do not have different meanings. Exactly the opposite is true of which they prefer. 62 percent of pedestrians and 72 percent of drivers prefer sign 6 to sign 5.

Neither sign 6 nor sign 6a have a very good pedestrian comprehension level. Both are below 85 percent, yet not significantly; however, they both are significantly lower than the best comprehension level (sign 3). In addition, both of these signs are significantly lower than 85 percent on who would take the correct action, and both have a higher percentage of those who think the closed sidewalk is on the opposite side than 5 and 5a.

Signs 6 and 6a have the best driver comprehension. While all of the signs' driver comprehensions were good, the ones with the pedestrian symbol were the best.

The pedestrian symbol is good for drivers. When most drivers see it, they think either that the sign is for pedestrians, or they think it means to be cautious of pedestrians. Both are acceptable outcomes. The wording, or more accurately the lack of wording is what is confusing pedestrians though, not the symbol itself. If worded differently, signs 6 and 6a would be better, but the whole point of the symbol is to eliminate wording. This elimination of wording is ineffective, because so many are confused as to what it means.

Distance Wording

In part three, one question asked which phrasing of distance is best. It gave four choices, "200 ft Ahead," "1 Block Ahead," "Past McDonalds," and "After Green St." The question asked if all four distances were equal, which one would be best to put in the place of the question mark in Figure. The results are in the graph below.

Figure 10. Distance Question Sign

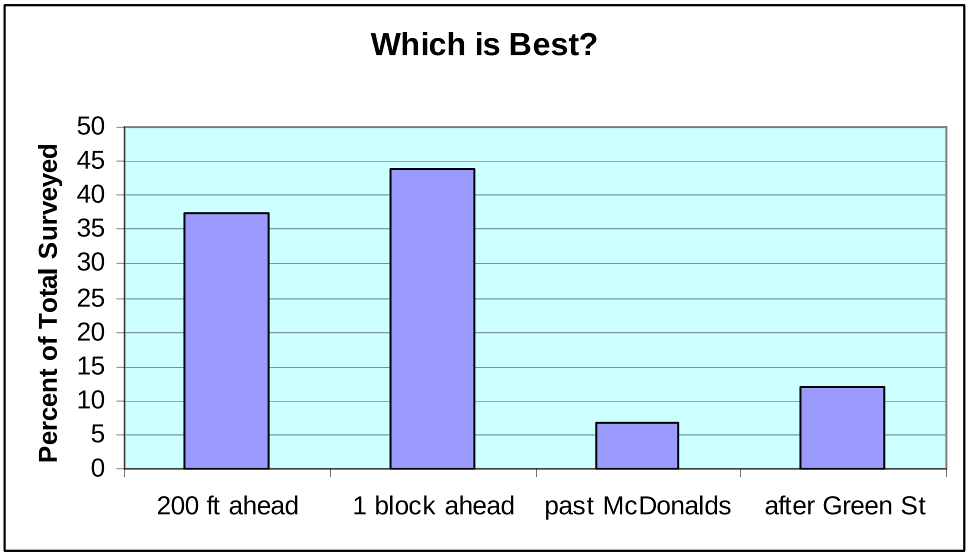

Figure 11. Distance Question Graph

Seven percent said "Past McDonalds" and 12 percent said "After Green St." Researchers noted while administering the survey that most participants who took the survey, assumed they were not familiar with the area, and thus these two choices did not make sense to them. The other two had better results.

The phrase "200 ft Ahead" received 37.5 percent approval, while 43.75 percent preferred "1 Block Ahead." This difference is not statistically significant. Most who said one of these choices said they liked that one because it was easier to figure out how far it is.

The only conclusion made from this data is that pedestrians prefer actual distances to landmarks. Researchers believe that the environment would have a significant impact on which distance terminology is more appropriate. The phrase "1 Block Ahead" would be more appropriate in an urban environment, while "200 ft Ahead" would be more suited to a rural area, where blocks are of unequal distances and harder to predict.

New Route Wording

Part three asked two questions about various phrasings of new routes. The section "Use Other Side vs. Cross Here" already discussed the first question. It asked users which phrases required them to select a different path. The choices were "Detour," "Cross Here," "Alternate Route," "Use Other Side," and "Alternate Path." The results are below.

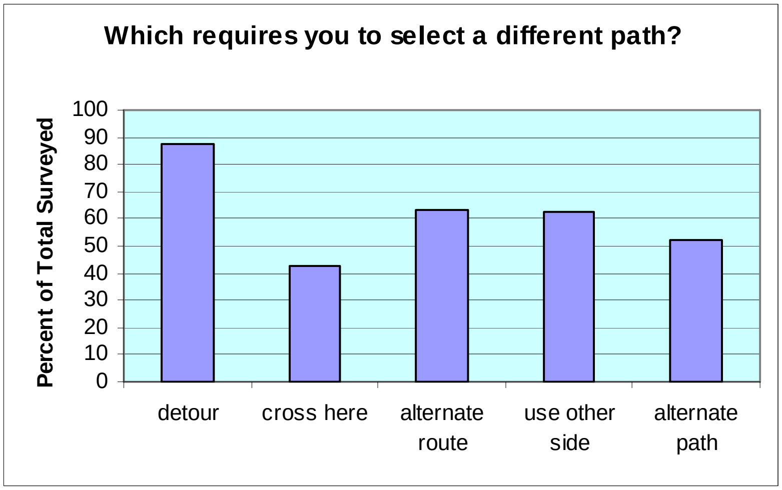

Figure 12. New Path Graph

"Detour" was the alternative most often selected to mean that a person must follow a different route. In addition to this, when forced to pick one alternative that is the best to use (in the first question participants could pick more than one answer) if a sidewalk is closed and users need to take a new route, 42 percent of participants said "Detour." Thirty-one percent said "Alternate Path," and 22 percent said "Alternate Route."

The creators of this survey hypothesized that pedestrians might not like the term "Detour," since it is generally on road signs. However, according to this study, that is not the case. Pedestrians still prefer the term "Detour." This study did not cover the possible affects on drivers of using this term for pedestrian signs.

Color

Pedestrian signs currently in use are white. The signs dealt with in this study are temporary though, and most temporary signs are orange. There are two sets of signs in this study that differ only in color, signs 5 and 5a, and signs 6 and 6a. In addition, part two of the survey has a section that evaluates color.

While comparing signs 5 and 5a, most of the data sets are similar. A few stand out though. The first is the number of pedestrians that would walk straight. This is essentially a blatant disregard of the sign, and almost twice as many would do it with sign 5 (white). Next, more participants understood but ignored sign 5. Sign 5a actually had the smallest percentage of those that would ignore it. Sign 5 had the least number of participants that said that the sign affected them by giving driving instructions.

Some of the same things are true of signs 6 and 6a. More would walk straight with sign 6 (white), and more would ignore sign 6. This data points to the fact that people are more likely to disregard a white sign.

The last data set to note out of these four signs is the fact that when the survey asked participants who would take the correct action why they would do so, the majority said in reference to the orange signs that the sign told them to." In reference to the white signs, the majority said, "Because the sidewalk is closed." Not only was this true of signs 5a and 6a, it was true of all of the orange signs, with the exception of sign 4. Most participants did not understand "Cross Here" without an arrow, and this skewed sign 4's results.

In part two of the pedestrian survey, 60 percent of participants say there is no difference between signs 5 and 5a. Forty-seven percent of drivers say there is no difference between the two. Both pedestrians and drivers that do say there is a difference mostly say that the orange sign means construction, at 11.6 percent and 16.8 percent respectively. After that, they say the orange sign means caution, at 10.4 percent and 10.2 percent respectively. An alarming figure is that only 1 percent of the combined totals of drivers and pedestrians say that the difference is the white sign is regulatory, and as such is law. Only 1.7 percent of the combined total said that the orange denotes a temporary sign.

Part two of the pedestrian survey asked participants which color of sign meant that you would be breaking the law by disobeying it. The correct answer of course is white, since regulatory signs are typically white. However, the majority of the population believes orange signs to be law. The results are below.

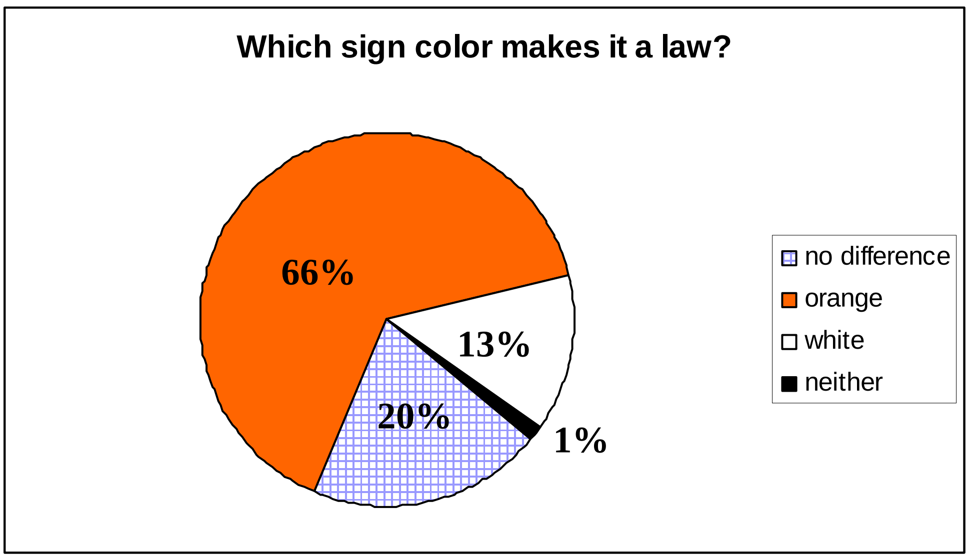

Figure 13. Law Graph

There are two main reasons people think this. The first is all the emphasis put on construction zones. Reduced speeds in work zones, fines doubling with workers present, and the give us a break campaign all contribute to people's awareness of getting tickets in construction zones. Since temporary signs are orange and are present in work zones, people are correlating getting tickets with orange signs. The researcher deducted the second reason by actually administering the survey himself, and listening to the reasoning of the participants. They say that orange stands out more, gets their attention more, thus it must be more important, and the more important sign must be a law.

Summing all of this up, most people pay more attention to orange signs. They catch people's attention more, and people are more likely to obey an orange sign. This has a dual effect though. While pedestrians are more likely not to ignore an orange sign, drivers would be more likely to think an orange sign is for them.

Shape

The signs in this study were two basic shapes, diamond and rectangular. Diamond signs are generally warning signs for drivers, and creators of the survey hypothesized that drivers might think the sign is for them, based on its shape. This is not the case however.

In part two, almost 90 percent of pedestrians say that sign 3 (diamond) and sign 5a (rectangular) has no difference. Almost 86 percent of drivers say there is no difference.

In part one, sign 5a's numbers overall were slightly worse than sign 3, but sign 5a (and sign 5) was the first sign on the survey. This may have slightly affected the results. In any case, the differences are not substantial enough to suggest a difference in comprehension of these two signs. Therefore, the shape of a sign does not affect user comprehension.

CONCLUSIONS

The researcher made several conclusions, and a final recommendation, based on the results of this study.

The following is a summary of conclusions made from this study:

- Drivers and pedestrians think orange is more important, and pedestrians are more likely to obey an orange sign
- The pedestrian symbol is best for keeping driver confusion at a minimum, however driver confusion is not a problem with these particular signs
- "Cross Here" is confusing without an arrow
- "Use Other Side" is good with or without an arrow
- Shape makes no difference to drivers or pedestrians
- The term detour is preferred by pedestrians

Signs 1, 2, 3, 5, and 5a, pictured below in Figure 14, all were satisfactory signs, and would be fit to use. In comparison to the other signs in all the questions, sign 1 was significantly different from the best results, according to the Z-test, in only one case. This is something that only signs 1 and 3 can claim. In fact, out of seventeen categories, sign 3 had six of the best results. This is the most of any sign. Any of these signs would be good to use though.

