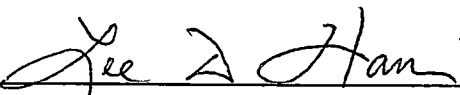


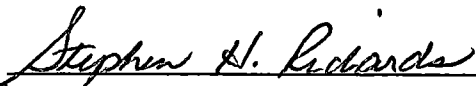
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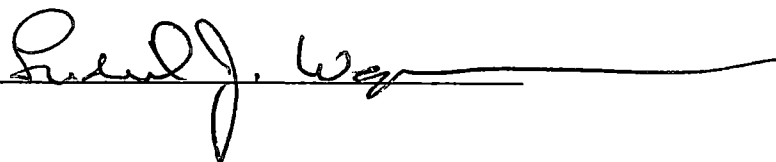
I am submitting herewith a thesis written by Timothy Bruce Luttrell entitled "An Analysis of Red Lens Strobe Signals and Their Effect on Reducing Right Angle Traffic Accidents." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.



Dr. Lee D. Han, Major Professor

We have read this thesis
and recommend its acceptance:





Accepted for the Council:



Associate Vice Chancellor
and Dean of the Graduate School

An Analysis of Red Lens Strobe Signals
and Their Effect on Reducing
Right Angle Traffic Accidents

A Thesis
Presented for the
Master of Science
Degree

The University of Tennessee, Knoxville

Timothy Bruce Luttrell
August 1999

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ABSTRACT

Many intersections across the United States experience high accident rates due to certain physical limitations and human-related factors. Often times many of these accidents can be attributed to limited sight distance, conflicting background conditions, or possibly the existence of an isolated signal in a rural area. Installation of a red lens strobe signal may potentially alleviate large numbers of certain types of accidents, by helping to drawing the driver's attention to the traffic signal. A limited number of studies have been performed with respect to determining the level of effectiveness of the strobe signals.

This study evaluates the effectiveness of red lens strobe signals currently in use in Knoxville. Accident data and volume data were obtained and accident rates were calculated for the intersections. The accident rates for both intersections before strobe installation were compared with the accident rates after installation. Based on a percent reduction in accident rate, this study demonstrates that strobe signals can be effective in reducing right-angle traffic accidents in some instances.

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I. INTRODUCTION

Background

Many cities experience traffic safety related problems at certain signalized intersections. Many substantial changes in traffic behavior have occurred, as well as increases in vehicle volumes and vehicle miles traveled (VMT). Although construction and upgrade activities allow for safer intersections, many still experience problems with respect to the safe movement of traffic.

To improve safety, the Traffic Engineering Department at the City of Knoxville has been experimenting with different traffic control devices. When a high accident location is discovered, traffic engineers analyze the types of accidents to determine what actions should be taken. At several intersections included in this study, advance-warning signs were installed to make drivers more aware of the signals. Clearance intervals were also increased to approximately four seconds of yellow time and 2 seconds of all red. These control measures were not successful in decreasing the number of traffic accidents at the intersections. This thesis will analyze a relatively new traffic control measure used by the City of Knoxville.

Problem Statement

The Literature Review of this thesis outlines several studies that have been performed to determine the effectiveness of red lens strobe signals on reducing traffic accidents. The problem of determining when a strobe is appropriate is not as simple as determining an outcome from one study and transferring the results to another location. The characteristics of an intersection are unique, as well as the accident problems associated with the intersection. This study will attempt to determine the effectiveness of red lens strobe signals on their respective intersections.

Several types of traffic control devices are in use today, but certain types of devices may be more appropriate in certain situations. For example, intersections that experience a high number of accidents due to limited signal sight distance may need an advanced warning device instead of a strobe lens. However, a signalized intersection may require a red lens strobe facing the westbound approach to assist drivers looking directly into the afternoon sunlight. Another example that may also warrant a strobe lens is a signalized intersection that exists in an

isolated, rural area. Drivers may approach the intersection and not observe the traffic signal after a long stretch of straight, uninterrupted roadway.

This thesis includes an extensive literature review and data analysis procedure. The literature review discusses certain aspects of traffic signals and intersections, including human reaction to a specific color of signal. The review also references other strobe signal effectiveness studies and the conclusions made from such studies. Accident reports were obtained from the City of Knoxville as part of the data collection process. ADT data was collected from the Knoxville Metropolitan Planning Organization. The data analysis process includes calculations such as accident rates and percent reduction in accidents. The effect of the strobe signals on the safety of the intersections in question is summarized in the Results section of this thesis, followed by conclusions.

II. LITERATURE REVIEW

Relevant Research Topics

Several studies have been performed to determine the effectiveness of certain colors on human perception.

According to New York optometrist Dr. Stephen Solomon, red is a color that is difficult to see by the average eye.

Also a volunteer firefighter, Dr. Solomon has stated that most fire rescue related equipment and vehicles are moving away from the traditional red towards a lime-yellow color.

A study was also performed to determine the effects of vehicle color on emergency vehicle accident rates at intersections. It was concluded that red vehicles had twice the number of accidents as lime-yellow vehicles. This evidence has also been used to persuade Insurance companies to lower rates for lime-yellow equipment in fire department policies. It has been suggested that red is a difficult color to see, therefore it must either be accompanied by a contrasting color or changed for effect.

With respect to strobe-supplemented red lens signals, several studies have been performed to determine possible advantages to using the strobe lens. One study confirmed the fact that several jurisdictions use the strobe supplement, including several in Florida, Oregon, Maryland,

South Carolina, North Carolina, Kansas, New York, and Tennessee. The strobe lenses were expected to be useful in reducing accident frequency at given locations. One study was performed to determine where strobe signals were used, why they were used, how accident rates were effected, and whether or not officials believe that they are effective.

This particular study commented on the fact that little has been written on the subject. It was stated that strobe signals had been in use for at least ten years prior to the study, or since the mid-1970's. Most of the information available at the time of this study was in the form of unpublished reports and memoranda from the strobe users.

Several different types of strobe-supplemented signals are in use today. The orientation of the strobe may be vertical or horizontal, and will likely be centered in the lens. Another type of strobe lens, named Halo, includes a circular ring around the normal 8 inch red lens of the signal. The intersections being studied in Knoxville utilize the Barlo strobe lens, which is horizontally oriented in the center of the red lens.

This study also included extensive research in determining what locations across the United States use

strobe- supplemented red indications (SSRI). Jurisdictions using SSRIs were located through the author's experience, conversations with the strobe manufacturer, and the Federal Highway Administration. Once the jurisdictions were located, cover letters and questionnaires were mailed out. Some of the data was not obtained because not all jurisdictions responded, and some of the ones who did respond did not have retrievable accident and volume data. Data that was deemed usable for the study was from only ten intersections, while a minimum of 57 locations used SSRI's.

Several reasons were given for installing strobe signals. The reasons fell into two main categories: excessive accident experience and the need to draw driver attention to an unexpected signal. The main types of accidents included in the responses were right-angle accidents and rear-end accidents.

The mean number of accidents per year before installation was compared with the mean number after installation. It was noted that a true before and after comparison could be biased based on the variation in the total number of accidents at a location. The null hypothesis stated that the mean number of accidents did not significantly change after installation. In five of the

six categories of accidents, increases were outweighed by decreases. However, the results were deemed to be "not statistically impressive".

Sign tests were used to compare before and after data. Accident rate categories were established and an analysis was performed. For categories such as "approach with strobe", the accident rates were found by dividing the number of accidents by the average daily traffic (ADT) for the approach. This number was then multiplied by one million. The same situation as above holds true, and the results were deemed to be "not statistically impressive".

These sign tests were also performed by intersection in that the mean yearly accident rate before installation was compared to the mean after installation. The same null hypothesis was utilized for this instance. Categories included right-angle accidents, rate of right-angle accidents, rear-end accidents, and rate of rear-end accidents. Another test, the t-test, determined that none of the differences were significant at the ten-percent confidence level.

This study concluded that many intersections equipped with strobe signals experienced a decrease in the number of accidents and accident rates. However, no statistical

significance can be attached to these decreases (Ryan 1984).

Another study was performed relative to railroad grade crossings. Several strobe lights were installed in Illinois to supplement conventional lights at the crossings. The lights were installed at seven grade crossings that were already protected by gates and other flashing lights. The results of this study were based on certain preliminary findings, one of which was traffic accident experience. The data that was used for accident analysis involved grade crossing related accidents that occurred when the crossing lights were fully functional. While researchers concluded that strobe lights are an effective warning device for oncoming motorists, results of the traffic accident analysis were deemed inconclusive (Bates 1986).

Another study was performed to analyze current traffic accident countermeasures with respect to high-speed signalized intersections. This study determined that certain problems arise after a new traffic signal is introduced, as well as when approaches to the signal offer poor visibility. One of the problems can be attributed to

the dilemma zone, where drivers are not able to stop soon enough or proceed through the intersection safely.

It was determined that the most frequently used countermeasures for this type of problem are active advance warning devices. These control devices have the ability to warn drivers sooner as to whether or not they should be prepared to stop or proceed. The red lens strobe signal was also studied, and the results were based on a review of current literature and a survey of practicing traffic engineers.

The above mentioned survey included the collection of data on the nature and severity of the accident problem, along with the evaluation of the implemented countermeasures. Response rates to the questionnaire were 62 percent for state agencies, 19 percent for local agencies, and 30 percent of all those surveyed responded in a complete and useful nature.

The surveyed agencies were asked to rank the problems they had experienced in order of descending importance. For local agencies, the main accident problems were experience at intersections hidden by horizontal or vertical curves. State agencies ranked rural intersections with unexpected signals as their main problem area,

followed by intersections hidden by horizontal curves, rural expressways with heavy truck traffic, and intersections hidden by crest vertical curves. Of the agencies that responded, it was concluded that most had used accident countermeasures as efforts to mainly reduce right-angle and rear-end accidents.

The survey also inquired about the type of countermeasures used by different agencies to reduce accident problems at high-speed signalized intersections. The most frequent countermeasures were traditional approaches to accident problems, detector placement, and clearance intervals. State agencies reported that flashing "red signal ahead" signs were the most widely used dynamic control device, followed by "prepare to stop when flashing" signs, and the least used device was reported to be the strobe signal.

Another category on the survey form dealt with effectiveness of the countermeasures. At the state level, detector placement and flashing "red signal ahead signs" were deemed the most effective. Flashing "signal ahead" signs and flashing strobe signals were rated just better than neutral. Local agencies placed a similar rating on the use of strobe signals; while other countermeasures such

as "prepare to stop when flashing" signs were rated higher than strobes.

The questionnaire also asked for the results of any statistical analyses that were performed on the respective countermeasures. More than one half of the studies involved evaluation of the flashing strobe signal. The results showed that while the strobe signals were effective in reducing right-angle accidents, no statistical significance could be attributed to the strobes.

In conclusion, the most popular dynamic devices at high accident locations are advance-warning signs, followed by strobe signals. The red lens strobe signals were also determined to be the least costly of the countermeasures. It was also concluded that activation of the flash at the end of the green cycle is more effective than activation at the beginning of the yellow (Eck and Sabra 1985). Strobe signals provide agencies with an alternative to other warning devices.

Other research was performed to describe exactly which situations and locations are determined to be prime candidates for strobe signals. In one particular study, it was determined that isolated intersections, unexpected signals, and signals following a transition from a grade-

separated highway to one with at-grade intersections were the main locations where strobes were used. Some locations, including intersections in North Carolina, also use other countermeasures concurrently with the strobe signal, making it impossible to determine the effectiveness of the strobe by itself.

This study noted that specific characteristics of an intersection lead agencies to the determination that a strobe signal would help reduce traffic accidents. Most agencies have no guidelines for strobe installation, and any type of preliminary studies or evaluations did not precede many of the installations. Some of the main reasons for installation included high truck volumes and high speed, accident experience, roadway geometry, and other features providing limited sight distance.

A "before and after" analysis was performed to determine the effects of the strobe lens on right-angle accidents, rear-end accidents, and total accidents. Based on three years of before data and three years of after data, the study concluded that there was no evidence that the strobe signals are effective in reducing traffic accidents. Also, it was noted that there was no basis for recommending the use of strobe signals, and the findings

could be used to justify the removal of such signals (Cottrell 1985). However, the fact that each intersection has unique characteristics makes it difficult to conclude that strobes will be ineffective at every intersection.