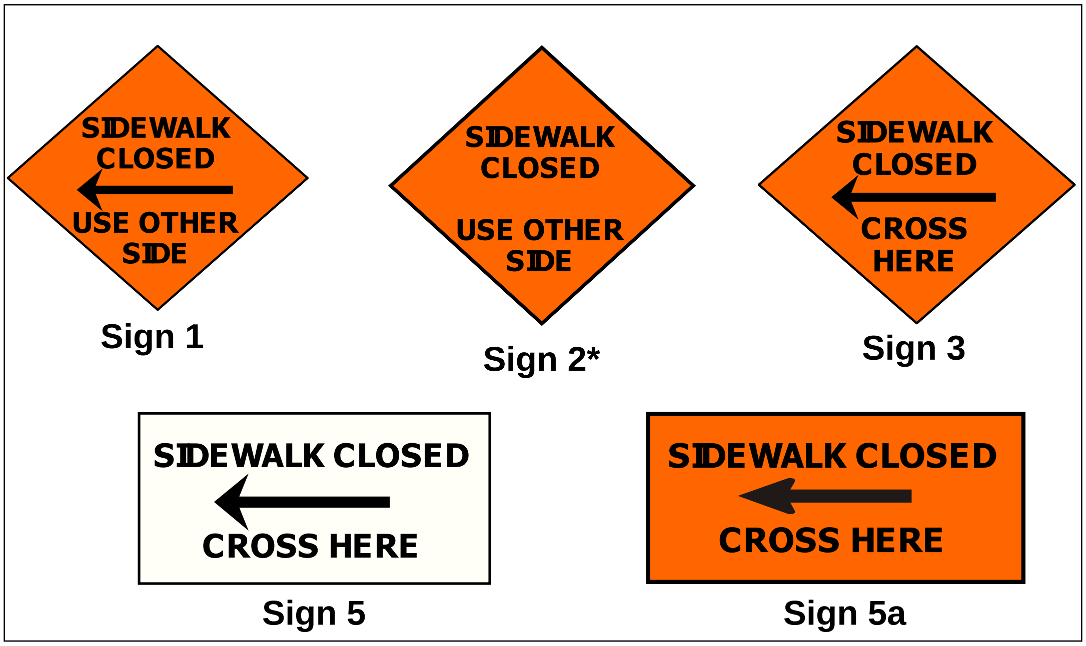

Figure 14. Acceptable Signs

*Note that both signs 1 and 2 have acceptable levels of comprehension, but 95 percent of those surveyed prefer sign 1 over sign 2.

The researcher has designed a sign that utilizes the best of the design variations analyzed in this research. The picture of the new sign is below. The researcher did not take into consideration any outside variables such as cost, sign size, letter size, or feasibility of actually using this sign that the creator of a sign would normally have to consider. What he attempted to do was create a sign that would be ideal for pedestrians to understand and obey, and that drivers would not find confusing. The researcher did not consider any other factors.

Figure 15. Recommended Sign

Note that in rural areas, where blocks are not as predictable, a distance in feet may substitute "1 Block Ahead." However, most situations requiring such a sign would be in an urban environment.

The researcher has attempted to maximize the results of this sign through the design. This sign is more specific as to where the closed sidewalk is located, and uses the preferred phrasing of distance. The pedestrian symbol should signal to drivers that it is not giving driving instructions, with the exception of use caution for pedestrians. "Cross Here" is more specific, and tells users exactly what to do, where as "Use Other Side" may seem open ended to some. The space between the two sets of text is intentional. It is to denote that the sidewalk ahead is closed, and pedestrians are to cross the street to avoid the closed sidewalk. In addition, the first line is only one line intentionally (as opposed to have "Sidewalk Closed" and "1 Block Ahead" on two separate lines). This is to avoid the confusion of people thinking they should cross one block ahead.

Again, signs 1, 2, 3, 5, and 5a are all acceptable signs to use, but the researcher has attempted to maximize all of the positive design features included in this research.

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APPENDIX A

Driver Survey

Location: __________ **Participant # ____**
Date: _____________ **Researcher: ____**

SURVEY 1-D

Demographics:
Gender: ❒ male ❒ female

Age: ❒ 16-25 ❒ 26-39 ❒ 40-54 ❒ 55-70 ❒ 71+

Education: ❒ some high school ❒ high school graduate
❒ some college ❒ college graduate

Before we begin, for all of the questions that I will ask, I want you to assume that you are DRIVING when you see the signs.

When you press the space bar your first sign will appear on the laptop monitor. You will have control over how long you view the message. So, the instant you understand the situation and know what you would do, you will need to press the space bar again to turn the image off. Then you will be asked questions about the information displayed on the screen. Do you have any questions?

Part 1: Comprehension
Sign 5: Rectangular White Cross Here
1. What does this sign mean to you as a driver? ____

2. Does this information affect you as a driver? ☐ Yes ☐ No
If yes, how?

If no, who do you think it affects? ☐ Pedestrians ☐ Other: ______________________________
How are they affected? ____

Press the space bar to see the next set of signs.

Sign 1: Use Other Side with Arrow
Questions:

1. What does this sign mean to you as a driver? ____

2. Does this information affect you as a driver? ☐ Yes ☐ No
If yes, how?

If no, who do you think it affects? ☐ Pedestrians ☐ Other: ______________________________

How are they affected? ____

Press the space bar to see the next set of signs.

Sign 6: Pedestrian Symbol White
Questions:
1. What does this sign mean to you as a driver? ______________________________

2. Does this information affect you as a driver? ☐ Yes ☐ No
If yes, how?

If no, who do you think it affects? ☐ Pedestrians ☐ Other: ____________________
How are they affected? ____

Part 2: Comparisons
The next time you press the space bar, you will see two signs shown side-by-side. As soon as the signs appear, I will ask you questions about the signs while they are still on the screen. So do not press the space bar again until we are finished with the questions.

Group 1: Signs 3 & 5a – diamond vs. rectangular

Do these signs have different meanings? ☐ Yes ☐ No
If yes: What is the difference? *(Answer can not just be shape, how does the different shape change the meaning to them.)* ____

Press the space bar to see the next set of signs.

Group 2: Signs 5 & 5a – white vs. orange

Would the color difference between the signs mean different things to you? ☐ Yes ☐ No
If yes, what?

Press the space bar to see the next set of signs.

Group 3: Sign 5 & 6 – words vs. symbol

Do these signs mean different things to you? ☐ Yes ☐ No
If yes, what is the difference? ____

Which sign do you prefer? ☐ Sign 5 (left) ☐ Sign 6 (right)
Why?

APPENDIX B

Pedestrian Survey

Location: ___________ **Participant # _____**
Date: ______________ **Researcher: _____**

SURVEY B1

Demographics:
Gender: ❒ male ❒ female

Age: ❒ 16-25 ❒ 26-39 ❒ 40-54 ❒ 55-70 ❒ 71+

Education: ❒ some high school ❒ high school graduate
❒ some college ❒ college graduate

Before we begin, for all of the questions that I will ask, I want you to assume that you are a PEDESTRIAN when you see the signs.

When you press the space bar your first sign will appear on the laptop monitor. You will have control over how long you view the message. So, the instant you understand the situation and know what you would do, you will need to press the space bar again to turn the image off. Then you will be asked questions about the information displayed on the screen. Do you have any questions?

Part 1: Comprehension
Sign 5: Rectangular White Cross Here
Questions:
1. What information is this sign providing to you? ______________________________________

2. Based on the information provided on the sign, what action would you take (if any)? _______
Why?

3. Would you change anything about the sign to improve it? ☐ Yes ☐ No
If yes, what?

Press the space bar to see the next sign.

Sign 1: Use Other Side with Arrow
Questions:
1. What information is this sign providing to you? ______________________________________

2. Based on the information provided on the sign, what action would you take (if any)? _______
Why?

3. Would you change anything about the sign to improve it? ☐ Yes ☐ No

If yes, what?

Press the space bar to see the next sign.

Sign 6: Pedestrian Symbol White

Questions:

1. What information is this sign providing to you? ____

2. Based on the information provided on the sign, what action would you take (if any)? ________
Why?

3. Would you change anything about the sign to improve it? ☐ Yes ☐ No
If yes, what?

Part 2: Comparisons

The next time you press the space bar, you will see two signs shown side-by-side. As soon as the signs appear, I will ask you questions about the signs while they are still on the screen.

Group 1: Signs 1 & 2 – arrow vs. no arrow
Which sign is better to help you decide on an action to take? ☐ Sign 1 (left) ☐ Sign 2 (right)
Why?

Press the space bar to see the next set of signs.

Group 2: Signs 2 & 4 – use other side vs. cross here
Which sign do you prefer? ☐ Sign 2 (left) ☐ Sign 4 (right)
Why?

Press the space bar to see the next set of signs.

Group 3: Signs 3 & 5a – diamond vs. rectangular

Do these signs have different meanings? ☐ Yes ☐ No
If yes: What is the difference? *(Answer can not just be shape, how does the different shape change the meaning to them.)* ____

Press the space bar to see the next set of signs.

Group 4: Signs 5 & 5a – white vs. orange

Would the color difference between the signs mean different things to you? ☐ Yes ☐ No
If yes, what?

Which color of sign (if any) would be more likely to mean that you are breaking a law if you continue to walk on this sidewalk? ☐ White (left) ☐ Orange (right) ☐ no difference

Press the space bar to see the next set of signs.

Group 5: Sign 5 & 6 – words vs. symbol

Do these signs mean different things to you? ☐ Yes ☐ No
If yes, what is the difference? ____

Which sign do you prefer? ☐ Sign 5 (left) ☐ Sign 6 (right)
Why?

Part 3: Wording Questions

1. Which (if any) of these phrases requires you to select a different path to follow? **(select as many options as you would like, or is there a different phrase you think should be used)**

☐ *Detour*
☐ *Alternate Route*
☐ *Alternate Path*
☐ *Cross Here*
☐ *Use Other Side*
☐ *Other:* ____________________

2. Which of the phrases listed below is the **best** to use if a sidewalk is closed and pedestrians will need to use a different route? *(select only one option*

☐ *Detour*
☐ *Alternate Route*
☐ *Alternate Path*
☐ *Other:* ____________________

3. If all of the phrases below represent the same walking distance, which phrase would be best to put where the "?" is to help you decide if the sidewalk is closed before or after your destination?

☐ *200 FEET AHEAD*
☐ *PAST MCDONALDS*
☐ *1 BLOCK AHEAD*
☐ *AFTER GREEN ST*
Why is that the best option? ____

We have two final questions about your walking experiences:

1. Approximately how often to you walk on a sidewalk near a road?
Once a Year Once a Month Once a week Several days a week Everyday
2. What percent of this walking time is in or near a road work area?
Never < 25% 25-50% 50-75% 75-100%

Analysis of Driver Compliance with Work Zone Speed Limits

Prepared for
Undergraduate Transportation Scholars Program

by

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August 10, 2007

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ACKNOWLEDGMENT

The research described in this paper was conducted as part of Project 0-5561, sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The research activities were conducted in support of the Undergraduate Transportation Scholars Program. The findings and recommendations included in this paper are based on the student's summer activities. They should be considered preliminary and not as representative of the findings and recommendations of the parent project. This paper has not been reviewed or approved by the sponsor. The contents of this paper reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of TxDOT and the FHWA.

SUMMARY

Work zones are a daily part of life for many drivers. It would seem obvious that speed limits in work zones would need to be reduced because they frequently have many hazardous elements that create a more dangerous roadway. But drivers often do not feel the need to comply to the reduced speed in a work zone, unless they themselves determine that the roadway is someway unsafe

The objective of this project was to determine what conditions cause drivers to actually reduce their speeds in a work zone. This research analyzed four locations with numerous hazards that could potentially cause drivers to comply with or not comply with the speed reduction. From this analysis, the researcher was able to better understand how drivers react to various work zone conditions. Encroachment into the travel lane results in driver compliance with the reduced work zone speed limit, while the initial work zone speed limit signing and work removed from the roadway do not result in driver compliance with the reduced work zone speed limit. In some situations, crossing and turning traffic, lane shifts, and lane closures result in driver compliance with the reduced work zone speed limit; however, more research is needed to determine their effect on drivers' speed.

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INTRODUCTION

Work zones are a daily part of life for many drivers. It would seem obvious that speed limits in work zones would need to be reduced because they frequently have many hazardous elements that create a more dangerous roadway (*1*). But studies have shown that speed limits have little effect on the driver's chosen speed. Also, drivers often do not feel the need to comply to the reduced speed in a work zone, unless they themselves determine that the roadway is someway unsafe (*2*).

Drivers choose their speed based on the evaluation of risk, travel time, fuel consumption, and potential for loss of life (*3*). Speed zones are established by the majority of drivers because it is assumed that most drivers operate their vehicles in a safe, reasonable, and prudent manor. If the majority of drivers are used to establish the speed zones, then this helps facilitate orderly movement by increasing the awareness of reasonable speeds for the zone (*2*). Properly set zones will help unfamiliar drivers with indication of speeds and reduce speed variation within the speed zone, thus improving overall safety on the roadway. Since, speed zones are established by the driver speed, it is important to have work zone speeds conform to what drivers believe to be a safe and prudent speed in the work zone.

Most drivers are accustomed to a clear, unobstructed roadway, but work zones present drivers with new challenges. Drivers are now required to recognize and obey a wide variety of traffic control devices. These devices often introduce conflict between the road users, construction activity, and equipment. These new restrictions often frustrate drivers by increasing travel time, which causes them to disregard the work zone speed limits (*4*). This makes the work zone even more hazardous and increases the risk of accidents. In fact, it has been shown that work zones have an increased accident rate, and speed is the most cited factor of causing accidents in a work zone (*5*).

There are many reasons that cause a reduction of speed in a work zone. The Texas Department of Transportation (TxDOT) currently uses a Work Zone Speed Limit Worksheet that includes seven potentially hazardous conditions and guidelines for regulatory speed limit determination (*6*). Therefore, it is important to analyze factors in work zones to better understand what drivers perceive as hazardous in work zones and cause them to decrease their speed.

Overall, it is necessary to understand what drivers believe to be a safe speed in a work zone, the work zone conditions that cause drivers to comply or not comply with a reduced work zone speed limit, and how these conditions compare with those used by TxDOT to determine when work zone speed limit reductions are necessary. This research will help determine driver compliance with work zone speeds and the correlating factors that impact the selection of speeds in a work zone.

BACKGROUND INFORMATION

Understanding how speed limits are established for a roadway is necessary for this project. Speed limits are based off the 85^{th} percentile speed. The 85^{th} percentile speed is the speed that 85 percent of drivers travel on a given section of roadway. This is also called the driver-defined maximum safe speed. This speed is found by conducting speed spot checks on a given roadway, and then performing a statistical analysis for the 85th percentile. Then the calculated 85th percentile speed is adjusted to the nearest 5 mile per hour (mph) increment. This adjusted speed is typically requested to be the established speed for the roadway.

Most roadways have user defined speeds, which makes most speed limits appealing to the drivers. These appealing speed limits or properly defined speed zoning can:

- help drivers adjust their speed to conditions,
- make enforcement easier by furnishing police officers with a reasonable indication of what is excessive speed,
- result in more drivers within the same speed range at each of the locations along the highway, and
- reduce the frequency and severity of crashes when accompanied by enforcement.

There are certain factors that affect the determination of a safe speed for a driver: the design of a roadway, the category of vehicle being driven, the type of driver, the amount of traffic, and the weather or visibility. These factors must be taken into account when determining if the 85th percentile speed is appropriate (*2*). Therefore, it is important to assume that the majority of drivers have good judgment to analyze these risks and can then determine a safe and prudent speed for themselves.

Speed control in work zones is organized into two schools of thought (*1*).

- Work zone speeds should be similar to normal roadway speeds in order to minimize speed differentials and thus accident potential.
- Work zone speeds should be reduced, since work zones typically contain many hazardous elements and are therefore inherently more dangerous.

In Texas, the procedure for developing work zone speed limits is based on a 10 mph reduction. Previous research showed that most drivers would always slow down in a work zone. But it became obvious that drivers would not often slow down to the advised speed limit. For example, researchers found that drivers would decrease their speeds by 7.2 mph for a 10 mph reduction, and they would only slow down 20.7 mph for a 30 mph reduction. It was also seen that most drivers would also slow down nearly the same amount no matter how large the speed reduction was (*3*). Therefore, it was seen that improper advisory speeds created adverse and undesired effects. These effects were:

- drivers ignore the signs, and by doing so, are subject to arrest;
- respect for all speed limit signs is lessened; and
- the law abiding driver becomes a traffic hazard by observing the reduced speed (*2*).

From the study, it was also seen that a 10 mph reduction resulted in the minimum increase in accident rate, and the higher reductions resulted in a very large increase of accident rates. From this data, it was concluded that the 10 mph reduction is the most ideal, and the current TxDOT Work Zone Speed Limit Worksheet is based off this recommendation.

GOAL AND OBJECTIVES

This research is designed to determine how drivers passing through a work zone react to the different conditions and factors used by TxDOT to justify reduced speeds in work zones (*6*). From this project, the researcher will have a better understanding of how drivers decide when a speed reduction is necessary for them to drive safely through the work zone. Also, the researcher will discover which conditions and factors from the TxDOT worksheet are most likely to cause a driver to adjust to the working conditions.

The research will show were driver compliance with reduced work zone speeds exists and were it does not. These speeds will be then matched to their location in the work zone to obtain which conditions are causing a driver to drive a reduced speed. This will show if drivers actually choose to comply with reduced speeds: for no part of the work zone, for the whole work zone, or for only certain sections of the work zone.

The researcher will be able to summarize how drivers drive in a work zone by having a better understanding of drivers' speed in a work zone. These overall objectives will give the researcher the baseline data that will help determine how drivers proceed through a work zone and what they identify as hazards that actually cause them to adjust to a safer, slower speed. These objectives will also allow the researcher to provide recommendations on how to improve work zone speed management and possibly help the Texas Transportation Institute Research Project (0-5561) *Improving Regulatory Speed Limit Management in Texas Work Zones*.

PROCEDURE

Site Selection

Data were collected at four work zones that covered a variety of work zone conditions and factors: US 84 in Littlefield west of Lubbock, SH 194 in Edmonson west of Plainview, I-40 just east of Amarillo, and SH 6 south of College Station. The US 84 work zone had a lane closure and temporary diversion with unexpected conditions (i.e., turning and crossing traffic) as major factors. The SH 194 work zone had lane encroachment, a temporary diversion, workers present within 2 to 10 ft of the traveled way unprotected barriers, and pavement edge drop off within 2 ft of the traveled way as major factors. It also had very rough roadway conditions due to the deterioration of the shoulder on which drivers in the westbound direction travel. The I-40 work zone had a lane closure and temporary diversion. The SH 6 work zone had roadside activity, shoulder activity, and a lane closure on one day of data collection. In addition, the SH 6 work zone had several construction entrances for work vehicle access and turning traffic (i.e., unexpected conditions).

Data Collection

Day data were collected at each site, and night data were collected at I-40 and SH 6 sites. At each site, the work zone layout was documented using a video camera and global positioning system (GPS) software in order to determine the conditions that drivers were encountering. Speed data were collected at a number of different nodes within each work zone in both directions of travel. The nodes where data were collected included the normal cruising speed for the roadway, the speeds after the reduced speed sign, the end of work zone, and near any unique characteristics of the work zone (e.g., lane closure). A minimum of 125 vehicle speeds (passenger and commercial vehicles) were collected with light detection and ranging (LIDAR) guns at each node. Also, other data were documented in order to see if any other factors were influencing drivers (e.g., police presence).

Data Reduction

After the data were collected, it was reduced and analyzed. A number of items were determined from these data:

- mean speed,
- 85th percentile speed, and
- percent exceeding the speed limit in the work zone.

The percent exceeding the speed limit was dividing into two categories: percent of drivers within 5 mph of the speed limit and percent of drivers over 5 mph.

The following statistics were computed to determine if each speed distribution was represented by a normal distribution, to ensure that the data was of good quality:

- sample variance,
- sample standard deviation,
- sample skewness,
- central dependency check, and
- measure of dispersion check.

RESULTS

US 84 – Littlefield

The US 84 Littlefield day data were collected on June 12, 2007. The US 84 site, before the presence the work zone, was a four-lane divided highway. But due to the work zone conditions, the entire eastbound side was closed. Therefore, all traffic was shifted to the westbound side using lane closures and temporary diversions creating a two lane, two way (2L2W) undivided highway. No work was done near the actual roadway because it was all on the other side of the median (i.e., in the eastbound travel lanes).

Table 1 and Table 2 show the eastbound and westbound data collection nodes, respectively. In both directions, it can be seen that the drivers are complying with the upstream regulatory speed limit of 70 mph (i.e., 85^{th} percentile speeds are within 5 mph of the speed limit and the percent of vehicles exceeding the speed limit by over 5 mph is less than 5 percent). However, at the first work zone speed limit sign and near the portable changeable message sign (PCMS) the 85^{th} percentile speeds are more than 5 mph over the work zone speed limit of 60 mph and the percent of vehicle exceeding the speed limit by over 5 mph ranges from 17 to 37 percent. Thus, most drivers have not changed their driving speeds and are not adhering to the reduced regulatory speed limit.

Table 1. Day Data for US 84 Eastbound

Nodes	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	**Exceeding 5 mph**	**Total**
FF Speed (70 mph)	72	36%	3%	39%
WZSL (60 mph)	69	38%	37%	75%
Before PCMS	69	32%	31%	63%
Right Lane Closure	64	32%	11%	43%
Begin Lane Shift	61	13%	3%	16%
2L2W No Crossovers	55	0%	0%	0%
2L2W Crossovers	54	1%	0%	1%
End Lane Shift	59	9%	1%	10%

FF-free flow; WZSL-work zone speed limit

Table 2. Day Data for US 84 Westbound

Nodes	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	**Exceeding 5 mph**	**Total**
FF speed (70 mph)	73	36%	4%	40%
WZSL (60 mph)	66	35%	17%	52%
Left Lane Closure	65	32%	10%	42%
Speed Trailer	60	8%	1%	9%
2L2W No Crossovers	56	3%	1%	4%
2L2W Crossovers	56	6%	1%	7%
End Work Zone	65	36%	13%	50%

At the lane closures the 85th percentile speed is approximately 65 mph (a 1 to 5 mph reduction from the first work zone speed limit sign) and the percent exceeding the speed limit by over 5 mph has been reduced to approximately 10 percent. At the beginning of the lane shift and at the speed trailer, drivers are complying with the reduced speed limit. This compliance is likely due to the design of the lane shift (i.e., it was fairly difficult to navigate at higher speeds) and the fact that drivers typically reduce their speed in the presence of a speed trailer, especially if enforcement is present in the area. In addition, drivers were entering the 2L2W, undivided roadway section, which might have increased driver workload requiring drivers to pay more attention to the driving task.

The increase in driver workload is also evident at the next two nodes, 2L2W no crossovers and 2L2W crossovers, which have 85th percentile speeds around 55 mph (approximately 5 mph under the reduced speed limit). This could be due the turning and crossing traffic (unexpected conditions) or the heavy presence of law enforcement in this area. The last node in each direction shows drivers exiting the work zone. In the eastbound direction, the 85th percentile speed is lower than in the westbound direction (59 and 65, respectively). This may be attributed to the design of the lane shift in the eastbound direction. But in both directions speeds are on the rise as drivers leave the 2L2W section and exit the work zone.

SH 194 – Edmonson

The SH 194 Edmonson day data were collected on June 13, 2007. The SH 194 site, before the presence the work zone, was a two-lane undivided highway. But due to the work zone conditions, the eastbound travel lane was closed due to the work. Therefore, all traffic was shifted to the westbound side by widening the westbound shoulder for the westbound direction to travel on and shifting the eastbound traffic into the original westbound travel lanes. There was lane encroachment, a pavement edge drop off within 2 ft of the traveled way, and workers present within 2 to 10 ft of the traveled way unprotected barriers on the eastbound side of the roadway.