The Tennessee Department of Transportation uses a combination of techniques to analyze and rank the safety of certain intersections and roadways. In identifying high accident locations, TDOT combines a rate quality control method with the calculation of a severity index. An actual accident rate is calculated along with a critical accident rate. The actual rate is then compared to four times the critical rate (factored in order to account for limited resources). If the actual rate is higher than the factored critical rate, the location is considered to be a high accident location. A severity index is also calculated by dividing the sum of the fatal and injury-related accidents by the total number of accidents. The severity index can also be used to rank certain high accident locations with respect to others. Information was not available as to whether or not TDOT uses red lens strobe signals to alleviate certain types of traffic accidents.

An interest in the effectiveness of strobe signals has been seen within the Virginia Department of Transportation.

The Virginia Transportation Research Council determined that the installation of two strobe signals on one approach was more effective in reducing the number of accidents than only one strobe per approach. With respect to total accidents, two intersections with only one strobe per approach experienced an increase in the number of accidents. At two sites with two strobe signals per approach, the total number of accidents decreased by 25% during the period of study (Cottrell 1994).

Several studies have been performed to determine the effectiveness of red lens strobe signals. All of the studies listed in this thesis were performed based upon the use of Barlo strobe signals. No data was found on the effectiveness of the Halo strobe signal versus the Barlo strobe signal. Many of the intersections had two lanes per approach, but only used one strobe signal. A coordinated effort is needed between researchers and a particular agency to carry out a more detailed strobe study. The determination of which intersections are appropriate candidates for strobe signals, as well as more specifics of the installation techniques needs to be identified.

III. RESEARCH APPROACH

Study Site Selections

The Traffic Engineering Department at the City of Knoxville has collected traffic accident reports for the past decade. Engineering technicians have created a database for these reports and filed hard copies of all accidents that have occurred within the city limits. Two intersections were chosen as candidates for red lens strobe signals, Western Avenue/Dale Avenue and Cedar Bluff Road/Interstate 40 Westbound Exit (See Figures 1 and 2).

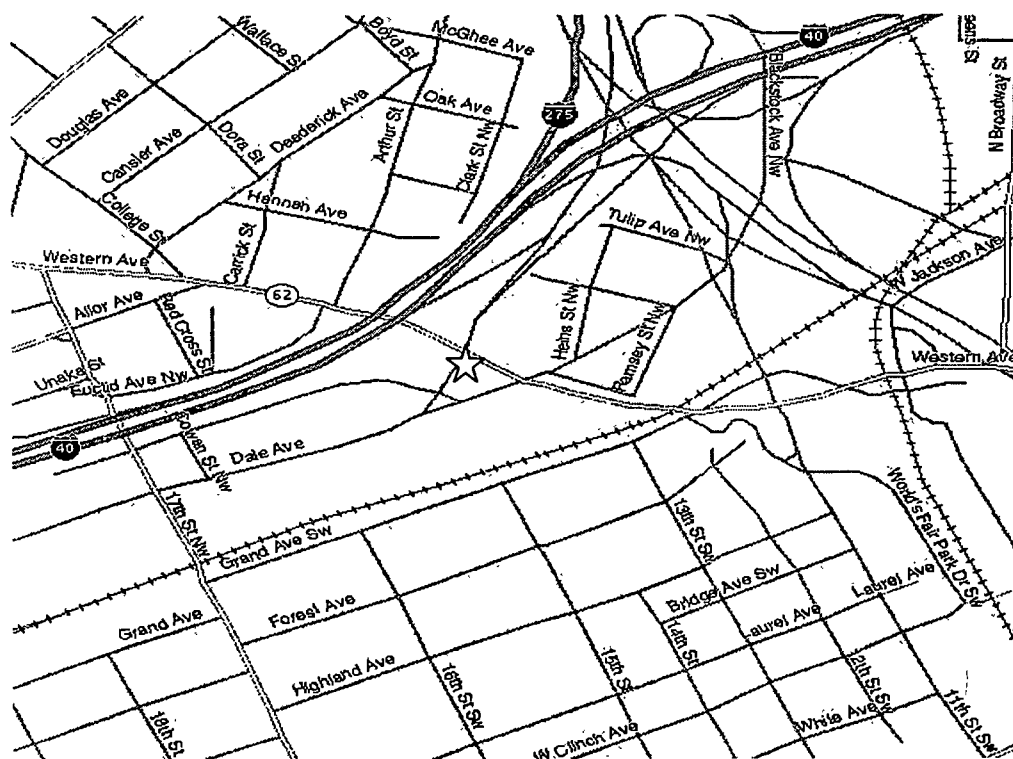


Figure 1. Location Map - Intersection of Western Avenue and Dale Avenue

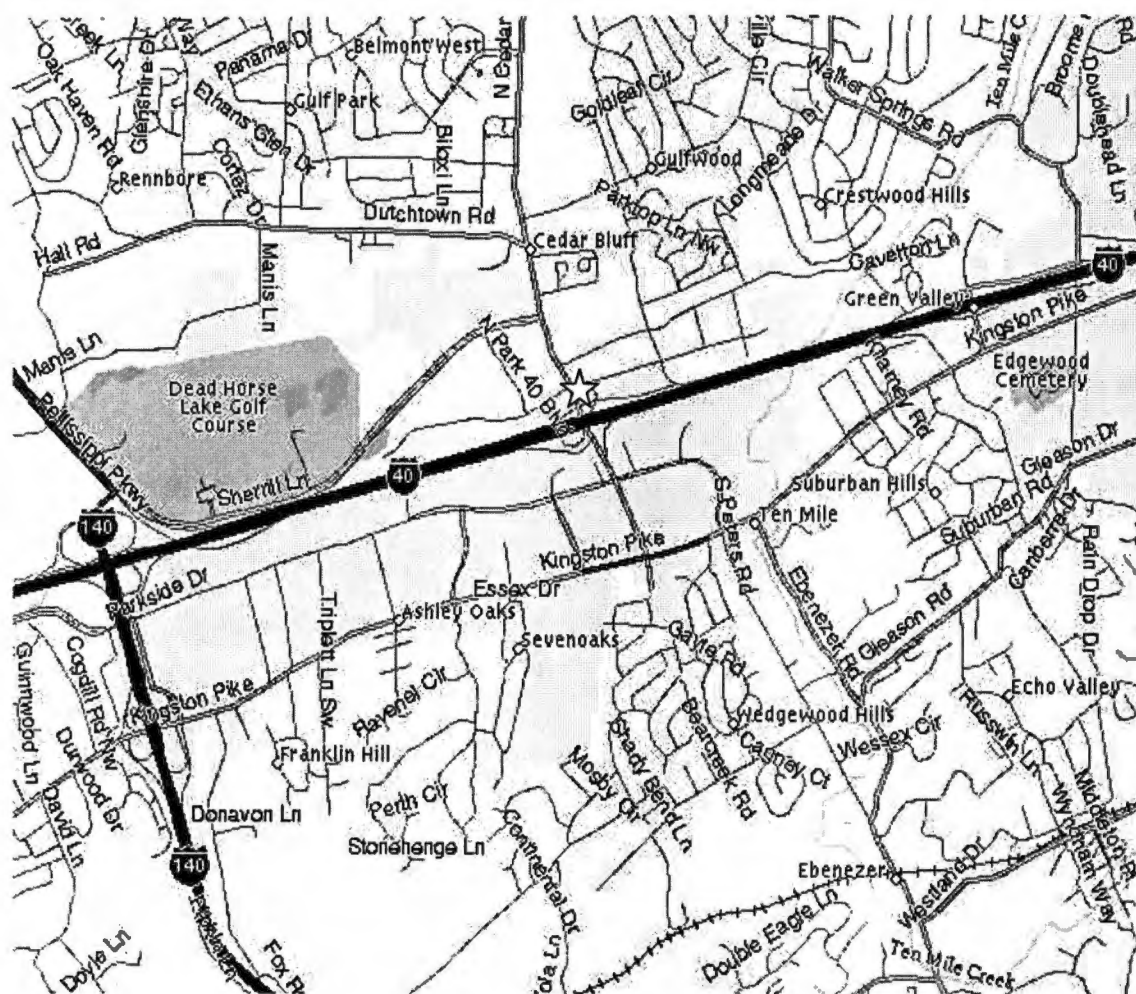


Figure 2. Location Map - Intersection of Cedar Bluff Road and I-40

The Western/Dale strobe was installed on December 29, 1998, while the Cedar Bluff/I-40 strobe was installed on January 4, 1999. The strobe approach on Western Avenue is a combination horizontal and vertical curve, while the strobe approach on cedar bluff road is relatively straight and level. A large number of accidents as well as

complaints from drivers about the visibility of the signal were key components in the decision to install red lens strobe signals at these intersections.

Other intersections in Knoxville currently utilizing strobe signals include:

- Chapman Highway and Stone Road
- Cumberland Avenue and Locust Street
- Kingston Pike and Capital Place
- Kingston Pike and Papermill Road

These intersections were excluded from the study due to problems identifying when the signals were installed. All strobe signals in Knoxville are Barlo strobe lenses, and are manufactured by the Elliott Equipment Corporation in Indianapolis, Indiana.

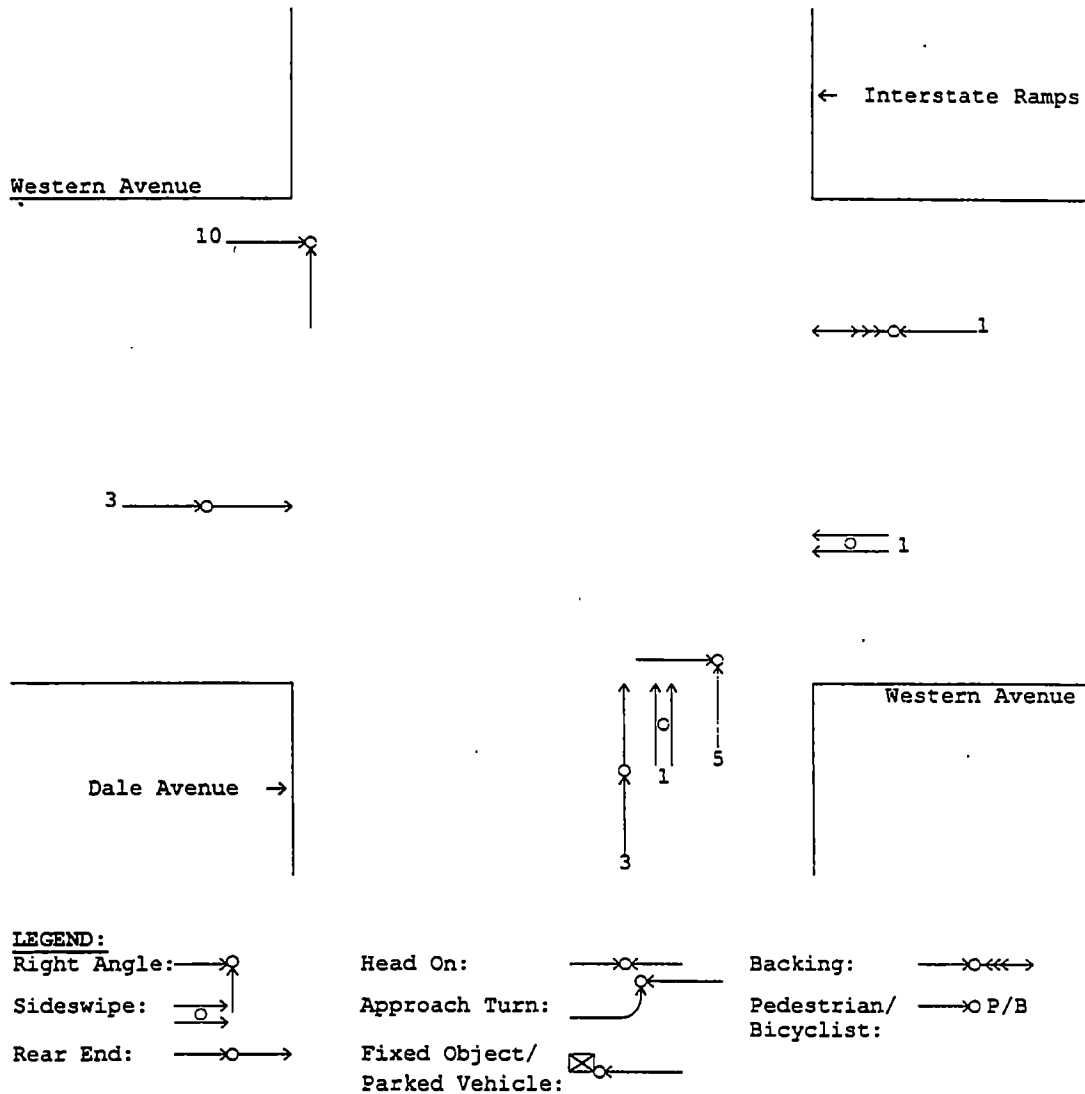
Data Collection

The beginning of the data collection process involved a database search of all accidents at the two specific intersections mentioned earlier. Once the search was completed, a list of accident records was printed and hard copies of all records were obtained from the City of Knoxville. The records were examined and the data was

determined to be substantial enough to analyze. Collision Diagrams were then assembled in order to determine the problems experienced by the intersection (see Figures 3 through 10).