Table 3 and Table 4 show the westbound and eastbound direction nodes, respectively. In both directions, it can be seen that the drivers are complying with the free flow speed. At the first work zone speed limit sign, the 85th percentile speed is still 70 mph resulting in 65 percent of the drivers exceeding the speed limit. In addition, 38 percent of the drivers were exceeding the speed limit by over 5 mph. Thus, drivers have not changed their driving speeds and are not adhering to the work zone speed limit.

Table 3. Day Data for SH 194 Westbound

Nodes [a]	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	Over 5 mph	Total
FF Speed (70 mph)	70	13%	1%	14%
WZSL (60 mph)	70	27%	38%	65%
Begin Lane Shift	65	17%	14%	31%
Work Activity	64	14%	13%	27%

[a] Data were not collected at the end of the work zone, because the work zone ended near the town of Edmonson in a 30 mph speed limit zone.

Table 4. Day Data for SH 194 Eastbound

Nodes [a]	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	Over 5 mph	Total
Work Activity	65	23%	14%	37%
End Work Zone	69	30%	29%	59%
FF Speed (70 mph)	70	12%	2%	14%

[a] Data were not collected at the WZSL 60 mph sign, because there was not a safe place to position the data collection vehicle.

At the lane shift and next to work activity, drivers begin to drop their speeds as seen by the decrease in the 85th percentile speed to approximately 65 mph. This decrease in speed may be attributed to the narrow lanes in transition and the added obstructions to the driver (i.e., pavement edge drop off and rough road). But even with these added factors, drivers only slightly decreased their speeds and still felt safe driving approximately 5 mph over the work zone speed limit. At these same nodes, between 27 to 37 percent of drivers were exceeding the speed limit, but most drivers are within 5 mph of the speed limit. At the end of the work zone, the 85th percentile speed increased to the normal free flow speed.

I-40 – Amarillo

The I-40 Amarillo day and night data were collected on June 14, 2007 and June 15, 2007. The I-40 site, before the presence of the work zone, was a four-lane divided highway. But due to the work zone conditions, the entire eastbound side was closed due to the work. Therefore, all traffic was shifted to the westbound side using lane closures and temporary diversions creating a 2L2W divided highway (i.e., opposite directions of travel separated by concrete barrier). All of the work activity was in the original eastbound travel lanes, so no work was done near the actual roadway. At night, there was no work activity present during data collection.

Table 5, Table 6, and Table 7 show the westbound day, westbound night, and eastbound day nodes, respectively. During the day, in both directions of travel, 53 to 59 percent of drivers are exceeding the free flow speed of 70 mph. However, only 41 to 45 percent of these drivers are only 5 mph above the speed limit. At the first work zone speed limit sign the 85th percentile speed decrease by approximately 5 mph to 70 mph, but this is still 10 mph over the work zone speed limit of 60 mph. Also, approximately 50 percent of the drivers are exceeding the speed limit by over 5 mph.

Table 5. Day Data for I-40 Eastbound

Nodes	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	Over 5 mph	Total
FF Speed (70 mph)	75	45%	14%	59%
WZSL (60 mph)	70	31%	52%	82%
Right Lane Closure	70	31%	35%	65%
Begin Lane Shift	66	25%	19%	43%
2L2W No Work Activity	66	48%	18%	65%
2L2W Work Activity	66	46%	17%	63%
End Lane Shift	62	24%	3%	27%

At the lane closures, the 85th percentile speeds are still 8 to 10 mph over the speed limit, but the percent exceeding the speed limit by over 5 mph decreased to between 23 and 35 percent. This is an indication that the variability in the speeds has been reduced. The lane shift resulted in a further decrease in the 85th percentile speed and the percent of drivers exceeding the speed limit by over 5 mph.

Table 6. Night Data for I-40 Eastbound

Nodes [a]	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	Over 5 mph	Total
FF Speed (65 mph)	71	39%	16%	54%
WZSL (60 mph)	67	47%	31%	78%
Right Lane Closure	65	31%	15%	46%
2L2W No Work Activity	64	22%	10%	32%

[a] No other nodes were collected at night due to time constraints.

Table 7. Day Data for I-40 Westbound

Nodes	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	Over 5 mph	Total
FF Speed (70 mph)	75	41%	12%	53%
WZSL (60 mph)	71	27%	50%	77%
Left Lane Closure	68	30%	23%	53%
2L2W Work Activity	65	33%	14%	46%
2L2W No Work Activity	66	43%	17%	60%

In the 2L2W section, there is little difference between the nodes with work activity and without work activity. Both nodes have 85th percentile speeds of approximately 66 mph and the percent of drivers exceeding the speed limit differs very little (between 14 and 18 percent). This shows that work far off the roadway will have little to no affect on driver's choice of speeds.

The night data were very similar to the day data with 85th percentile speeds ranging from 64 to 67 mph throughout the work zone (4 to 7 mph over the speed limit). Again, the percent of drivers exceeding the speed limit was the highest at the first work zone speed limit sign, but at night fewer drivers were exceeding the speed limit by over 5 mph.

Throughout this whole work zone, the 85th percentile speeds are not in compliance with the speed limit. This may be due to the fact that the travel lane width was not reduced, there was a large shoulder, and there was concrete barrier between the two directions of travel allowing drivers to feel comfortable driving above the posted speed limit.

SH 6 – College Station

The SH 6 College Station day and night data was collected on July 9, 2007 to July 12, 2007. The SH 6 site, before the presence of the work zone, was a four-lane undivided highway. But due to the work zone conditions, a section of the southbound and northbound directions of travel had to be shifted to the frontage road. The rest of the roadway is mostly undivided but there is a section with a two-way left turning lane. Most of the work is far off the roadway on the northbound side, but there is a section near the southern end of the project where work activity is on both sides of roadway. At night, there was work activity near the beginning of the lane shift in the northbound direction and at the end of the lane shift in the southbound direction. There was no work activity present in the remainder of the work zone at night.

Table 8, Table 9, Table 10, and Table 11 show the northbound day, northbound night, southbound day, and southbound night nodes for SH 6, respectively. During the day at the free flow nodes, drivers are complying with the speed limit better in the southbound direction than in the northbound direction. At the first work zone speed limit sign there is a 7 to 11 mph decrease in the 85th percentile speed, but the 85th percentile speeds are still 9 to 10 mph over the speed limit of 55 mph. Throughout the work zone, the 85th percentile speeds range from 61 to 65 mph and the percent of drivers exceeding the speed limit by over 5 mph ranges from 5 to 29 percent. This indicates that drivers are traveling at a fairly constant speed throughout the work zone; however, they are not in compliance with the work zone speed limit. This is interesting because there is heavy enforcement throughout the work zone. Thus, drivers are willing to take the risk of driving over the speed limit even when there is heavy police presence.

Table 8. Day Data for SH 6 Northbound

Nodes	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	Over 5 mph	Total
FF Speed (70 mph)	76	34%	17%	51%
WZSL (55 mph)	65	40%	34%	73%
Speed Trailer [a]	61	50%	15%	66%
Construction Entrance [b]	62	45%	19%	65%
Work Northbound Side	64	43%	29%	72%
Begin Lane Shift	62	37%	21%	58%
Frontage Road	61	49%	20%	69%
Left Lane Closure [c]	63	42%	25%	67%
Left Lane Closure Work [c]	57	28%	2%	29%

[a] Work activity on both sides of the roadway.
[b] Work activity on the northbound side of the roadway.
[c] Data were collected at the lane closure nodes on a different day than the rest of the data.

During the day when there was a left lane closure, the 85th percentile speed and the percent of drivers exceeding the speed limit by over 5 mph at the lane closure were very similar to the rest of the work zone (63 mph and 25 percent, respectively). However, when work was present inside the closed travel lane, the 85th percentile speed and the percent of drivers exceeding the speed limit by over 5 mph decreased to 57 mph and two percent, respectively. This was the only location in the work zone during the day where drivers were in compliance with the work zone speed limit. Thus, work in a closed travel lane immediately adjacent to an open lane of travel results in drivers slowing down.

Table 9. Night Data for SH 6 Northbound

Nodes [a]	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	Over 5 mph	Total
FF Speed (65 mph)	72	45%	25%	70%
WZSL (55 mph)	63	42%	34%	76%
Speed Trailer	60	49%	12%	62%
Construction Entrance	59	44%	5%	49%
Begin Lane Shift [b]	58	29%	8%	37%
Frontage Road	58	30%	5%	35%

[a] No other nodes were collected at night due to time constraints.
[b] Work activity between two directions of travel.

Table 10. Day Data for SH 6 Southbound

Nodes	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	Over 5 mph	Total
FF Speed (70 mph)	71	24%	1%	25%
WZSL (55 mph) / Begin Lane Shift	64	32%	34%	67%
Frontage Road	61	37%	21%	58%
End Lane Shift	63	38%	24%	62%
Speed Trailer	61	46%	16%	62%
Work Northbound Side	63	42%	24%	65%
Construction Entrance [a]	62	21%	5%	26%
Work Both Sides	63	38%	27%	66%

[a] Work activity on the northbound side of the roadway.

Table 11. Night Data for SH 6 Southbound

Nodes [a]	85th Speed (mph)	% Exceeding the Speed Limit		
		Within 5 mph	Over 5 mph	Total
FF Speed (65 mph)	69	26%	9%	35%
WZSL (55 mph) / Begin Lane Shift	63	42%	22%	65%
Frontage Road	60	49%	15%	64%
End Lane Shift [b]	59	29%	11%	40%
Speed Trailer	61	45%	13%	57%
Construction Entrance	62	46%	19%	65%

[a] No other nodes were collected at night due to time constraints.
[b] Work activity between two directions of travel.

At night, both directions of travel have very similar data with the 85th percentile speed being approximately 60 mph and the percent of drivers exceeding the speed limit by over 5 mph ranging from 5 to 34 percent. The night also shows that the work activity between the two directions of travel did not seem to influence driver speeds. Overall, the trends in the night data were similar to the day data.

SUMMARY AND CONCLUSIONS

Summary

At all of the sites, drivers did not comply with the reduced work zone speed limit at the initial work zone signing. At the US 84 site, drivers only complied with the reduced work zone speed limit at the lane shifts and in the 2L2W roadway section. At the lane closures, the 85th percentile speed was reduced to within 5 mph of the work zone speed limit, but approximately 40 percent of the drivers were exceeding the speed limit. At the SH 194 site, the 85th percentile speed was reduced to within 5 mph of the work zone speed limit at the lane shift and next to the work activity. At the I-40 site, the results showed that lane closures and lane shifts that are designed for higher speeds have little effect on drivers' choice of speed. Also, 2L2W sections that do not reduce the travel lane width, have wide shoulders, and concrete barrier separating the two directions of travel allow drivers to travel at relatively higher speeds. Also, work activity that is far off the roadway does not seem to affect driver speeds. At the SH 6 site, drivers only complied with the reduced work zone speed limit when work was in a closed travel lane immediately adjacent to an open lane of travel. Also at this site, drivers seem to be willing to risk driving over the speed limit in the sections where the work activity is far off the roadway even when there is heavy enforcement.

Factors that Result in Driver Compliance

From the data, it can be seen that work encroaching on the roadway reduces drivers' speeds. Two nodes, SH 6 lane closure with work activity in the closed travel lane and SH 194 work activity within 2 to 10 ft of an open travel lane, show high driver compliance for these types of sections. Crossing and turning traffic is another factor that might reduce driving speeds and result in compliance with the reduced work zone speed limit. This can be seen from the nodes on US 84 in the 2L2W sections. However, heavy enforcement in the area might have affected the reduced speeds. Another condition that results in driver compliance with reduced work zone speed limits is lane shifts. This was demonstrated at the following nodes: US 84 begin lane shift, US 84 end lane shift, and I 40 end lane shift nodes. These shifts were designed for lower speeds and thus were difficult to navigate at higher speeds. But the SH 6 lane shift nodes and the I-40 begin lane shift node were designed for higher speeds; thus, drivers did not have to reduce their speed as they traveled through these lane shifts. More research needs to be done on the design of lane shifts and how it relates to driver compliance with the work zone speed limit.

Factors that Do Not Result in Driver Compliance

Initial work zone speed limit signs have little effect on changing driver speeds, resulting in low compliance at these locations where no work activity or apparent hazards exist. Work activity that is far off the roadway also does not affect driver speeds. The US 84, I-40, SH 6 sites show little to no change in speed when work activity is not close to the road. The lane closures at the US 84, I-40, and SH 6 sites show minimal driver compliance, but it does appear that drivers begin to slow down slightly even though they are not in compliance with the speed limit. Therefore, it appears more research needs to be done to determine the affect of lane closure on drivers' speed.

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Nighttime Driver Needs: An Analysis of Current Guide Sign Standards and the Need for Change

Prepared for
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August 10, 2007

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ACKNOWLEDGEMENT

The research described in this paper was conducted as part of Project 0-5235, sponsored by the Texas Department of Transportation (TxDOT). The research activities were conducted in support of the Undergraduate Transportation Scholars Program. The findings and recommendations included in this paper are based on the student's summer activities. They should be considered preliminary and not as representative of the findings and recommendations of the parent project. This paper has not been reviewed or approved by the sponsor. The contents of this paper reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of TxDOT.

SUMMARY

Seeing a road sign at night is more difficult than doing so during the day due to the lack of an overarching light source. Drivers must rely on either headlamp illumination or floodlighting in order to be able to see the information presented on a road sign. When illumination is provided by vehicle headlamps, the driver is able to see the sign due to retroreflective sheeting on the sign.

There are 10 current ASTM Types for retroreflective sheeting. The document ASTM D4956 contains detailed specifications on each of the sheeting types, but the specification is not performance-based. Rather, the document is a catalog of the available sheeting types along with specifications for each.

The researcher helped conduct an experiment involving 36 subjects each driving 12 laps around a closed course that contained a self-illuminated warning, guide, and regulatory sign. The distance from the sign at which the subject was able to read it ("legibility distance") was recorded at each sign. Each sign had changeable legends, and a different legend was on the sign during each lap. Only the guide sign data was analyzed for this paper.

Based on the work presented in this paper, it appears that luminance levels near 30 cd/m^2 provide a breakeven point considering nighttime legibility of drivers young and old and the costs associated with providing brighter and brighter signs. It should be noted that additional work is needed and this finding is based on the limited analysis of one sign. Additional legibility data will be analyzed as well as eye tracker data, which is expected to provide even greater resolution in the findings.

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INTRODUCTION

Driving at nighttime is an obstacle that nearly every driver must face. Though the roads are usually not as congested as they are during daytime peak hour traffic, the experience can be more daunting due to the lack of an overarching light source, such as the Sun, to help the driver view critical road signs on his or her commute. Since this source of road sign illumination is not available after sunset, the driver must rely on two main factors to be able to adequately see the sign: 1) the light received by the road sign from the car's headlights ("illuminance") and 2) the light reflected back at the driver so that he or she is able to see it ("luminance"). The best ratio of these two factors ("retroreflectivity") is critical to the driver's ability to drive in a safe and efficient manner during nighttime hours (*1*).

Currently, there are about 10 different classifications of sheeting materials available to construct road signs so that the nighttime driver will be able to see the information presented. These sheeting types are documented along with a short description in ASTM's specification D4956, *Standards Specification for Retroreflective Sheeting for Traffic Control* (*2*). However, the 10 classifications are not performance-based; rather, they are based on measurable product differences in retroreflectivity under varying geometries that the ASTM committee members discuss and debate. A performance-based specification would be one that categorizes sheeting types by their ability to provide the optimal luminance for the tasks of sign detection and sign legibility. The D4956 specification serves as a catalog of the types of current retroreflective materials rather than a document that can be used by an agency having jurisdiction to specify the most appropriate type of sheeting material for traffic signs (*3*).

As the number of sheeting types has increased over the years, each new type has been associated with a new product developed to theoretically improve the nighttime driver's ability to view signs and obtain the applicable information from those signs. However, there has been little or no performance-based research in the past to prove whether or not each new sheeting type actually improves the nighttime driver's ability to view and obtain information from signs in comparison with previous material types.

What matters most is each driver's safety, which is directly correlated to the driver's need to be able to focus on the task at hand – namely controlling, guiding, and navigating the vehicle (*1*). The information on each road sign must be presented in such a way as to minimize distraction from performing those three tasks, while optimizing a sign's ability to provide the necessary information at the appropriate time so the driver can safely drive the vehicle to a particular destination. Therefore, a performance-based specification is desired to provide guidance to sheeting manufacturers to better enable them to develop the appropriate sign sheeting materials. The research contained in this document is a smaller task of a larger project funded by the Texas Department of Transportation (TxDOT) that will be the first large step towards such a specification (*4*).

BACKGROUND INFORMATION

There are four main components that impact the nighttime visibility of retroreflective traffic signs. These four components are (4):

- the amount of light reaching the sign (illuminance),
- the returned light that makes the sign appear bright (luminance),
- the efficiency of the retroreflective material (retroreflectivity), and
- the visual capabilities of the driver (human factors).

For nighttime driving, retroreflective traffic signs must rely on headlamp illumination to work properly. Currently, both the Texas and national *Manual on Uniform Traffic Control Devices* (MUTCD) require that regulatory, warning, and guide signs be retroreflective or illuminated to show the same shape and similar color by both day and night (5). This is quite a vague requirement, which has resulted in the lack of an across-the-board minimum or desired retroreflectivity specification.

Prior to the 1900s, retroreflective sheeting relied on glass beads to redirect the light of the headlamp back to the driver (ASTM Types I, II, and III). In the 1900s, three new types of retroreflective sheeting were introduced that use tiny micro-sized prisms to redirect the light back to the driver (ASTM Types VII, VIII, and IX). When these new types were released, they were advertised by manufactures as being brighter and better than their predecessors. After several research projects, TxDOT signing practices now include microprismatic retroreflective sheeting for guide signs, warning signs, and work zone signs (4).

The light emitted by a car's headlights above the horizontal plane illuminates overhead guide signs. There has been much debate over how much light to allow headlamp manufactures to create above the horizontal because it can cause a discomforting glare to drivers approaching from the opposite direction. In recent years, the amount of light allowed above the horizontal in the U.S. has been decreased in an attempt to harmonize it with European and Japanese standards for the future creation of a global headlamp specification (4).

The property of retroreflectivity is used to define and quantify how well retroreflective sheeting redirects light back to the driver. However, unlike many other values used within transportation engineering, retroreflectivity is not a static value; it represents one of an infinite number of possible values for each road sign. This is due to the fact that the efficiency of retroreflective sheeting is extremely dependent on where the vehicle's headlamps are, where the sign is in relation to the headlamps, the style and age of the headlamps, and where the driver's eyes are in relation to the sign and the headlamps (4).

In theory, retroreflective surfaces redirect light directly back to the source. However, if this were the case with road signs, retroreflective sheeting materials would be of no use to the nighttime driver because the light would be directed back to the headlamp and not back to the driver's eyes. Fortunately, the light is reflected back in a conical shape and the driver's eyes generally fall within the cone. The cone varies with different sheeting types and with different viewing angles.

There are four angles used to describe the roadway environment with respect to retroreflective sheeting and the measurement of its efficiency. These four angles are described by the application system as such: an observation angle (α), entrance angle (β), orientation angle (ω_s), and rotation angle (ε). Figure 1 shows the relationship of these four angles as seen from a roadway perspective. Though all four angles are needed to *fully* define the efficiency and performance of retroreflective sheeting, the orientation and rotation angles have been mostly ignored for many years because sheeting materials which use microspherical glass beads are naturally insensitive to these angles. However, for microprismatic materials, the orientation and rotation angles must be considered (4).

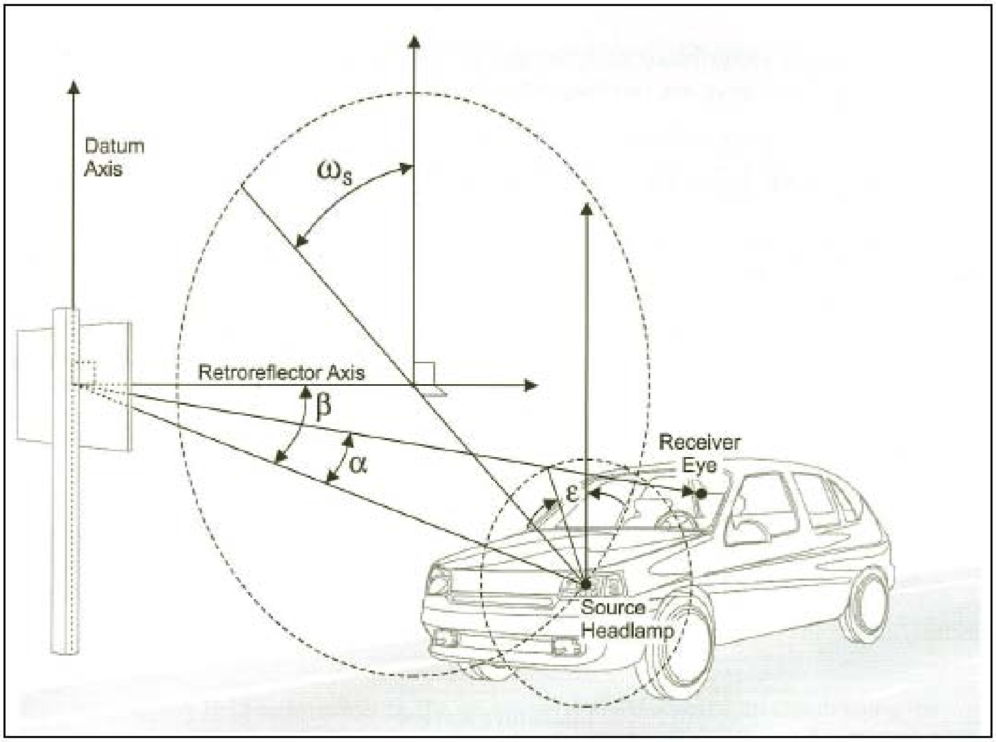

Figure 1. Angles Used in Measuring Retroreflectivity (4)

The luminance of a particular road sign must be adjusted due to two main factors that impact the amount of actual luminance available from the sign. The first factor is the impact of light scatter caused by the transmission of light through the windshield, or "windshield transmissivity." The second factor is the transmission of light through the air and the resulting scattering by dust particles, or "atmospheric transmissivity (4)."

Figure 2 demonstrates how the luminance changes with respect to distance from the sign. The main trend shown is that with all sheeting types, the luminance starts at some intermediate level and increases slowly to a maximum, after which it decreases rapidly. The fundamental question in determining the best amount of retroreflectivity is as follows: what would the ideal shape of these curves be in order to maximize sign performance? If "maximum performance" curves can be determined, states will be able to write new specifications and provide sheeting manufacturers a set of criteria that all nighttime drivers need.