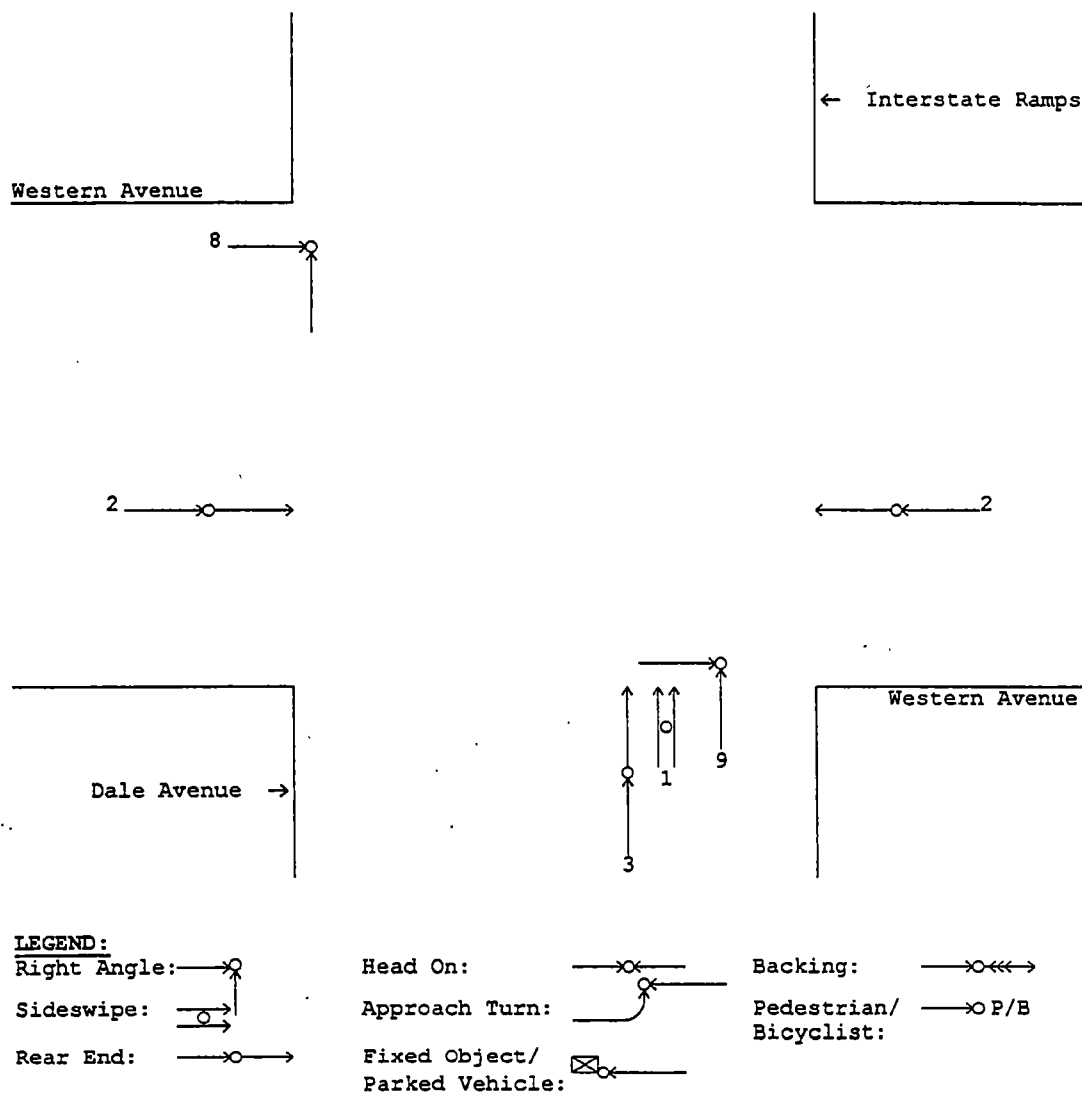
The Collision Diagrams show the total number of accidents for each specific collision type. For example, the 1996 diagram for the intersection of Western and Dale (Figure 1) shows ten right-angle accidents caused by the driver on the eastbound approach. If the right-angle accident symbol is located on the west leg of the intersection pointing east, the eastbound driver was at fault. Other accident types are also shown, including the total number that occurred.

The collision diagrams also showed that drivers who disregarded the signal on the northbound Dale Avenue approach caused a significant number of accidents during each year of the study period. In fact, the signal was disregarded more times on the northbound approach than on the eastbound approach in both 1997 and 1999. After reviewing the diagrams, the City of Knoxville installed a strobe lens on the northbound Dale Avenue approach.



Note: If a circle is filled solid, then at least one of that type of accident had an injury or fatality.

Figure 3. 1996 Collision Diagram for the Intersection of Western Avenue and Dale Avenue



Note: If a circle is filled solid, then at least one of that type of accident had an injury or fatality.

Figure 4. 1997 Collision Diagram for the Intersection of Western Avenue and Dale Avenue

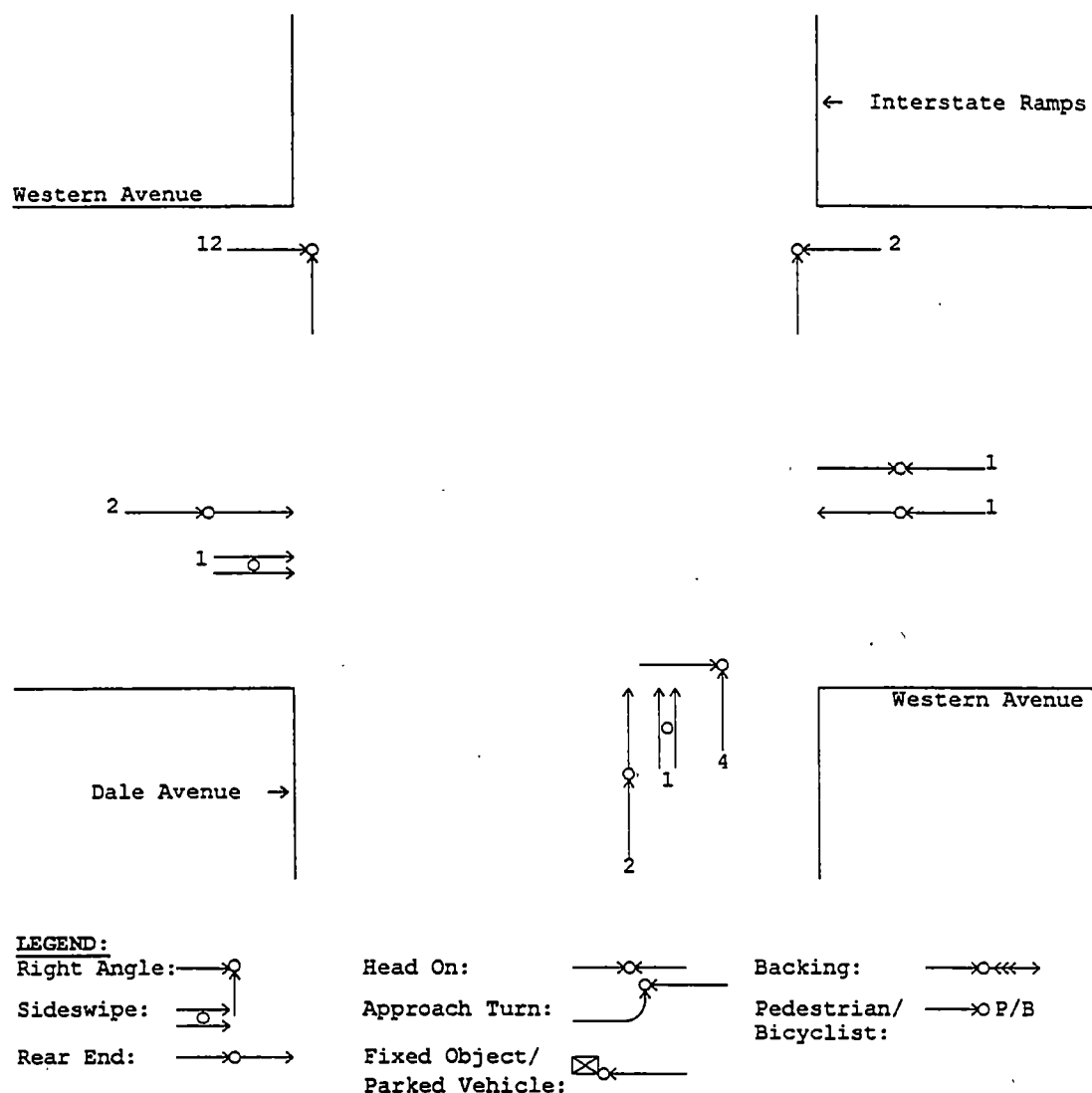


Figure 5. 1998 Collision Diagram for the Intersection of Western Avenue and Dale Avenue