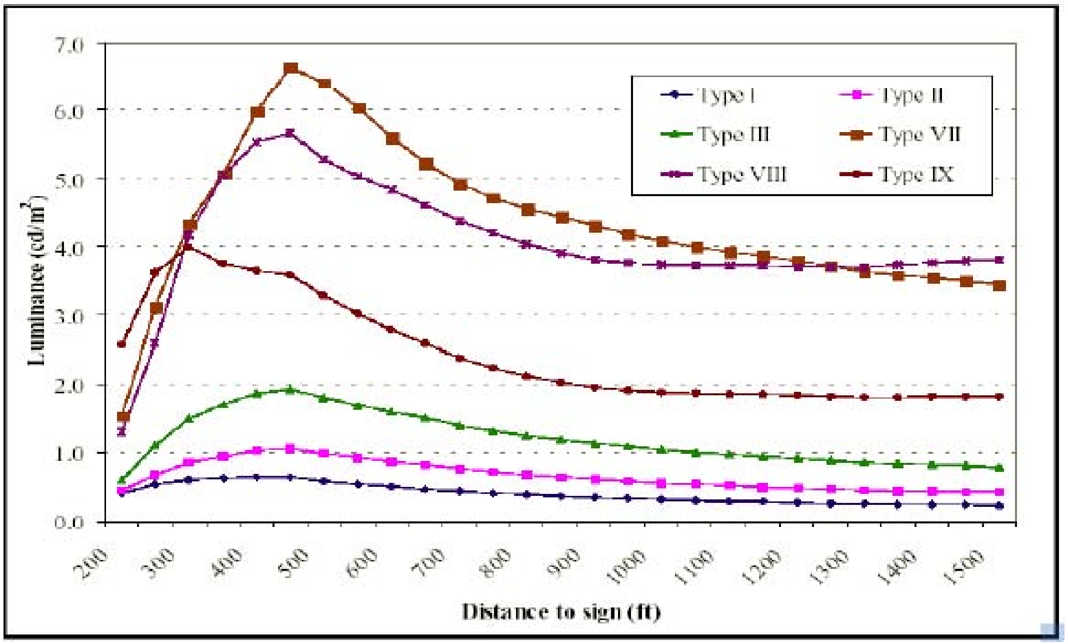

Figure 2. Typical Luminance Curves of Various Sheeting Types (4)

Most states currently use the specifications for sheeting found in ASTM D4956 or a slight modification thereof. Texas, for instance, uses the ASTM specification as the basic background for the state specification DMS-8300. Many agencies use D4956 as though it were a performance-based specification, thinking that somehow the Type designations relate directly to performance on the road. This line of thinking is not entirely correct because the Type designation scheme used by ASTM is not meant to define performance. In addition, the geometries used when testing ASTM sheeting types are not necessarily representative of real driving situations (*4*). It is clear from these and other factors that a performance-based specification is desired in order that driver's needs may be met in nighttime driving conditions.

GOAL AND OBJECTIVES

The goal of Texas Transportation Institute's Project 0-5235 is to conduct research to develop a performance-based specification for nighttime driving. The researcher's goal in the UGTSP subset, which fell in Phase II of Project 0-5235, was to collect, reduce, and analyze guide sign data in accordance with the overall objective. The objectives that were accomplished throughout the course of the program are as follows:

- Review relevant literature
- Prepare a written and oral proposal
- Collect data related to guide sign
- Code video files and reduce data
- Perform statistical analysis to determine if profile significantly affects legibility distance
- Interpret results in terms of ability to explain and represent driver behavior
- Explain and summarize data into a final report and an oral summary of findings

METHODOLOGY

Data Collection

Data collection began on May 30, 2007 and ended on July 24, 2007. The project was originally scheduled to end much sooner, but factors such as equipment failure, high wind, rain, and course obstructions caused multiple cancellations. There were a total of 36 individuals ("subjects") tested for this experiment. Two subjects were scheduled for data collection each Sunday through Thursday night. All data collection was performed at Texas A&M's Riverside Campus in Bryan, Texas, as shown in Figure 3.

Figure 3. Riverside Campus Aerial Map

The main piece of equipment that was used in this study is the *ViewPoint EyeTracker*® by Arrington, Research, Inc. This setup utilized Arrington's *ViewPoint*® software and *EyeFrame* hardware, as shown in Figure 4 and Figure 5, respectively. This technology allowed the researcher to determine where the subject was looking throughout the experiment by using infrared light, two eye-tracking cameras, and another camera pointed towards the forward scene. Other devices used to collect data include a distance measuring instrument (DMI) with video titling equipment, a customized DMI control box, and a specialized laptop computer, all located inside the instrumented vehicle, a 2006 Toyota Highlander, as shown in Figure 6. It should be noted that the data collected from the eye-tracker equipment was not used in the analysis or discussion within this document because not all of the available had been completely processed. The results associated with the eye-tracker data may be found in the Project 0-5235 report.

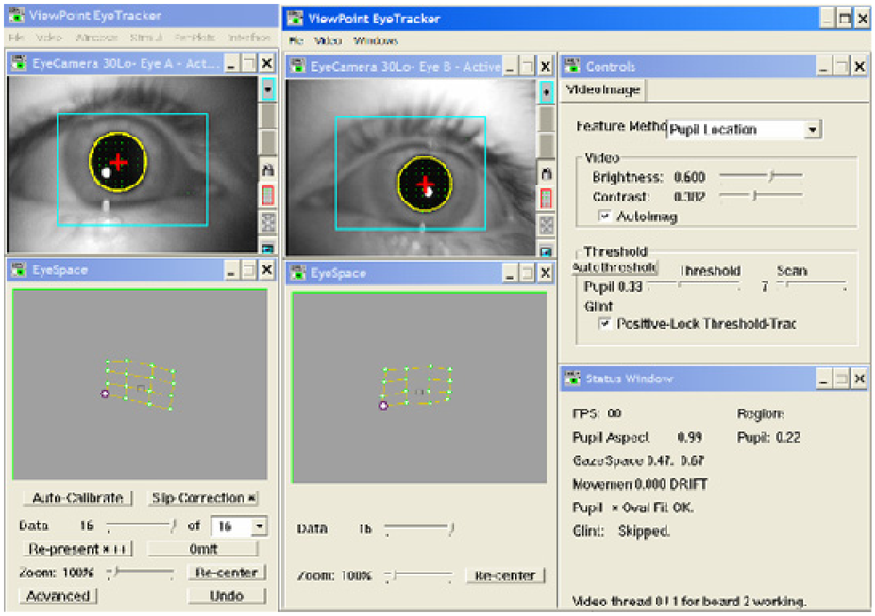

Figure 4. *ViewPoint* Software

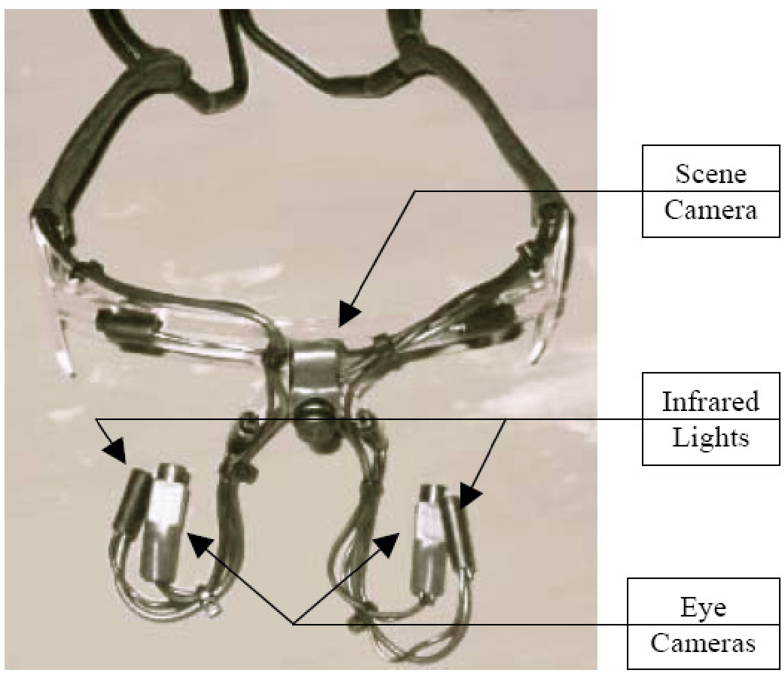

Figure 5. *EyeFrame* Components (*1*)

Figure 6. Instrumented Vehicle

Upon arrival, the subject read information regarding the project and signed a liability waiver, after which he or she took a color blindness test and a visual acuity test. During the color blindness test the subject was asked to identify numbers hidden in a small group of colored dots. If the subject was not color blind, he or she was able to identify the numbers with ease. An example of a figure used in the colorblindness test is shown in Figure 7. During the visual acuity test, the subject was asked to stand 20 feet away from a chart that decreases in font size from top to bottom and read the smallest line that he or she could. An example of the chart used in the visual acuity test is shown in Figure 8.

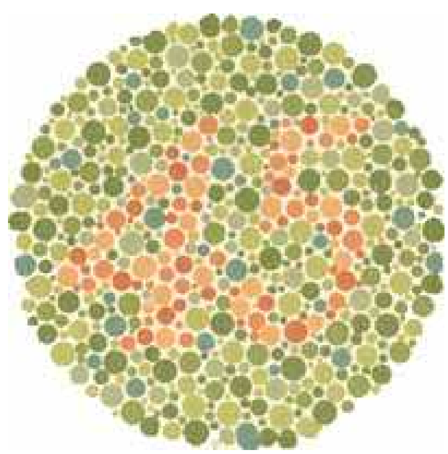

Figure 7. Color Blindness Test Figure

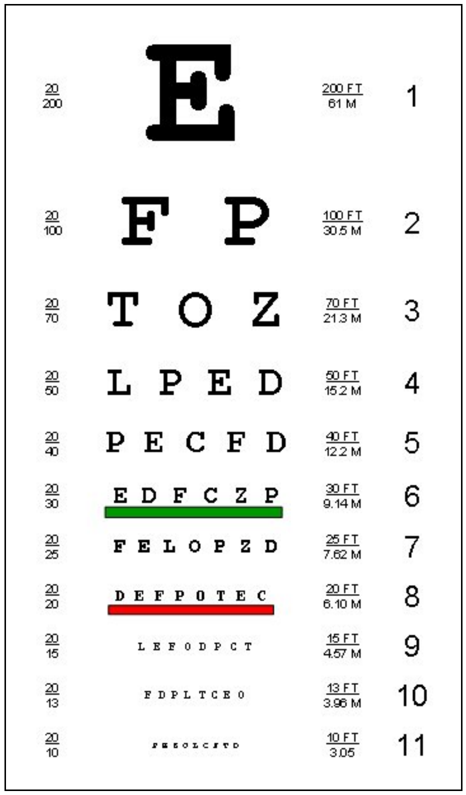

Figure 8. Visual Acuity Test Chart

After the tests, the subject entered the instrumented vehicle and drove it a short distance to the *EyeTracker* calibration site. The subject then had the *EyeFrame* apparatus fitted to his or her face. Once the *EyeFrame* was secured to the subject's head by the adjustable strap, each of the two eye cameras were adjusted so that the subject's eye was at the center of the viewing area. Finally, the forward scene camera was adjusted to capture the same view that the subject saw. A picture of the *EyeFrame* correctly in place on the subject's head is shown in Figure 9.

Figure 9. *EyeFrame* on Subject's Head

The subject then placed his or her head in a chinrest tripod placed 55 feet away from the 40-foot tall calibration grid on the side of a building. The shear size of the grid was important in that a larger grid improves the accuracy of the calibration. The grid contained 16 points across the field of view. The subject fixated on each of these points while keeping his or her head relatively immobile and the position of his or her eyes was recorded, which allowed the *ViewPoint* software to calibrate for each eye. This calibration process was performed for each subject and ensured that the *EyeFrame* system was correctly set up for each subject's different facial structure. Pictures of the calibration grid and chinrest tripod are shown in Figure 10.

	
Calibration Grid	**Chinrest Tripod**

Figure 10. Calibration Setup

After the calibration process, the subject drove to the beginning of the course, where he or she stopped the instrumented vehicle and was given instructions from the individual collecting data in the vehicle ("data collector"). The data collector sat in the back seat of the vehicle and operated the laptop, DMI, and LED lights, and recorded the distance at which the subject read the sign aloud ("legibility distance"). The subject was informed before driving around the course that the purpose of the experiment was to determine how well the *EyeFrame* device tracked his or her eyes. Any mention of the signs was avoided so that the subject would not focus solely on reading the signs, but rather drive the vehicle as he or she would in a normal driving situation. The subject was informed at the end of the course what the real purpose of the experiment was.