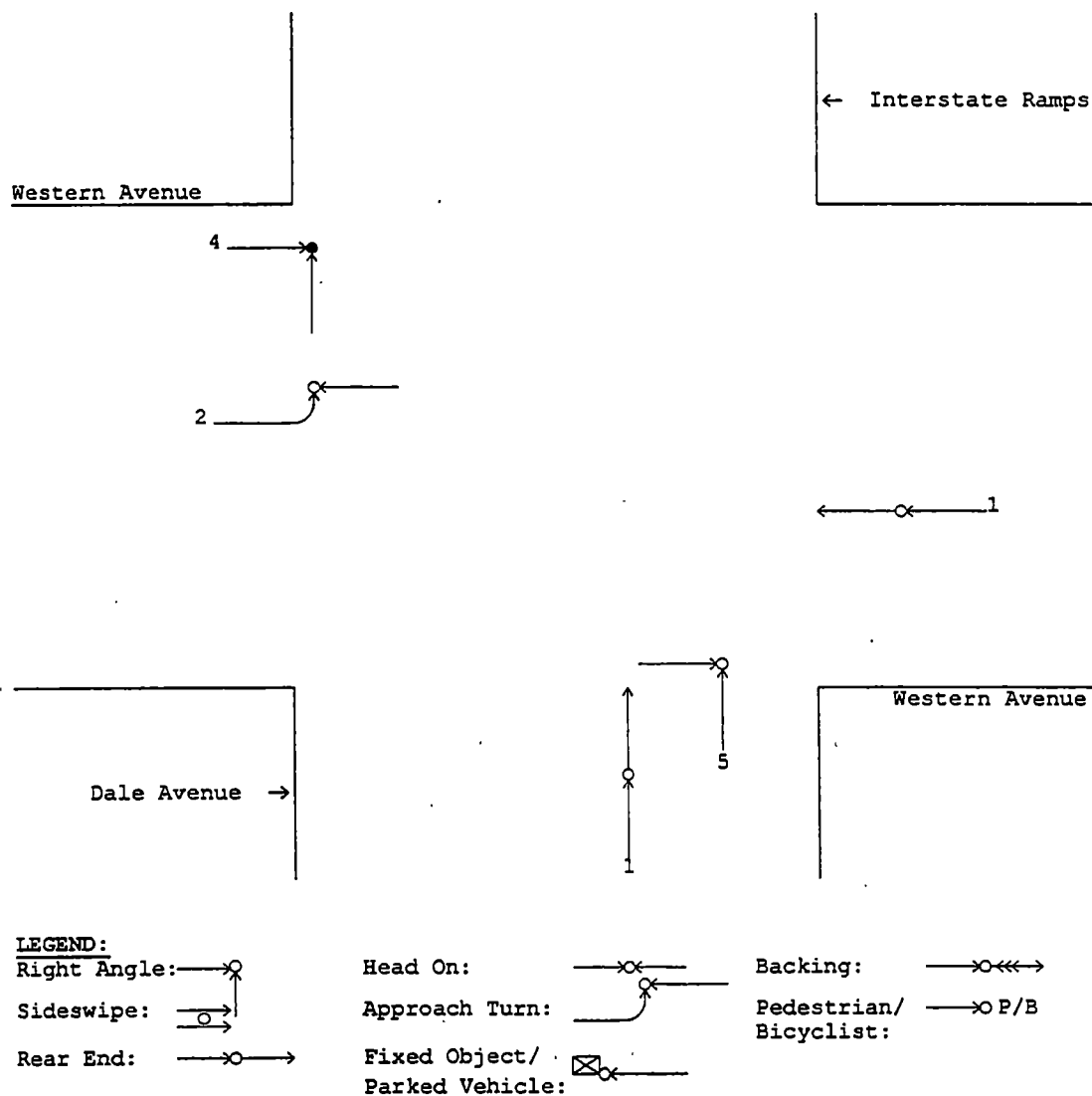
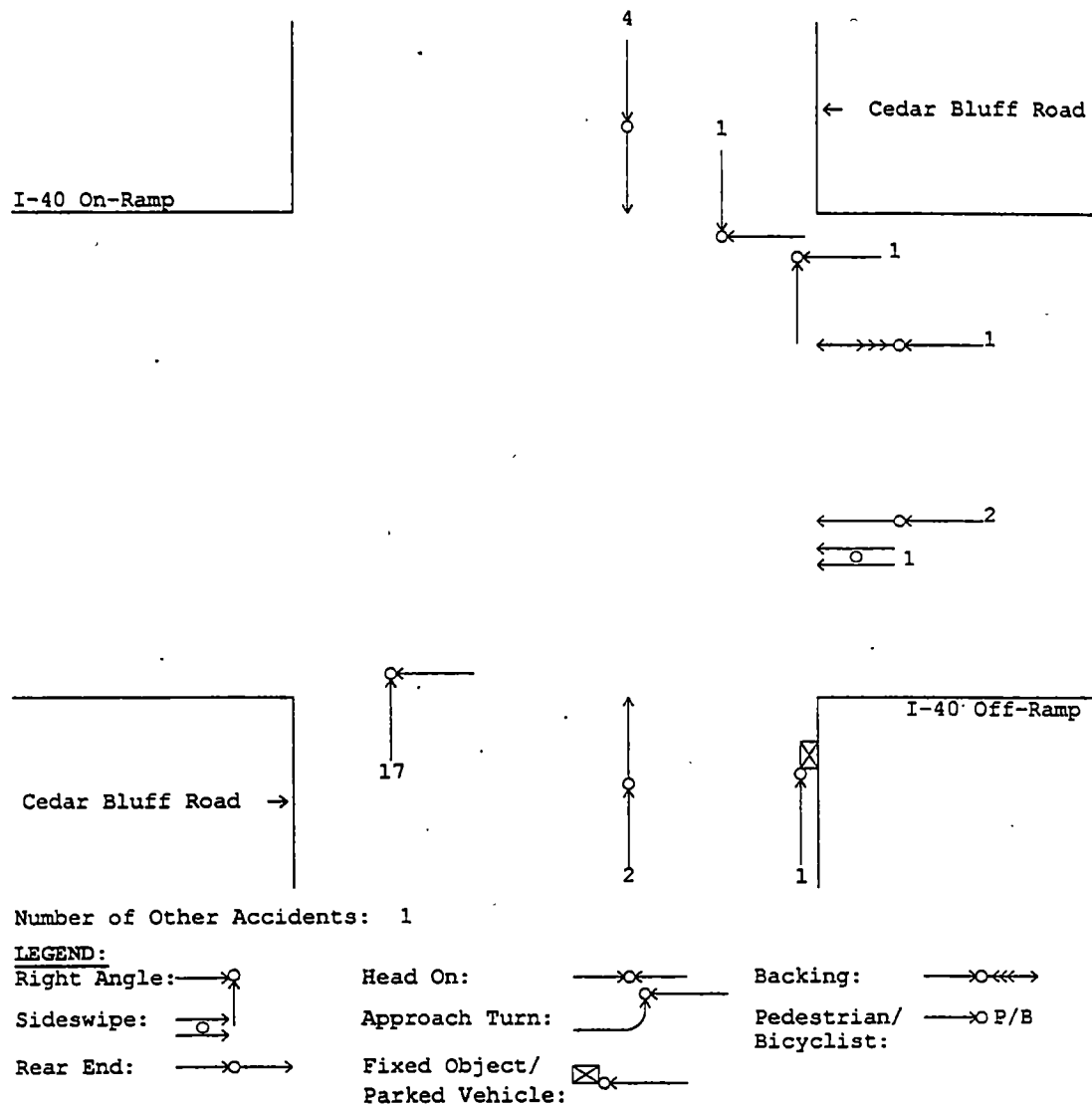
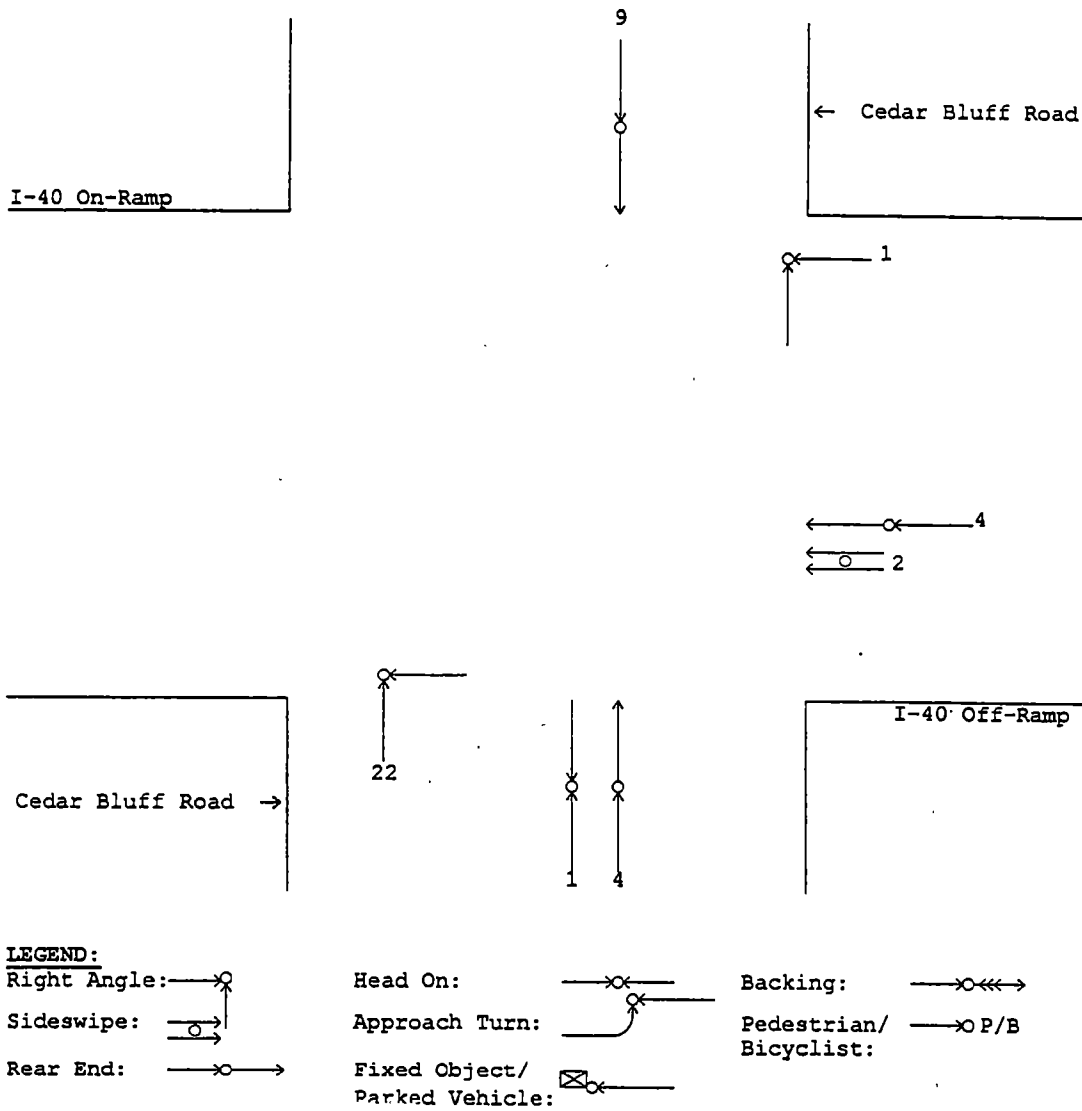


Figure 6. 1999 Collision Diagram for the Intersection of Western Avenue and Dale Avenue



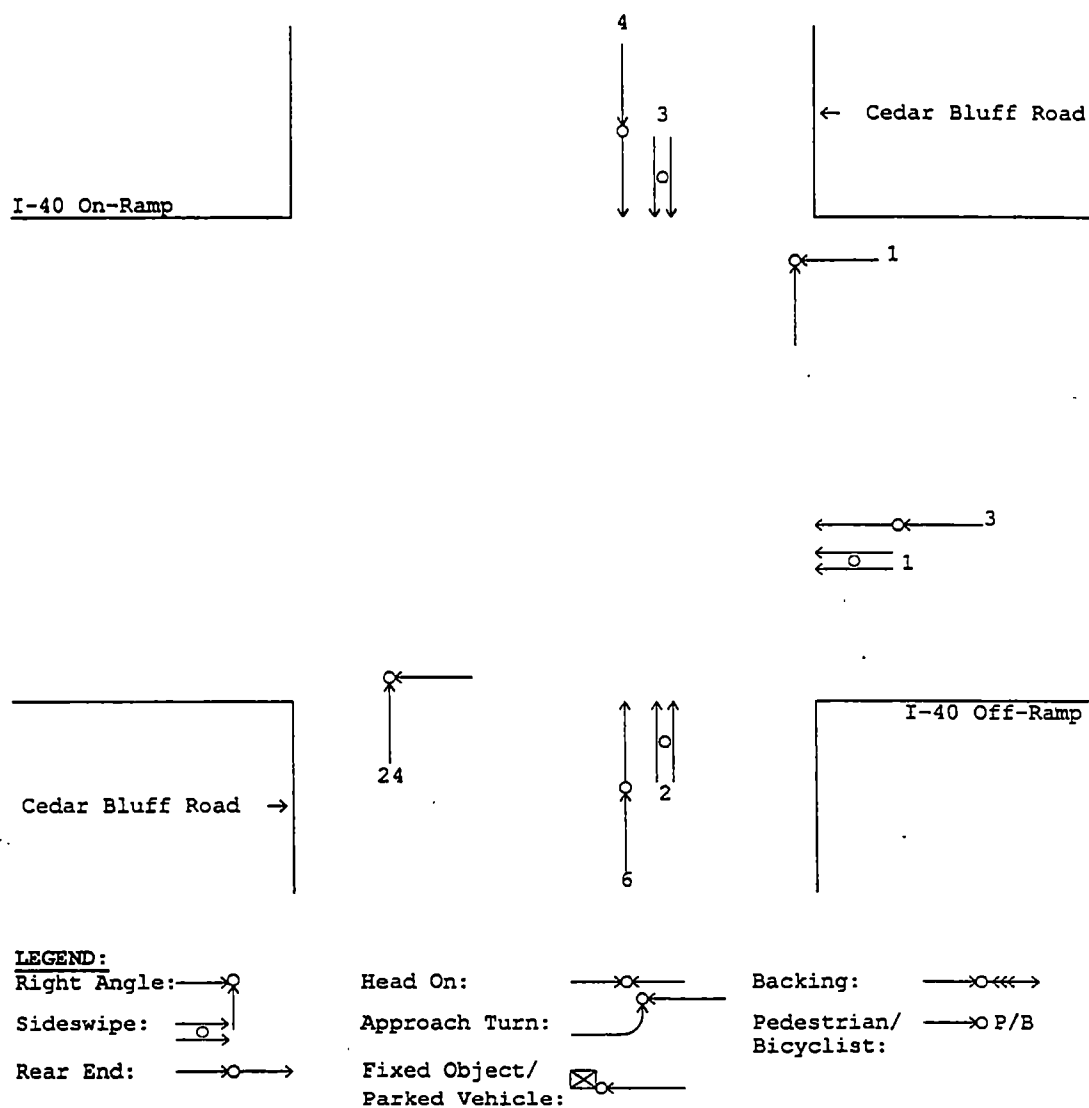
Note: If a circle is filled solid, then at least one of that type of accident had an injury or fatality.