Each subject completed 12 laps around a closed course. The subject viewed a warning, guide, and regulatory sign and observed the set of words ("legend") on each of these signs, which changed every lap. Luminance "profiles" were used to control how bright each sign was at each moment in time. The profile began running when the instrumented vehicle crossed over a trip wire that was connected to a laptop powered by a portable generator, as shown in Figure 11. Texas Transportation Institute (TTI) employees worked throughout the subject's laps and upon passing of the vehicle had approximately 5 minutes to change the legend and set up the next luminance profile.

Figure 11. Controller Box, Laptop, and Generator

As soon as the subject was able to view each sign's legend, he or she was asked to read the legend aloud to the data collector. For the guide sign, the subject was instructed each lap to read only one line of the legend. After viewing each sign, the subject stopped between two orange barrels so that the data collector could reset the *ViewPoint*® software, after which the data collector instructed the subject to continue on to view the next sign.

The data collector also triggered a single LED light on the side- and rear-view mirrors at various times throughout the course so that the subject was required to consistently scan those mirrors for the light. When the subject saw a light on, he or she informed the data collector which light was visible by saying either the word "side" or "rear". If the subject did not detect the light after it had been on for five seconds, the data collector informed the subject which light had been on. The LED light system was in place to simulate normal open road driving conditions, in which a driver should scan both mirrors for other cars and hazards.

The guide sign had an added difficultly in that it was lifted 18 feet above the ground in order to properly represent the position of a guide sign on the side of a freeway. The sign was connected to a motorized winch that allowed the sign to be raised and lowered in order to change the legend for each lap. A picture of the guide sign is shown in Figure 12.

Figure 12. Guide Sign

After completion of 12 laps around the course, the subject drove the instrumented vehicle back to its original location. Upon arrival, the subject was informed that the test he or she just completed was actually a research study related to how bright road signs need to be at night rather than a test to see how well the *EyeFrame* device tracks the eye.

There were 6 luminance profiles and 12 legends used during data collection. Each profile and legend was used for each subject, and each combination of profile and legend was chosen randomly. The legends and luminance profiles used during the experiment are shown in Table 1 and Figure 13, respectively. Table 2 shows the peak luminance (in cd/m^2) for each profile.

Table 1. Legends

Lake Port	Gray Cape	East Road
Lake Camp	Bear Port	Owen Park
Gray Bend	Long Camp	Bear Cape
East Park	Long Bend	Owen Road

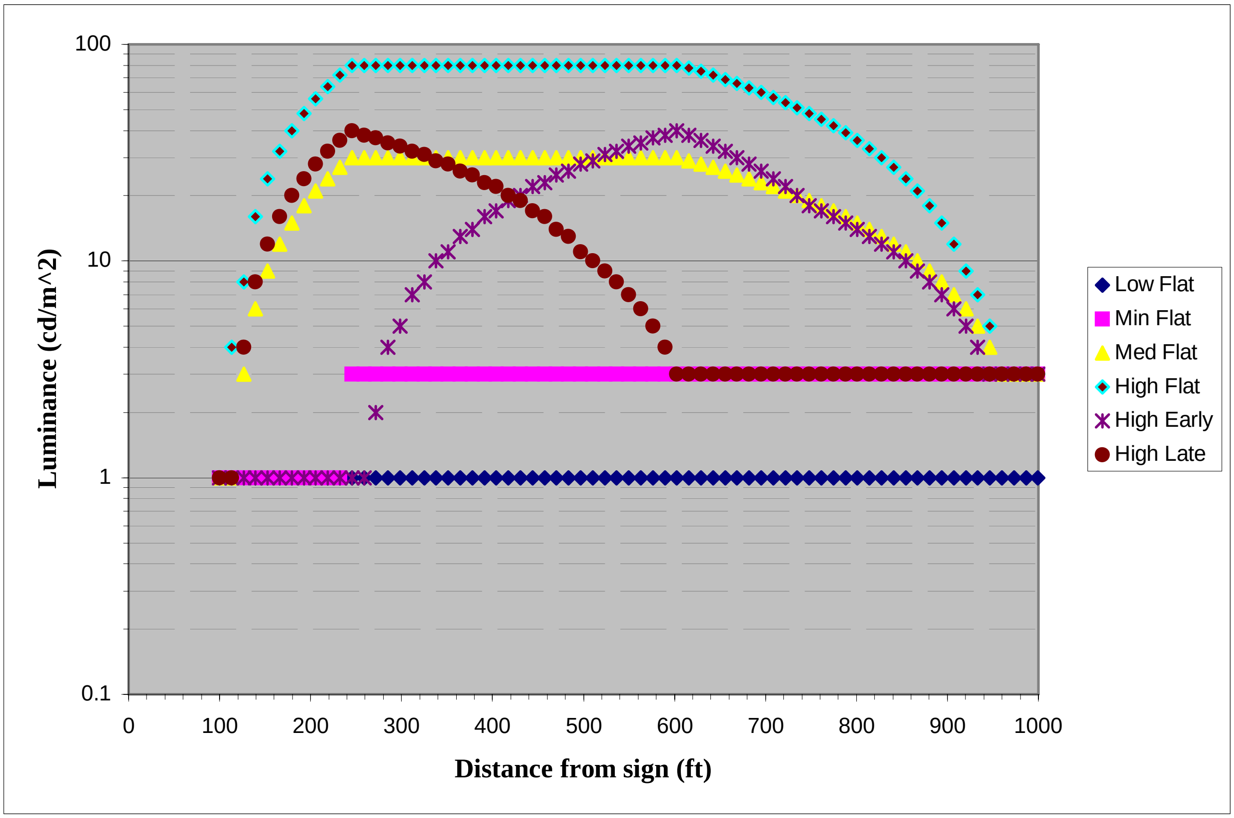

Figure 13. Luminance Profiles

Table 2. Peak Luminance Levels

Profile	**Peak Luminance (cd/m^2)**
Low Flat	1
Min Flat	3
Med Flat	30
High Flat	80
High Early	40
High Late	40

Data Reduction

Large amounts of data were accumulated each night that data collection was performed at the Texas A&M Riverside Campus. The researcher worked with other TTI employees to "code" and reduce the data from each subject throughout the data collection process. The "coding" process involved the researcher viewing the warning, guide, and regulatory sign video files through the

ViewPointMovie Player by Arrington, Research, Inc. *ViewPointMovie Player* played the video file produced by the *EyeTracker* setup, which consisted of the forward scene camera's view with a red dot clearly visible to signify where the subject was looking. In addition, the time and distance, both of which started at 0 for each sign, was located at the top of the video file.

Because of limitations with equipment, the sign could only be seen near the end of each video file. In order to be able to recognize when the subject was looking at the sign even when the sign was not visible on the video file, a transparency was placed over the computer screen and the area where the sign was located was circled with a marker, as shown in Figure 14.

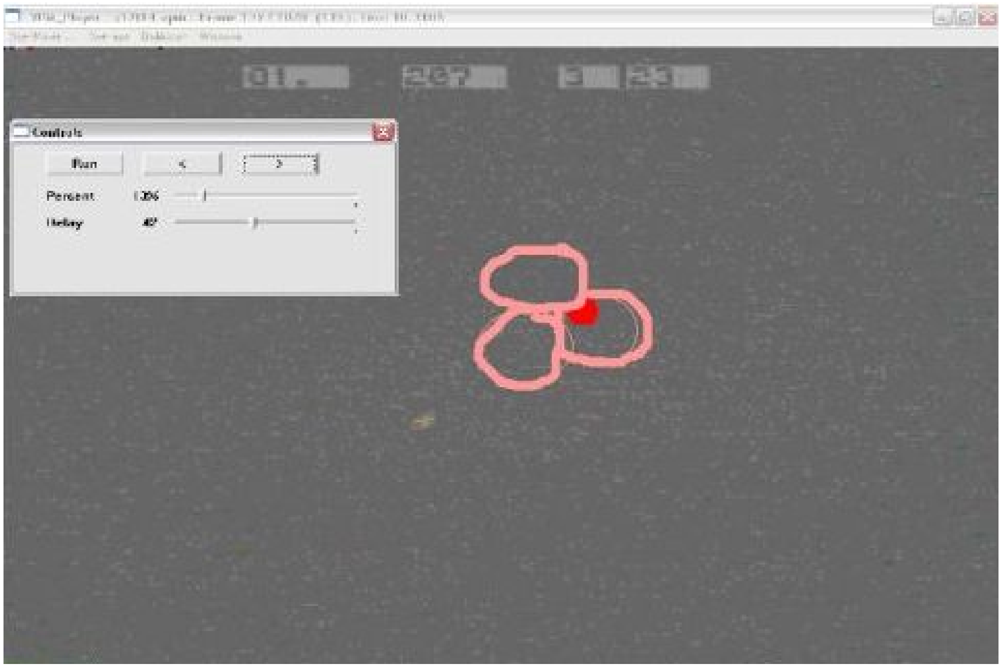

Figure 14. *ViewPointMovie Player* With Transparency Outline

By using the transparency and marker technique it was possible to recognize when the subject was looking at the sign by keeping track of when the red dot fell within the circle. The "coding" technique involved both observing the *ViewPointMovie Player* file and recording the following in spreadsheet format: subject number, sign, video file title, legend, profile, legibility distance, glance time, and distance covered while each glance was being made. Each sign was color-coded as follows: yellow for the warning sign, green for the guide sign, and no background color for the regulatory sign. An example of this spreadsheet is shown in Figure 15.

						Glance At Sign Information							
Subj.					Leg.	Start		Dist.	End		Dist.	Duration	
No.	Sign	File	Legend	Profile	Dist.	Time	Dist.	from	Time	Dist.	from	Time	Dist.
7	W	F1	11	2	156.2	0.9	3	1347	1.1	3	1347	0.2	0
7	W	F1	11	2	156.2	2.5	14	1336	3.2	17	1333	0.7	3
7	W	F1	11	2	156.2	2.2	37	1313	5.1	43	1307	2.9	6
7	W	F1	11	2	156.2	6.7	80	1270	7.8	110	1240	1.1	30
7	W	F1	11	2	156.2	9.6	169	1181	10.4	198	1152	0.8	29
7	W	F1	11	2	156.2	14.7	371	979	14.9	380	970	0.2	9
7	W	F1	11	2	156.2	15.4	401	949	15.6	411	939	0.2	10
7	W	F1	11	2	156.2	16.6	453	897	18.3	527	823	1.7	74
7	W	F1	11	2	156.2	19.3	571	779	21.4	660	690	2.1	89
7	W	F1	11	2	156.2	22.7	716	634	23.8	765	585	1.1	49
7	W	F1	11	2	156.2	25.1	819	531	26.1	862	488	1	43
7	W	F1	11	2	156.2	27.3	916	434	32.6	1143	207	5.3	227
7	W	F1	11	2	156.2	32.8	1152	198	33.7	1190	160	0.9	38
7	G	F2	22	8	325.1	2.4	0	3033	4.4	25	3008	2	25
7	G	F2	22	8	325.1	5.8	56	2977	6.3	70	2963	0.5	14
7	G	F2	22	8	325.1	9.5	177	2856	11.1	243	2790	1.6	66
7	G	F2	22	8	325.1	12.5	303	2730	12.8	316	2717	0.3	13
7	G	F2	22	8	325.1	13.2	335	2698	15.2	421	2612	2	86
7	G	F2	22	8	325.1	16.4	472	2561	16.8	489	2544	0.4	17
7	G	F2	22	8	325.1	17.8	531	2502	19.8	618	2415	2	87
7	G	F2	22	8	325.1	20.7	657	2376	21.7	701	2332	1	44
7	G	F2	22	8	325.1	21.9	710	2323	22.1	719	2314	0.2	9
7	G	F2	22	8	325.1	23.1	760	2273	24.2	807	2226	1.1	47
7	G	F2	22	8	325.1	25	842	2191	25.4	859	2174	0.4	17
7	G	F2	22	8	325.1	26.1	890	2143	26.7	916	2117	0.6	26
7	G	F2	22	8	325.1	29	1014	2019	29.8	1048	1985	0.8	34
7	G	F2	22	8	325.1	30.1	1063	1970	32.9	1183	1850	2.8	120
7	G	F2	22	8	325.1	33.6	1214	1819	33.8	1221	1812	0.2	7
7	G	F2	22	8	325.1	34.8	1265	1768	35.6	1299	1734	0.8	34
7	G	F2	22	8	325.1	36.3	1329	1704	37.5	1382	1651	1.2	53
7	G	F2	22	8	325.1	37.8	1393	1640	38.5	1424	1609	0.7	31
7	G	F2	22	8	325.1	38.8	1437	1596	41	1531	1502	2.2	94
7	G	F2	22	8	325.1	42.1	1500	1533	44.9	1700	1333	2.8	200
7	G	F2	22	8	325.1	45.6	1731	1302	46	1748	1285	0.4	17
7	G	F2	22	8	325.1	47.1	1795	1238	47.9	1829	1204	0.8	34