Figure 7. 1996 Collision Diagram for the Intersection of Cedar Bluff Road and the I-40 Westbound Off-Ramp



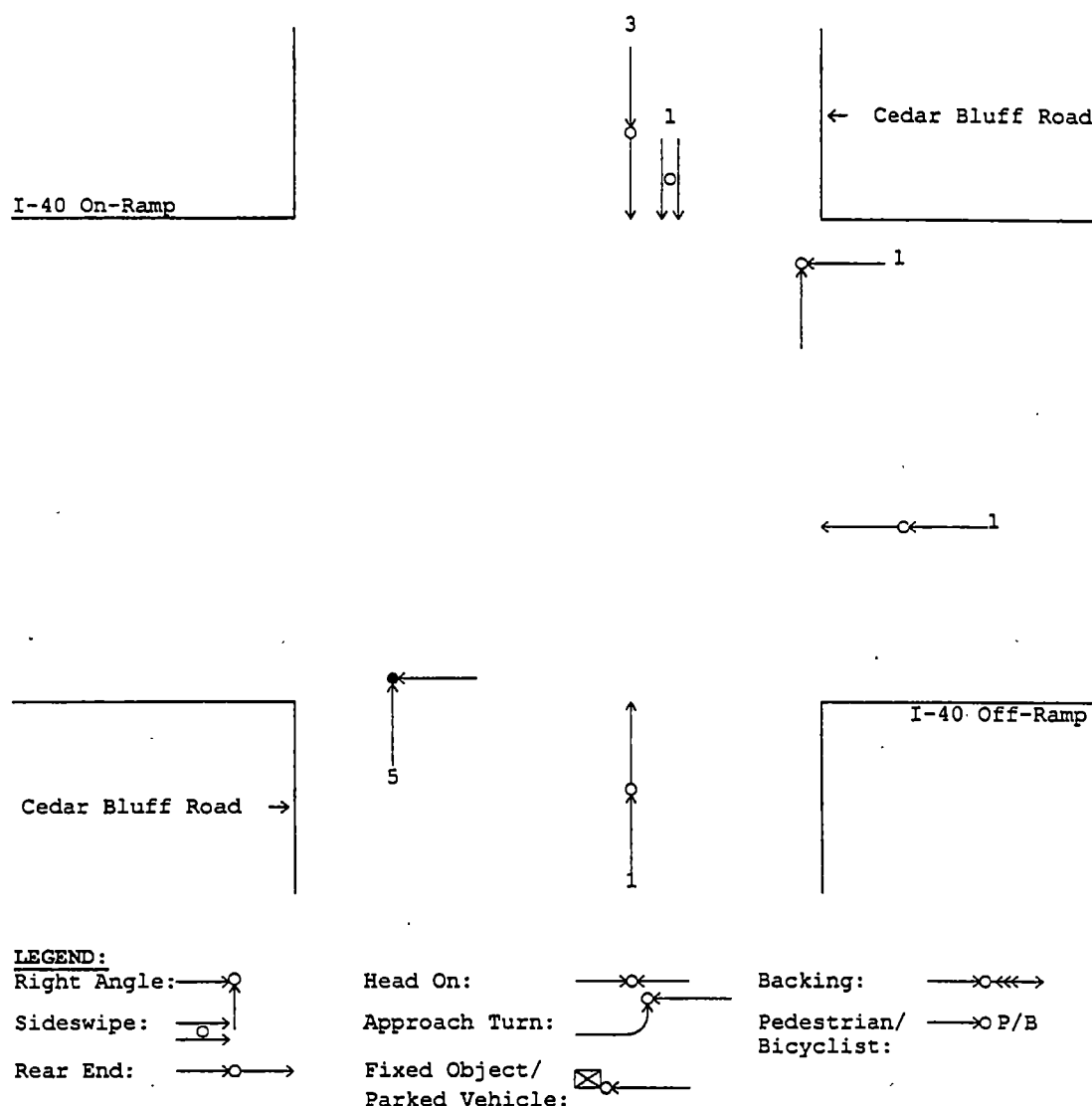
Note: If a circle is filled solid, then at least one of that type of accident had an injury or fatality.

Figure 8. 1997 Collision Diagram for the Intersection of Cedar Bluff Road and the I-40 Westbound Off-Ramp



Note: If a circle is filled solid, then at least one of that type of accident had an injury or fatality.

Figure 9. 1998 Collision Diagram for the Intersection of Cedar Bluff Road and the I-40 Westbound Off-Ramp



Note: If a circle is filled solid, then at least one of that type of accident had an injury or fatality.

Figure 10. 1999 Collision Diagram for the Intersection of Cedar Bluff Road and the I-40 Westbound Off-Ramp

Analysis Types

Many different procedures can be used analyze accident trends. For example, one type of analysis relates the accident history of an improvement that was made at one location with the history of similar locations where no improvement was made (ITE 1978). Both locations of study must involve the same time period. This type of analysis is called a parallel analysis.

Another method of analysis, called performance standard analysis, relates accident data at a location where an improvement has been made with a pre-established standard for the particular improvement (ITE 1978). This type of analysis also helps relate the overall effectiveness of an improvement, and may also help to establish performance standards.

The third main type of analysis is called before-and-after analysis. This type of analysis relates the accident history at a particular location before an improvement is made with the history at the same location after the improvement. Due to the nature of the data available, a before-and-after analysis will be performed on both intersections of interest.

IV. ANALYSIS AND MODEL CONSTRUCTION

Filtering

In before-and-after accident analysis, the "before" study period and the "after" study period should be the same. However, the strobes for the intersections in question were not installed until the end of 1998. This creates a situation where there are three years of data before installation and only six months of data after installation. To account for this difference, only the first six months of each year will be used.

Once the search was performed and all records were obtained, the data set was found to include irrelevant reports. For example, when a search was performed on "Cedar Bluff and Interstate 40" the results would produce several accidents that actually occurred on the Interstate. These reports were excluded in the beginning, and only reports that documented an accident occurring at the two specific intersections were considered part of the data.

Empirical Data Analysis

The categories used in setting up the model include report number, date and time, type of accident, and weather and road conditions. In order to determine if weather was

a main cause of accidents, percentages of accidents that occurred on wet pavement were determined. The accidents of interest at the Cedar Bluff and I-40 off-ramp intersection occurred during dry conditions 82% of the time on average (see Table 1). The accidents of interest at the Western and Dale intersection occurred during dry conditions 86% of the time on average (see Table 2). These percentages were used to rule out the idea that the drivers were unable to stop at the signal due to wet pavement conditions.

Table 1. Road Conditions During Accidents For Intersection of Cedar Bluff and I-40

Year	Road Conditions	Percentage of Accidents Occurring During Conditions
1996	Dry	78
	Wet	16
	Icy/Snowy	6
1997	Dry	79
	Wet	21
	Icy/Snowy	0
1998	Dry	87
	Wet	13
	Icy/Snowy	0
1999	Dry	83
	Wet	17
	Icy/Snowy	0

Table 2. Road Conditions During Accidents For
Intersection of Western and Dale

Year	Road Conditions	Percentage of Accidents Occurring During Conditions
1996	Dry	88
	Wet	12
	Icy/Snowy	0
1997	Dry	100
	Wet	0
	Icy/Snowy	0
1998	Dry	75
	Wet	21
	Icy/Snowy	4
1999	Dry	79
	Wet	14
	Icy/Snowy	7

It is difficult to determine whether or not light conditions had a significant effect on the number of accidents at these locations. Traffic volumes are heavier during the daytime hours, but no volume data was available to represent the difference in night and day traffic. With respect to the number of right-angle accidents, more accidents occurred during the daylight hours for the Cedar Bluff Road intersection. The data for the intersection of Western and Dale was inconclusive.

Statistical/Time-Series Analyses

An automated process was used in order to evaluate the significance of the strobe signals on reducing traffic accidents. A program was written by the Tennessee Department of Transportation (TDOT) to analyze accident rates and exposure before and after an improvement. The program allows the user to input variables such as the number of accidents, ADT, statewide average accident rate, and type of roadway. The program then calculates the percent reduction in accidents.

Several adjustments were made in the data set due to uneven time periods. First, an average number of accidents was determined from the first six months of 1996, 1997, and 1998. The average number of accidents was input into the program and compared with the number of accidents in the first six months of 1999. The period of study before installation was set as the first six months of 1998 for ease of input and analysis. The period of study after installation was input as the actual period, or the first six months of 1999.

A period of study is input into the program to begin the analysis, and the automated process calculates the number of days in the study. Once the data was gathered

and pertinent information was found, several other factors were input into the program. These factors include entering volume, type of highway, and a statewide average accident rate that was obtained from a table of rates made available by TDOT.

Once these variables were input, exposure and exposure rates were calculated. Exposure is defined as the 24-hour total entering volume multiplied by the number of days in the study. The exposure rate is obtained by dividing the exposure by one million. Average daily traffic values were obtained from the Knoxville Metropolitan Planning Organization (MPO) for use in the analysis (See Table 3).

A comparison was made between the critical accident rate, the statewide average accident rate, and the actual accident rate. To calculate the actual accident rate (R_i) the number of accidents was multiplied by one million, and the resulting number was divided by the exposure. Exposure is defined as the number of vehicles entering the intersection.

$$R_i = \frac{A(1,000,000)}{E} \quad (4.3.1)$$

Where: R_i = actual accident rate (acc/mev)
 A = number of accidents of interest
 E = exposure (no. of vehicles)

Table 3. Average Daily Traffic Values

Location	1996	1997	1998	Avg.*	1999
North of Cedar Bluff Road Intersection	31358	30912	36336	32869	38186
South of Cedar Bluff Road Intersection	10350	10800	13419	11523	14592**
East of Cedar Bluff Road Intersection (I-40 Exit)	11330	-	11406	11368	11444**
East of Western/Dale Intersection	18009	17897	18093	18000	19306
West of Western/Dale Intersection	12720	13827	17251	14599	18130**
South of Western/Dale Intersection	6611	-	-	6611	6611**

* Average Used as "Before Installation" ADT

** Projected ADT Value

- Data Not Available

A critical accident rate was then computed based on the following equation.

$$R_c = R_a + K (R_a/M)^{1/2} + (1/2)M \quad (4.3.3)$$

Where: R_c = critical accident rate (acc/mev)
 R_a = average accident rate (acc/mev)
 K = probability constant (1.645 at a 95% confidence level)
 M = exposure (per mev)

Each of the three accident rates is determined in order to make comparisons and classifications. If the actual rate is higher than the average rate and critical rate, then the intersection is considered a high accident intersection (see Figures 11 and 12). The average rate was taken from the TDOT accident rate table for an urban, multilane, divided roadway.

The next step in the process was to determine the percent reduction in accident rate. This percent reduction is calculated based on the following formula.

$$PR = 100 \left(\frac{AR_b - AR_a}{AR_b} \right) \quad (4.3.4)$$

Where: PR = percent reduction in accident rate
 AR_b = accident rate before improvement
 AR_a = accident rate after improvement

Once the percent reduction in accidents is determined, a Poisson test was used to determine the significance of the accident rate reduction. Graphs were drawn and a point was

TENNESSEE DEPARTMENT OF TRANSPORTATION SURVEY & DESIGN DEPARTMENT KNOXVILLE		
Date:	7/1/99	**** ACCIDENT RATES (Intersection)
Calc. by:	Tim Luttrell	
Location:	Cedar Bluff Road and I-40 Westbound Exit Ramp Knoxville, TN	
DATA: Period of study: 1/1/98 to 6/30/98		Use Tab Key to move between shaded cells
Number of accidents: 11 (A) Number of days in study: 180 (T) TMC date: Entering volume: 33564 (C) Day of week: Type of highway: 4 lane urban Statewide average accident rate: 0.26 (Ra) from Table I. Day of week factor: 1 (Fd) from Table II 24 hour expansion factor: 1 (Fp) from Table III.		
24 HOUR TOTAL ENTERING VOLUME: (C)*(Fd)*(Fp) = (SV) (33564) * (1) * (1) = 33564.000 (SV)		
EXPOSURE: (T)*(SV) = (E) (180) * (33564) = 6041520 (E)		
EXPOSURE RATE: (E) / 1000000 = (M) 6041520 / 1000000 = 6.042 (M)		
ACTUAL ACCIDENT RATE (Ri): (A) * 1000000 / (T)*(SV) = (R) (11) * 1000000 / (180 * 33564) = 1.8207 (R)		
CRITICAL ACCIDENT RATE (Rc): $Ra + K(Ra/M)^{1/2} + (1/2M) =$ (0.26) + (1.645) * (0.26 / 6.042)^{1/2} + (1/2(6.042)) = 0.684 (Rc)		CONFIDENCE LEVEL (%) 95.0
SUMMARY: Actual Accident Rate : 1.821 Acc/MV Statewide Average Accident Rate: 0.260 Acc/MV Critical Accident Rate : 0.684 Acc/MV Qualifies for Safety Funding: NO		
SEVERITY INDEX (SI): $SI = \frac{(No. of Fatal Accidents) + (No. of Injury Accidents)}{(Total Number of Accidents)}$ SI = () + () / (11) = SEVERITY INDEX = 0.455 RATIO: R/Rc = 2.662		

Figure 11. Accident Rate Calculations Worksheet
Before Strobe Installation

TENNESSEE DEPARTMENT OF TRANSPORTATION SURVEY & DESIGN DEPARTMENT KNOXVILLE		
Date:	7/1/99	**** ACCIDENT RATES (Intersection)
Calc. by:	Tim Luttrell	
Location:	Cedar Bluff Road and I-40 Westbound Exit Ramp Knoxville, TN	
DATA: Period of study: 1/1/99 to 6/30/99 Number of accidents: 5 (A) Number of days in study: 180 (T) TMC date: AVG ADT Entering volume: 37833 (C) Day of week: Type of highway: 4-Lane Urban Statewide average accident rate: 0.26 (Ra) from Table I. Day of week factor: 1 (Fd) from Table II 24 hour expansion factor: 1 (Fp) from Table III.		Use Tab Key to move between shaded cells
24 HOUR TOTAL ENTERING VOLUME: (C)*(Fd)*(Fp) = (SV) (37833) * (1) * (1) = 37833.000 (SV)		
EXPOSURE: (T)*(SV) = (180) * (37833) = 6809940 (E)		
EXPOSURE RATE: (E) / 1000000 = (6809940) / 1000000 = 6.810 (M)		
ACTUAL ACCIDENT RATE (Ri): (A) * 1000000 / (T)*(SV) = (5) * 1000000 / (6809940) = 0.7342 (R)		
CRITICAL ACCIDENT RATE (Rc): $Ra + K(Ra/M)^{1/2} + (1/2M) =$ (0.26) + (1.645) * (0.26 / 6.810)^{1/2} + (1/2(6.810)) = 0.655 (Rc)		
SUMMARY: Actual Accident Rate : 0.734 Acc/MV Statewide Average Accident Rate: 0.260 Acc/MV Critical Accident Rate : 0.655 Acc/MV Qualifies for Safety Funding: NO		
SEVERITY INDEX (SI): $SI = \frac{(No. of Fatal Accidents) + (No. of Injury Accidents)}{(Total Number of Accidents)}$ SI = (0) + (1) / (5) = SEVERITY INDEX = 0.200 RATIO: R/Rc = 1.121		

Figure 12. Accident Rate Calculations Worksheet
After Strobe Installation

plotted to show the significance of the percent reduction in accidents (see figure 13).

Exposure Data Analysis

A more significant representation of the problem at an intersection is defined by exposure. The fact that certain intersections experience different volumes makes it difficult to limit the analysis to only the number of accidents. Exposure is used as the denominator in the actual accident rate formula. The statistical calculations and explanations above include specifics on exposure and exposure rates.

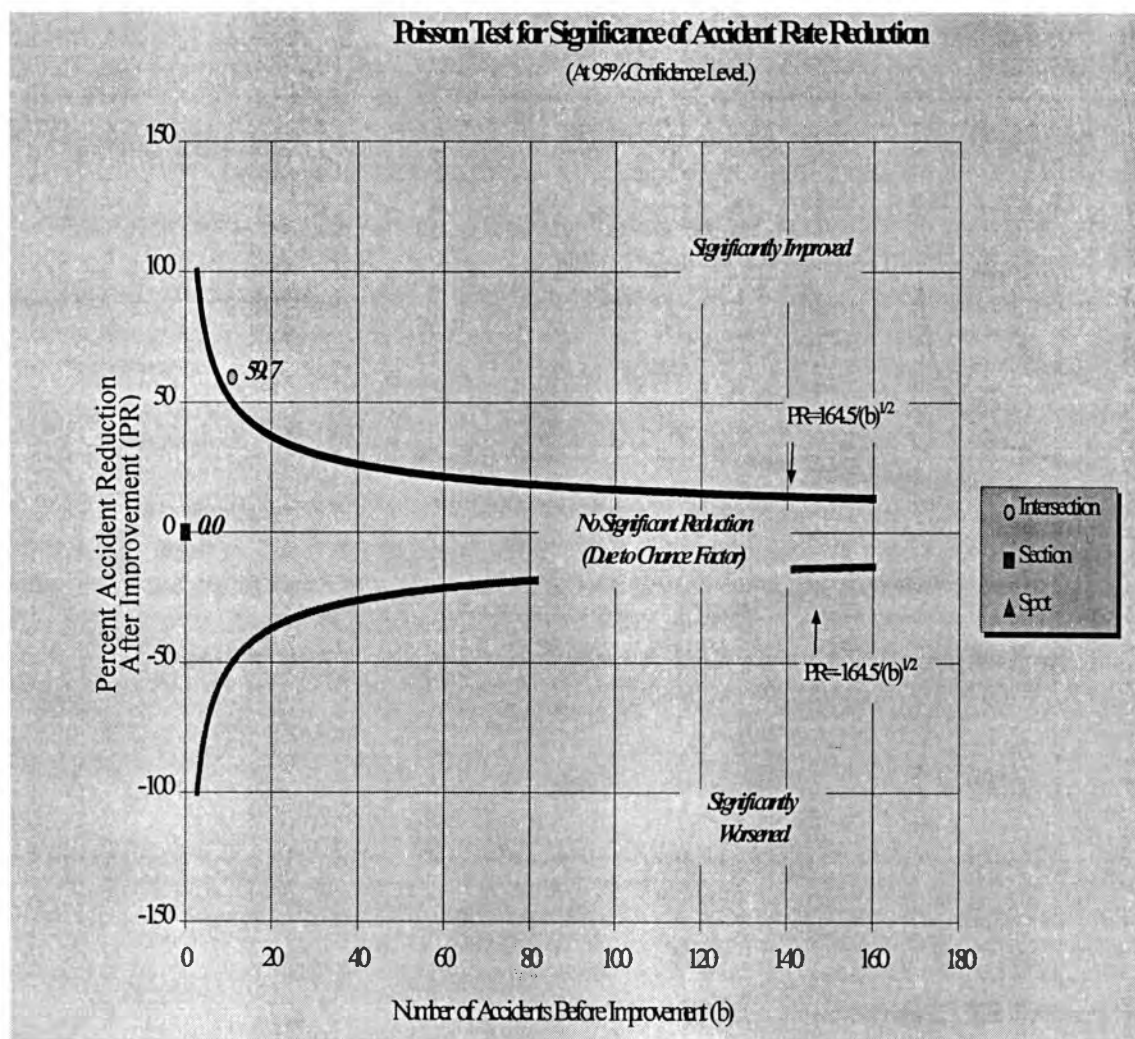


Figure 13. Poisson Test for Significance of Accident Rate Reduction for the Intersection of Cedar Bluff Road and I-40

V. RESULTS

The intersection of Cedar Bluff Road and the Interstate 40 Westbound Exit Ramp experienced a significant reduction in the mean value of right-angle traffic accidents after installation of the red lens strobe signal. The mean number of right-angle accidents before installation was eleven, while the number of accidents after installation for a comparable period was five. The intersection experienced a 60% reduction in the right-angle accident rate, based on the first six months of each year in the study period.

The intersection of Cedar Bluff Road and the I-40 Exit experienced a 37% reduction in total accidents after strobe installation. Based on the Poisson Test, this reduction was plotted and fell just under the line distinguishing significant from not significant. Although the reduction was deemed to be not significant, the strobe did not adversely affect the total number of accidents at this intersection.

Several factors ruled out certain conditions as being the cause of the high accident rate, including the fact that 82% of the accidents occurred during dry pavement conditions and no significant intersection construction or

upgrades were performed during the study period. Based on these facts, it can be concluded that the strobe was effective in reducing right-angle accidents. There was no significant reduction or increase in rear-end accidents at the intersection of Cedar Bluff Road and the I-40 Exit.

The intersection of Western Avenue and Dale Avenue did not experience a significant reduction in the mean value of right-angle accidents. An equal number of accidents of interest occurred during the first six months of 1996, 1997, and 1999. This can be attributed to the fact that the strobe signal follows a combination vertical and horizontal curve. Also, there is less of a difference between safe stopping distance and actual stopping distance for this intersection. The idea that a large number of accidents were caused by pavement conditions was also ruled out based on the fact that on average 86% of accidents occurred during dry conditions. Also, it was apparent that no construction or upgrade activities were performed during the study period.

The intersection of Western and Dale experienced a slight increase in the total number of accidents. However, no significance can be attributed to this increase based on

the Poisson Test. It was inconclusive as to whether the strobe had a significant effect on rear-end accidents.

VI. CONCLUSIONS

This study determined that red lens strobe signals are effective in reducing right-angle traffic accidents in some situations. However, in some cases the strobes are not significantly effective in reducing right-angle accidents. Each intersection has unique characteristics and features such as roadway geometry and driver speeds and habits. Any such characteristic may be a substantial part of the reason why strobes do not effectively alleviate the problem. A preliminary evaluation of an intersection is essential in determining, based on an engineering judgment, whether or not the installation of a strobe lens is appropriate.

The analysis techniques used in this study were chosen based on the type and quantity of data obtained. Other techniques are available and may produce somewhat different results. The conclusions presented in this thesis are based on the previously mentioned analysis techniques. The limitations of this study have been described.

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APPENDICES

Appendix A. Accident Data

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/9/96	9600837	3	14:00	2	2	1	south on cedar bluff
2	1/9/96	9600882	3	21:35	6	3	2	ran light - north on cedar bluff
3	1/26/96	96002722	6	7:10	6	3	4	ran light - north on cedar bluff
4	2/6/96	96003736	4	15:25	2	2	4	north on cedar bluff at light
5	4/26/96	96012221	6	11:26	2	3	1	ran light - north on cedar bluff
6	5/19/96	96014707	1	21:15	6	3	1	ran light - north on cedar bluff
7	6/19/96	96017956	4	1:50	6	3	1	ran light - north on cedar bluff
8	6/25/96	96018647	3	11:27	2	3	2	ran light - north on cedar bluff
9	6/27/96	96018888	5	13:15	2	3	1	ran light - north on cedar bluff
10	6/29/96	96019158	7	15:02	2	3	1	ran light - north on cedar bluff
11	7/13/96	96020649	6	21:11	6	3	1	ran light - north on cedar bluff
12	7/16/96	96021124	3	19:55	2	3	1	ran light - north on cedar bluff
13	7/20/96	96021654	7	19:40	3	3	4	single vehicle accident
14	7/25/96	96022306	5	15:03	2	2	4	following too closely
15	8/2/96	96023269	6	8:27	2	2	2	west on I-40 off-ramp
16	9/5/96	96027414	5	15:17	2	2	1	south on cedar bluff
17	9/12/96	96028154	5	10:58	2	3	1	ran light - north on cedar bluff
18	9/13/96	96028240	6	8:31	2	3	1	ran light - west on I-40 ramp
19	9/15/96	96028465	1	13:55	2	3	1	ran light - north on cedar bluff
20	10/4/96	96030648	6	8:10	2	3	2	ran light - north on cedar bluff
21	10/24/96	96033099	5	10:23	2	3	1	ran light - north on cedar bluff
22	10/31/96	96034058	5	13:19	2	3	1	ran light - north on cedar bluff
23	11/2/96	96034319	7	14:01	2	2	1	backing up at light
24	11/4/96	96034466	2	0:30	6	2	1	west on I-40 off-ramp
25	11/6/96	96034801	4	18:19	6	2	2	north on cedar bluff at light
26	12/3/96	96037847	3	8:50	2	2	1	south on cedar bluff
27	12/5/96	96038059	5	3:01	6	3	2	west on I-40 off-ramp
28	12/13/96	96039136	6	19:11	6	3	2	ran light - south on cedar bluff
29	12/20/96	96039892	6	14:13	2	3	1	ran light - north on cedar bluff
30	12/21/96	96039965	7	0:46	6	2	1	south on cedar bluff
31	12/22/96	96040150	1	19:27	6	3	4	ran light - north on cedar bluff
32	12/31/96	96041123	3	9:55	2	3	2	ran light - north on cedar bluff