Figure 15. Video Coding Spreadsheet

After coding two subjects, the researcher gathered all completed video coding sheets and combined that data with the demographics sheet to create a data sheet to be used for the UGTSP subset. This data sheet included only guide sign data and contained the following information: subject number, gender, age, age group, visual acuity, colorblindness test result, sign, lap, file number, legend, profile, legibility distance, duration of look where sign was read aloud ("legibility task look"), and distance traveled during the legibility task look. At the time of this document, the full set of data was only available for five subjects, but the demographics, profile, legend, and legibility distance was available for all 36 subjects. An example of this spreadsheet is shown in Figure 16. The subjects' age group was divided into the following two groups: 54 and Younger (0) and 55 and Older (1). The subjects' visual acuity was divided into the following two groups: 20/20 and Better (0) and 20/25 and Worse (1). The subject's gender was divided into the following two groups: Male (0) and Female (1). Table 3 shows the subjects' demographic information.

UGTSP 5235 Phase 2 **Guide Sign** Data Sheet - Marc Sandhu

Subject	Gender	Age	Age Group	Visual Acuity	Colorblind?	Sign	Lap	File #	Legend	Profile	Leg. Distance	Duration	Distance Traveled
7	1	42	0	25	0	2	1	2	22	8	325.1	4.9	203
7	1	42	0	25	0	2	2	5	23	9	336.2	5.7	245
7	1	42	0	25	0	2	3	8	24	10	526.8	0.3	29
7	1	42	0	25	0	2	4	11	13	11	472.7	7.7	332
7	1	42	0	25	0	2	5	14	14	12	143.4	0.8	33
7	1	42	0	25	0	2	6	17	15	8	414.1	1.7	74
7	1	42	0	25	0	2	7	20	16	10	301.4	2.3	107
7	1	42	0	25	0	2	8	23	17	7	354.8	1.3	45
7	1	42	0	25	0	2	9	26	18	11	529	1.7	73
7	1	42	0	25	0	2	10	29	.	.	.	.	.
7	1	42	0	25	0	2	11	32	20	11	404.4	3.9	175
7	1	42	0	25	0	2	12	35	21	7	356.2	7.7	344

Figure 16. UGTSP Guide Sign Spreadsheet

Table 3. Demographic Information

Age Group	
<=55	**25**
>55	**11**
Gender	
M	**17**
F	**19**
Visual Acuity	
20/20 and Better	**23**
20/25 and Worse	**13**

Data Analysis

A statistical analysis was performed by Mr. Nathaniel Litton and Dr. Eun Sug Park. The software used for the analysis was the JMP® statistical package, an SAS product that provides enhanced analysis capabilities. The objective of the analysis was to determine if profile affects legibility distance.

For the analysis, the dependent variable was Legibility Distance and the main factors of interest were Gender, Age Group, Visual Acuity Group, Legend, and Profile. The data was analyzed as a split-plot design, with the Subject treated as the whole plot and each treatment combination handled as the split-plot. Gender, Age Group, and Visual Acuity were all treated as whole plot factors (because they were constant throughout every lap for each subject), while Legend and Profile served as split-plot factors (because they changed with each lap). The model that was analyzed included all main effects (Gender, Age Group, Visual Acuity Group, Legend, and Profile) as well as Age Group*Profile and Visual Acuity Group*Profile interactions.

RESULTS

Table 4 shows the Average Legibility Distance (in feet) for each Profile used in the experiment. The best performing Profile was the High Flat Profile. The Medium Flat and High Early Profiles also performed well.

Table 4. Average Legibility Distance for Each Profile

Profile	**Avg Leg Distance (ft from sign)**
Low Flat	352.35
Min Flat	370.49
Med Flat	465.97
High Flat	477.79
High Early	456.71
High Late	389.76

Analysis of the main model showed that the Visual Acuity*Profile interaction term is not significant. The analysis was rerun after removing the Visual Acuity*Profile term and the results are as shown in

Table 5. The table shows that AgeGroup*Profile interaction is significant at an α-level of 0.05, indicating that there is evidence of interaction between Age Group and Profile with respect to Legibility Distance. A plot showing the interaction between Age Group and Profile with respect to Legibility Distance is shown in Figure 17. In addition, it was found that at an α-level of 0.05, Gender and Legend are not significant and the Visual Acuity Group has a borderline significance.

Table 5. Main Effects w/ 1 Two-Way Interactions

Source	**d.f**	**Sum Sq.**	**Mean Sq.**	**F**	**Prob>F**
Gender	1	2565.4	2565.4	0.5168	0.4781
Age Group	1	2900.1	2900.1	0.5843	0.451
Visual Acuity Group	1	19094.7	19094.7	3.847	0.0598
Legend	11	71616.9	6510.6	1.3117	0.2162
Profile	5	634492.5	126898.5	25.5662	<0.0001
Age Group*Profile	5	68124.3	13624.9	2.745	0.0191
Subject	32	3976498	124265.6		

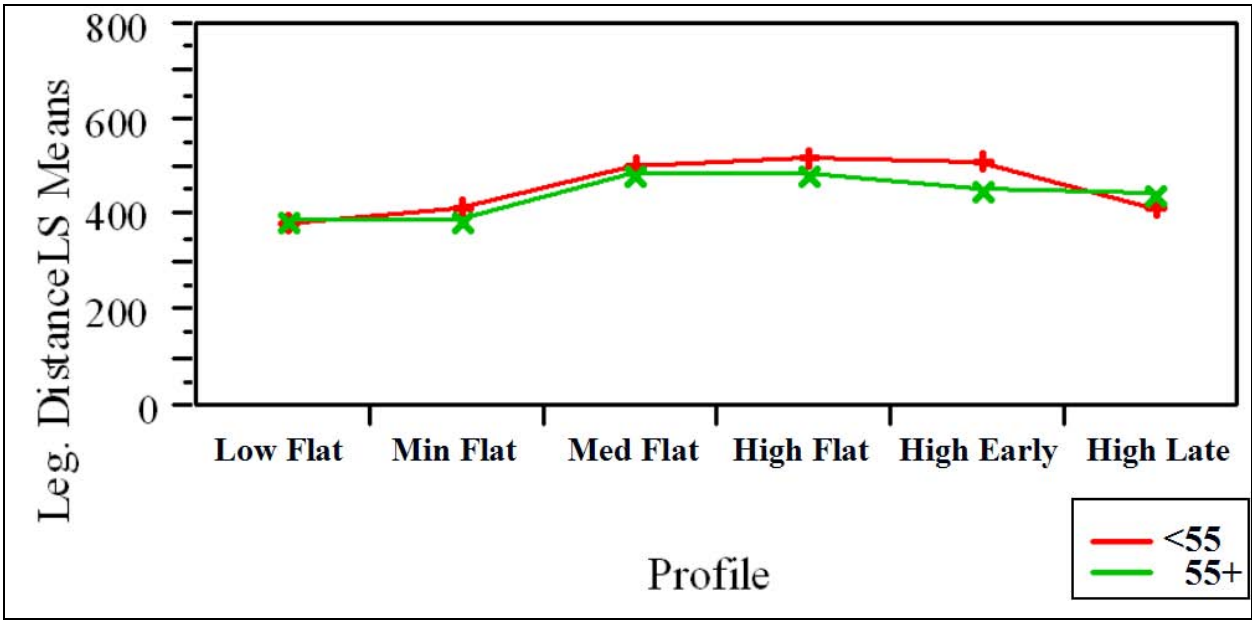

Figure 17. Age Group*Profile LS Means Interaction Plot

It is evident from Figure 17 that the difference in Legibility Distance across profiles does not remain constant between subjects under 55 and subjects 55 and older, which indicates the presence of interaction. Therefore, the effect of Profile was investigated separately for each Age Group. For example, in Figure 17, the High Early Profile resulted in a higher Legibility Distance than the High Late Profile for subjects younger than 55, but the opposite was true for subjects 55 and older. Figure 17 shows that the profile that resulted in the highest value for Legibility Distance for both Age Groups is the High Flat Profile, which makes it the best performing Profile in the experiment.

To find out which of the Mean Legibility Distances in Figure 17 are statistically different, a multiple comparison procedure was performed. The results are summarized in Table 6, which shows the groupings for the combinations of Age Group and Profile. The levels not connected by the same letter are significantly different. For example, for subjects under 55, the Medium Flat, High Flat, and High Early Profiles are not statistically different from one another while the Low Flat, Min Flat, and High Late are statistically different from the Medium Flat, High Flat, and High Early Profiles, but not statistically different from one another. Likewise, for subjects 55 and older, the Medium Flat, High Flat, High Early, and High Late Profiles are not statistically different from one another while the Low Flat and Min Flat Profiles are statistically different from the Medium Flat and High Flat Profiles, but not statistically different from each other. The last column of Table 6 shows the Least Squares Mean (in feet) for each of the Age Group and Profile combinations.

Table 6. Age Group, Profile Groupings

Profile					Least Sq Mean (ft from sign)
Younger – High Flat	A	B			486.63952
Younger – High Early	A	B			475.55244
Younger – Med Flat	A	B			466.25930
Older – Med Flat	A		C		425.54648
Older – High Flat	A		C		421.98691
Older – High Early	A	B	C	D	390.33895
Older – High Late	A	B	C	D	386.72849
Younger – High Late			C	D	378.43421
Younger – Min Flat			C	D	376.94781
Younger – Low Flat			C	D	349.64708
Older – Low Flat		B		D	328.98207
Older – Min Flat		B		D	326.42294

Table 7 contains the least squares means for the Visual Acuity Group, and Table 8 contains the corresponding t-test results. It is evident from Table 8 that the data supports that the Mean Legibility Distance for subjects with 20/20 vision or better is higher than the Mean Legibility Distance for subjects with 20/25 vision or worse.

Table 7. Least Squares Mean for Visual Acuity Group

Visual Acuity Group	Least Sq Mean (ft from sign)
20/20 and Better	451.50807
20/25 and Worse	350.73964

Table 8. Comparison of Visual Acuity Groups

Difference	-100.77	**t Ratio**	-1.96138
Std Err Dif	51.38	**DF**	28
		Prob > |t|	0.0598
		Prob > t	0.9701
		Prob < t	0.0299

CONCLUSION

The profiles with the greatest performance in this project were the High Flat, Medium Flat, and High Early Profiles. The High Flat Profile produced the highest value for Legibility Distance, which makes it the Profile of choice. However, as shown in Table 2, the peak Luminance level for the High Flat Profile is 80 cd/m^2, which is a very high value by today's standards of retroreflective sheeting. The Medium Flat Profile's peak is 30 cd/m^2, and the High Early Profile's peak is 40 cd/m^2.

Based on the work presented in this paper, it appears that luminance levels near 30 cd/m^2 provide a breakeven point considering nighttime legibility of drivers young and old and the costs associated with providing brighter and brighter signs. It should be noted that additional work is needed and this finding is based on the limited analysis of one sign. Additional legibility data will be analyzed as well as eye tracker data, which is expected to provide even greater resolution in the findings.

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