1996

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/3/97	97000305	6	14:55	2	4	2	west on 40 off ramp
2	1/10/97	97001315	6	14:30	2	2	2	west on 40 off ramp
3	1/12/97	97001215	1	16:50	2	3	1	ran light - north on cedar bluff
4	1/22/97	97002492	4	23:50	6	3	4	ran light - north on cedar bluff
5	1/29/97	97003345	4	11:05	2	3	1	ran light - north on cedar bluff
6	2/15/97	97005296	7	21:28	6	3	1	ran light - north on cedar bluff
7	2/18/97	97005606	3	19:51	6	3	1	ran light - north on cedar bluff
8	3/11/97	97008165	3	13:46	2	3	1	ran light - north on cedar bluff
9	3/17/97	97008860	2	14:33	2	2	2	ran light - north on cedar bluff
10	3/19/97	97009068	4	8:56	2	2	4	ran light - north on cedar bluff
11	3/25/97	97009798	3	14:41	2	3	1	ran light - north on cedar bluff
12	3/29/97	97010220	7	9:16	2	3	1	ran light - north on cedar bluff
13	3/29/97	97010204	7	3:15	6	2	4	ran light - north on cedar bluff
14	4/11/97	97011777	6	13:11	2	3	1	ran light - north on cedar bluff
15	4/22/97	97013057	3	11:00	2	2	1	ran light - north on cedar bluff
16	4/23/97	97013261	4	23:30	6	3	4	ran light - north on cedar bluff
17	4/23/97	97013210	4	16:45	2	2	4	ran light - north on cedar bluff
18	4/29/97	97013966	3	14:45	2	3	1	ran light - north on cedar bluff
19	5/2/97	97014386	6	18:54	2	2	2	ran light - north on cedar bluff
20	5/11/97	97015463	1	12:44	2	1	1	ran light - north on cedar bluff
21	6/11/97	97019345	4	6:55	2	2	4	ran light - north on cedar bluff
22	6/15/97	97019915	1	14:54	2	3	1	ran light - north on cedar bluff
23	7/15/97	97023623	3	7:49	2	3	2	ran light - north on cedar bluff
24	7/16/97	97023782	4	12:10	2	2	1	ran light - north on cedar bluff
25	7/18/97	97024047	6	12:02	2	3	1	ran light - north on cedar bluff
26	7/23/97	97024780	4	22:47	6	3	4	ran light - north on cedar bluff
27	8/7/97	97026592	5	15:40	2	2	2	ran light - west on 40 off ramp
28	8/11/97	97027032	2	8:19	2	3	3	ran light - north on cedar bluff
29	8/21/97	97028404	5	12:21	2	2	1	ran light - north on cedar bluff
30	8/22/97	97028515	6	9:53	2	2	1	ran light - north on cedar bluff
31	8/23/97	97028703	7	17:44	2	2	1	ran light - north on cedar bluff
32	9/3/97	97030176	4	13:38	2	3	1	ran light - north on cedar bluff
33	9/7/97	97030717	1	13:03	2	4	1	ran light - north on cedar bluff
34	9/23/97	97032965	3	21:58	6	2	1	ran light - north on cedar bluff
35	10/9/97	97035278	5	14:18	2	2	1	ran light - north on cedar bluff
36	10/12/97	97035667	1	0:33	6	2	1	ran light - north on cedar bluff
37	10/16/97	97036270	5	6:45	6	2	1	ran light - north on cedar bluff
38	10/17/97	97036486	6	13:09	2	2	2	ran light - north on cedar bluff
39	11/17/97	97040870	2	17:25	6	3	2	ran light - north on cedar bluff
40	11/28/97	97042287	6	9:45	2	3	1	ran light - north on cedar bluff
41	12/2/97	97042860	3	15:15	2	3	2	ran light - north on cedar bluff
42	12/5/97	97043364	6	19:51	6	3	1	ran light - north on cedar bluff
43	12/23/97	97045796	3	13:00	2	3	2	ran light - north on cedar bluff

1997

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/5/98	98000541	2	15:05	2	3	2	ran light - north on cedar bluff
2	1/9/98	98001042	6	8:07	2	2	2	west on 40 off ramp
3	1/27/98	98003496	3	12:00	2	3	5	ran light - north on cedar bluff
4	1/30/98	98004008	6	18:20	6	4	1	west on 40 off ramp
5	2/9/98	98005174	2	18:32	6	4	2	north on cedar bluff at light
6	3/7/98	98008617	7	14:20	2	2	2	west on 40 off ramp
7	3/31/98	98011727	2	17:36	2	2	1	south on cedar bluff at light
8	4/2/98	98012172	5	13:12	2	3	1	ran light - north on cedar bluff
9	4/15/98	98014089	4	17:52	2	3	2	ran light - north on cedar bluff
10	4/27/98	98015859	2	15:16	2	3	4	ran light - north on cedar bluff
11	5/13/98	98018259	4	9:21	2	3	1	ran light - north on cedar bluff
12	5/14/98	98018474	5	17:02	2	3	2	ran light - north on cedar bluff
13	5/20/98	98019326	4	9:31	2	2	2	north on cedar bluff at light
14	5/22/98	98019701	6	17:10	2	4	2	south on cedar bluff at light
15	5/28/98	98020564	5	15:04	2	3	1	ran light - north on cedar bluff
16	6/1/98	98021154	2	20:23	2	3	1	ran light - north on cedar bluff
17	6/2/98	98021462	4	15:08	2	3	1	ran light - north on cedar bluff
18	6/16/98	98023513	3	8:57	2	3	1	ran light - west on 40 off ramp
19	6/23/98	98024637	3	11:44	2	3	2	ran light - north on cedar bluff
20	6/24/98	98024792	4	13:00	2	3	1	ran light - north on cedar bluff
21	7/25/98	98029543	7	21:15	6	2	1	north on cedar bluff at light
22	7/27/98	98029760	2	10:40	2	3	2	ran light - north on cedar bluff
23	8/5/98	98031159	4	9:38	2	3	1	ran light - north on cedar bluff
24	8/6/98	98031333	5	11:25	2	3	1	ran light - north on cedar bluff
25	8/10/98	98032073	2	21:01	6	2	2	south on cedar bluff at light
26	8/22/98	98033969	7	18:13	2	3	1	ran light - north on cedar bluff
27	8/24/98	98034220	2	13:35	2	3	1	ran light - north on cedar bluff
28	9/24/98	98038992	5	14:26	2	2	2	ran light - north on cedar bluff
29	10/5/98	98040710	2	19:53	6	3	2	ran light - north on cedar bluff
30	10/14/98	98042051	4	16:15	2	4	1	south on cedar bluff at light
31	10/27/98	98043934	3	14:52	2	2	1	north on cedar bluff at light
32	10/28/98	98044128	4	20:47	2	2	2	north on cedar bluff at light
33	11/2/98	98044804	2	16:35	3	4	2	north on cedar bluff at light
34	11/2/98	98044774	2	13:18	2	3	2	ran light - north on cedar bluff
35	11/4/98	98045048	4	7:58	2	2	2	north on cedar bluff at light
36	11/12/98	98046223	5	13:30	2	3	1	ran light - north on cedar bluff
37	11/17/98	98046903	3	7:13	2	3	2	ran light - north on cedar bluff
38	11/18/98	98047144	4	17:17	2	2	1	north on cedar bluff at light
39	11/24/98	98047961	3	11:55	2	2	1	south on cedar bluff at light
40	11/25/98	98048169	4	20:25	6	2	2	south on cedar bluff at light
41	12/2/98	98048956	4	13:27	2	3	2	ran light - north on cedar bluff
42	12/11/98	98050306	6	10:30	2	4	2	south on cedar bluff at light
43	12/15/98	98050975	3	11:35	2	3	2	ran light - north on cedar bluff
44	12/19/98	98051589	7	12:17	2	3	4	ran light - north on cedar bluff
45	12/30/98	98052924	4	14:09	2	2	1	south on cedar bluff at light

1998

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/11/99	99001250	2	10:59	2	3	1	ran light - north on cedar bluff
2	1/25/99	99003476	2	15:10	2	4	1	south on cedar bluff
3	2/3/99	99004516	4	12:35	2	3	1	ran light - north on cedar bluff
4	3/12/99	99009674	6	10:28	2	3	1	ran light - north on cedar bluff
5	3/27/99	99011841	7	13:26	2	2	1	north on cedar bluff
6	3/27/99	99011866	7	16:13	2	3	1	ran light - north on cedar bluff
7	3/31/99	99012400	4	14:05	2	2	4	south on cedar bluff
8	4/16/99	99015036	6	20:31	6	3	1	ran light - west on 40 off ramp
9	4/17/99	99015129	7	12:29	2	2	2	south on cedar bluff
10	5/6/99	99018214	5	9:26	1	2	2	west on 40 off ramp
11	5/14/99	99019571	6	13:43	2	3	1	ran light - north on cedar bluff
12	6/17/99	99021667	5	19:47	6	2	1	south on cedar bluff

666T

Type of Accident Codes
1 - head on
2 - rear end
3 - angle
4 - sideswipe - same direction
5 - sideswipe - opposite direction
7 - other

Day Codes
1 - Sunday
2 - Monday
3 - Tuesday
4 - Wednesday
5 - Thursday
6 - Friday
7 - Saturday

Light Conditions
1 - Dawn
2 - Daylight
3 - Dusk
5 - Dark (No Street Lights)
6 - Dark (Street Lights On)
7 - Dark (Street Lights Off)

Weather Conditions
1 - Clear
2 - Cloudy
3 - Foggy
4 - Raining
5 - Snowing
6 - Other

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/19/96	96002001	6	20:17	6	3	2	ran light - north on dale
2	1/28/96	96002862	1	2:22	6	3	2	failure to yield
3	2/14/96	96004564	4	23:47	6	3	2	ran light - north on dale
4	3/14/96	96007562	5	11:46	2	3	2	ran light - east on western
5	3/31/96	96009404	1	13:00	2	4	2	failure to yield
6	4/13/96	96010729	7	1:16	6	3	2	ran light - east on western
7	4/24/96	96012034	4	21:22	6	3	1	ran light - east on western
8	4/24/96	96012035	4	21:24	6	7	1	secondary
9	4/25/96	96012070	5	6:20	2	3	1	ran light - north on dale
10	6/4/96	96016301	3	11:58	2	4	1	failure to yield
11	6/4/96	96016277	3	7:50	2	3	1	ran light - north on dale
12	6/20/96	96018087	5	7:17	2	2	1	east of intersection
13	7/9/96	96020205	3	10:57	2	3	1	ran light - north on dale
14	7/20/96	96021614	7	14:41	2	2	2	east on western
15	8/4/96	96023529	1	16:22	2	3	1	ran light - east on western
16	8/13/96	96024623	3	13:23	2	7	1	failure to yield
17	9/3/96	96027194	3	19:30	2	3	2	ran light - east on western
18	9/27/96	96029940	6	22:42	6	3	2	ran light - east on western
19	10/5/96	96030821	7	18:03	2	3	2	pushed vehicle in fence
20	10/10/96	96031415	5	23:43	5	3	2	ran light - east on western
21	10/19/96	96032519	7	12:38	2	3	1	ran light - east on western
22	11/6/96	96034722	4	7:55	2	4	2	failure to yield
23	11/13/96	96035631	4	20:00	6	3	2	ran light - east on western
24	11/14/96	96035686	5	11:08	2	3	4	ran light - east on western
25	12/10/96	96038657	3	10:10	2	3	1	failure to yield
26	12/30/96	96041050	2	17:20	3	2	4	failure to yield

1996

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type	Weather	Notes
1	1/11/97	97001129	7	15:00	2	3	2	ran light - east on western
2	1/17/97	97001725	6	0:15	6	2	2	north on dale
3	1/17/97	97001810	6	6:26	6	3	2	ran light - east on western
4	1/23/97	97002629	5	20:08	4	3	2	improper left turn
5	1/23/97	97002563	5	12:20	2	3	2	ran light - north on dale
6	1/30/97	97003490	5	12:50	2	2	1	following too closely
7	2/20/97	97005828	5	12:16	2	4	2	failure to yield
8	3/13/97	97008408	5	13:58	2	3	2	ran light - north on dale
9	4/18/97	97012671	6	23:55	6	3	2	ran light - north on dale
10	4/20/97	97012805	1	8:33	2	3	1	ran light - north on dale
11	4/26/97	97013647	7	21:59	6	3	2	ran light - east on western
12	6/23/97	97020863	2	10:52	2	3	1	ran light - one direction
13	6/25/97	97021091	4	1:40	6	3	1	ran light - north on dale
14	9/7/97	97030683	1	3:04	6	3	2	ran light - one direction
15	9/12/97	97031444	6	16:41	2	2	1	following too closely
16	9/13/97	97031650	7	23:55	6	3	1	failure to yield
17	9/18/97	97032201	5	10:31	2	2	1	following too closely
18	9/18/97	97032282	5	21:47	6	3	1	fatality - northbound
19	9/19/97	97032385	6	16:20	2	2	1	following too closely
20	10/3/97	97034530	6	22:55	6	3	1	ran light - east on western
21	10/8/97	97035134	4	11:40	2	3	1	ran light - east on western
22	10/9/97	97035236	5	9:25	2	3	1	failure to yield
23	10/13/97	97035819	2	11:25	2	2	1	following too closely
24	10/22/97	97037173	4	15:21	2	2	1	ran light - east on western
25	11/11/97	97039906	3	6:52	1	3	2	ran light - east on western
26	11/23/97	97041652	1	11:35	2	3	1	ran light - east on western
27	11/25/97	97041950	3	13:42	2	3	1	ran light - north on dale

1997

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/2/98	98000110	6	11:34	2	2	1	following too closely
2	2/7/98	98004981	7	21:18	6	3	1	ran light - north on dale
3	4/3/98	98012416	6	21:42	6	3	4	ran light - north on dale
4	5/30/98	98020819	7	6:08	1	4	1	eastbound on western
5	6/3/98	98021405	4	9:10	2	3	1	ran light - north on dale
6	6/4/98	98021581	5	11:00	2	3	2	ran light - east on western
7	7/2/98	98025967	5	15:44	2	3	1	turning - failure to yield
8	7/9/98	98026934	5	12:10	2	2	1	following too closely
9	7/10/98	98027157	6	17:33	2	3	1	ran light - east on western
10	7/19/98	98028567	1	22:08	6	3	1	ran light - west on western
11	7/24/98	98029296	6	11:09	2	3	4	ran light - east on western
12	7/29/98	98030131	4	18:56	2	1	1	driver in insulin shock
13	8/15/98	98032823	7	13:41	2	3	4	ran light - east on western
14	8/16/98	98032938	1	7:35	2	3	4	ran light - east on western
15	8/25/98	98034462	3	19:17	2	3	1	ran light - north on dale
16	9/18/98	98038061	6	9:45	2	3	1	ran light - east on western
17	9/20/98	98038452	1	21:47	6	3	1	ran light - east on western
18	9/22/98	98038711	3	15:56	2	4	1	ran light - east on western
19	10/1/98	98040041	5	11:11	2	2	1	ran light - north on dale
20	11/6/98	98045359	6	10:24	2	2	2	following too closely
21	11/10/98	98045973	3	18:20	6	3	4	ran light - west on western
22	11/15/98	98046709	1	21:30	6	3	1	ran light - east on western
23	11/24/98	98047978	3	13:38	2	3	1	ran light - east on western
24	11/28/98	98048432	7	8:25	2	3	1	ran light - east on western
25	12/2/98	98048918	4	7:56	2	2	1	failure to yield
26	12/3/98	98049067	5	9:45	2	3	2	ran light - east on western
27	12/7/98	98049693	2	17:22	6	3	4	ran light - east on western
28	12/30/98	98052912	4	13:06	2	3	1	ran light - north on dale

1998

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/4/99	99000353	2	15:17	2	3	2	ran light - north on dale
2	2/2/99	99004359	3	10:31	2	3	4	not permitted left turn
3	2/5/99	99004800	6	16:27	2	3	1	failure to yield
4	2/24/99	99007476	4	17:06	2	3	2	ran light - north on dale
5	3/4/99	99008572	5	18:21	3	3	1	ran light - north on dale
6	3/25/99	99011590	5	15:48	2	2	1	following too closely
7	3/26/99	99011781	6	21:36	6	3	2	ran light - north on dale
8	4/8/99	99018710	7	23:05	6	3	1	ran light - east on western
9	4/15/99	99014809	5	16:37	2	3	2	ran light - east on western
10	4/15/99	99013110	2	7:14	2	3	1	ran light - north on dale
11	4/5/99	99013238	2	21:31	6	3	1	ran light - east on western
12	5/5/99	99018061	4	12:20	2	3	4	failure to yield
13	6/4/99	99022786	6	17:36	2	2	1	following too closely
14	6/7/99	99023269	2	22:00	6	3	1	ran light - east on western

1999

Day Codes
1 - Sunday
2 - Monday
3 - Tuesday
4 - Wednesday
5 - Thursday
6 - Friday
7 - Saturday

Type of Accident Codes
1 - head on
2 - rear end
3 - angle
4 - sideswipe - same direction
5 - sideswipe - opposite direction
7 - other

Weather Conditions
1 - Clear
2 - Cloudy
3 - Foggy
4 - Raining
5 - Snowing
6 - Other

Light Conditions
1 - Dawn
2 - Daylight
3 - Dusk
5 - Dark (No Street Lights)
6 - Dark (Street Lights On)
7 - Dark (Street Lights Off)

Appendix B. Data Used in the Analysis

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/9/96	96000882	3	21:35	6	3	2	ran light - north on cedar bluff
2	1/26/96	96002722	6	7:10	6	3	4	ran light - north on cedar bluff
3	4/26/96	96012221	6	11:26	2	3	1	ran light - north on cedar bluff
4	5/19/96	96014707	1	21:15	6	3	1	ran light - north on cedar bluff
5	6/19/96	96017956	4	1:50	6	3	1	ran light - north on cedar bluff
6	6/25/96	96018647	3	11:27	2	3	2	ran light - north on cedar bluff
7	6/27/96	96018888	5	13:15	2	3	1	ran light - north on cedar bluff
8	6/29/96	96019158	7	15:02	2	3	1	ran light - north on cedar bluff

1996

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/12/97	97001215	1	16:50	2	3	1	ran light - north on cedar bluff
2	1/22/97	97002492	4	23:50	6	3	4	ran light - north on cedar bluff
3	1/29/97	97003345	4	11:05	2	3	1	ran light - north on cedar bluff
4	2/15/97	97005296	7	21:28	6	3	1	ran light - north on cedar bluff
5	2/18/97	97005606	3	19:51	6	3	1	ran light - north on cedar bluff
6	3/11/97	97008165	3	13:46	2	3	1	ran light - north on cedar bluff
7	3/19/97	97009068	4	8:56	2	3	4	ran light - north on cedar bluff
8	3/25/97	97009798	3	14:41	2	3	1	ran light - north on cedar bluff
9	3/29/97	97010220	7	9:16	2	3	1	ran light - north on cedar bluff
10	4/11/97	97011777	6	13:11	2	3	1	ran light - north on cedar bluff
11	4/23/97	97013261	4	23:30	6	3	4	ran light - north on cedar bluff
12	4/29/97	97013966	3	14:45	2	3	1	ran light - north on cedar bluff
13	5/11/97	97015463	1	12:44	2	1	1	ran light - north on cedar bluff
14	6/15/97	97019915	1	14:54	2	3	1	ran light - north on cedar bluff

1997

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/5/98	98000541	2	15:05	2	3	2	ran light - north on cedar bluff
2	1/27/98	98003496	3	12:00	2	3	5	ran light - north on cedar bluff
3	4/2/98	98012172	5	13:12	2	3	1	ran light - north on cedar bluff
4	4/15/98	98014089	4	17:52	2	3	2	ran light - north on cedar bluff
5	4/27/98	98015859	2	15:16	2	3	4	ran light - north on cedar bluff
6	5/13/98	98018259	4	9:21	2	3	1	ran light - north on cedar bluff
7	5/14/98	98018474	5	17:02	2	3	2	ran light - north on cedar bluff
8	5/28/98	98020564	5	15:04	2	3	1	ran light - north on cedar bluff
9	6/1/98	98021154	2	20:23	2	3	1	ran light - north on cedar bluff
10	6/2/98	98021462	4	15:08	2	3	1	ran light - north on cedar bluff
11	6/23/98	98024637	3	11:44	2	3	2	ran light - north on cedar bluff
12	6/24/98	98024792	4	13:00	2	3	1	ran light - north on cedar bluff

1998

Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
1	1/11/99	99001250	2	10:59	2	3	1	ran light - north on cedar bluff
2	2/3/99	99004516	4	12:35	2	3	1	ran light - north on cedar bluff
3	3/12/99	99009674	6	10:28	2	3	1	ran light - north on cedar bluff
4	3/27/99	99011866	7	16:13	2	3	1	ran light - north on cedar bluff
5	5/14/99	99019571	6	13:43	2	3	1	ran light - north on cedar bluff

1999

1996		Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
		1	3/14/96	96007662	5	11:46	2	3	2	ran light - east on western
		2	4/13/96	96010729	7	1:16	6	3	2	ran light - east on western
		3	4/24/96	96012034	4	21:22	6	3	1	ran light - east on western

1997		Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type	Weather	Notes
		1	1/11/97	97001129	7	15:00	2	3	2	ran light - east on western
		2	1/17/97	97001810	6	6:26	6	3	2	ran light - east on western
		3	4/26/97	97013647	7	21:59	6	3	2	ran light - east on western

1998		Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
		1	6/4/98	98021581	5	11:00	2	3	2	ran light - east on western

1999		Accident #	Date	Local Agency #	Day Code	Time	Light Code	Type (1-4)	Weather	Notes
		1	4/8/99	99018710	7	23:05	6	3	1	ran light - east on western
		2	4/15/99	99014809	5	16:37	2	3	2	ran light - east on western
		3	4/5/99	99013238	2	21:31	6	3	1	ran light - east on western
		4	6/7/99	99023269	2	22:00	6	3	1	ran light - east on western

Appendix C. Average Accident Rates Table

Tennessee Department of Transportation
Average Accident Rates For 1994 - 1996

Type of Location	Type of Accident Rate	Rural					Urban				
		Multilane					Multilane				
		2-Lane	Undivided	Divided	Turn Lane	Freeway	2-Lane	Undivided	Divided	Turn Lane	Freeway
Sections (Accidents/ Million VMT)	Noninjury	1.07	1.05	0.58	1.07	0.29	2.29	3.71	2.04	3.76	0.75
	Injury	0.67	0.57	0.36	0.51	0.15	1.01	1.61	0.93	1.63	0.34
	Fatal	0.03	0.03	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.01
	Total	1.77	1.65	0.96	1.60	0.45	3.32	5.34	2.98	5.41	1.10
Spots (Accidents/ Million Vehicles)	Noninjury	0.32	0.15	0.12	0.20	0.08	0.22	0.17	0.13	0.19	0.08
	Injury	0.20	0.08	0.07	0.08	0.04	0.10	0.07	0.06	0.08	0.03
	Fatal	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total	0.53	0.24	0.19	0.28	0.12	0.32	0.24	0.19	0.27	0.11
Intersections (Accidents/ Million Vehicles)	Noninjury	0.11	0.10	0.08	0.10	0.02	0.17	0.24	0.18	0.24	0.03
	Injury	0.06	0.05	0.05	0.05	0.01	0.07	0.10	0.08	0.11	0.01
	Fatal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total	0.17	0.15	0.13	0.15	0.03	0.24	0.34	0.26	0.35	0.04
Bridges (Accidents/ Million Vehicles)	Noninjury	0.03	0.01	0.02	0.03	0.01	0.03	0.05	0.03	0.02	0.02
	Injury	0.02	0.01	0.01	0.00	0.01	0.01	0.02	0.01	0.01	0.01
	Fatal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total	0.05	0.02	0.03	0.03	0.02	0.04	0.07	0.04	0.03	0.03
Railroad Crossings (Accidents/ Million Vehicles)	Noninjury	0.07	0.27	0.06	0.00	0.00	0.06	0.04	0.08	0.04	0.10
	Injury	0.03	0.27	0.06	0.00	0.00	0.02	0.02	0.04	0.02	0.06
	Fatal	0.00	0.00	0.02	0.07	0.00	0.00	0.00	0.00	0.00	0.00
	Total	0.10	0.54	0.14	0.07	0.00	0.08	0.06	0.12	0.06	0.16

VITA

Timothy Bruce Luttrell was born in Knoxville, Tennessee on May 30, 1975. He attended elementary and middle school in Fountain City, and graduated from Central High School in May of 1993. The following August he entered The University of Tennessee, Knoxville where he received his Bachelor of Science degree in Civil Engineering on May 15, 1998. He then applied to The Graduate School at the University of Tennessee, where he worked as a Graduate Research Assistant while pursuing a Master of Science Degree in Civil Engineering with concentration in transportation engineering. The degree was completed in August of 1999.