



SAFETY EFFECT OF BARRIER CURB ON HIGH-SPEED SUBURBAN MULTILANE HIGHWAYS

RESEARCH REPORT 04690-6

**TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS**

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1. Report No. TTI-04690-6	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle SAFETY EFFECTS OF BARRIER CURB ON HIGH-SPEED SUBURBAN MULTILANE HIGHWAYS		5. Report Date August 1996	
		6. Performing Organization Code	
7. Author(s) Krista Lienau		8. Performing Organization Report No. 04690-6	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. DTFH61-92-X-00019	
12. Sponsoring Agency Name and Address Federal Highway Administration U.S. Department of Transportation 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Interim: Jan. 1993 - Dec. 1994	
		14. Sponsoring Agency Code	
15. Supplementary Notes Agreement Officer's Technical Representative (AOTR): Jeffrey E. Paniati			
16. Abstract Many roadways in growing suburban areas are in need of capacity expansion but have restricted right-of-way due to roadside commercial and residential development. In order to add lanes, shoulders are converted to travel lanes, and the roadway's drainage system is converted from a rural parallel drainage ditch to a curb and gutter section. This report investigated the safety effects of barrier curb on high-speed suburban multilane highways through the collection and analysis of accident data pertaining to these sections. Accident data was collected for 10 before/after Texas sites and 9 matched pair Illinois sites. The data was analyzed with respect to accident rates by accident type, accident severity, and accident characteristic frequencies. Recommendations were made that special attention be given to drainage provisions to prevent storm water ponding on high-speed curb and gutter sections. It was also recommended that lighting be installed to increase nighttime visibility of the curb. Barrier curb is not recommended for use on high-speed suburban multilane highways combining low driveway density with high traffic volumes as it may pose safety problems on this type of roadway.			
17. Key Words Highway safety, barrier curbs, suburban multilane highways		18. Distribution Statement 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) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 84	22. Price

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1. INTRODUCTION

BACKGROUND

Increasing capacity on roadways in developing suburban areas is a major concern of roadway designers as these areas become more urbanized and the roadway volumes continue to increase. Expansion of roadways to increase their capacity is necessary in these developing suburban areas; however, additional right-of-way is difficult and expensive to obtain due to heavy roadside development. Many roadways in need of expansion were originally designed as two-lane rural highways and utilized parallel drainage ditches for drainage. Therefore, to add lanes, shoulders were converted to travel lanes, and the roadway's drainage system was converted from a rural parallel drainage ditch to a curb and gutter section. This conversion eliminated the need to acquire additional right-of-way, and presented a more cost-effective option.

Primarily, these roadway sections were originally designed according to rural guidelines, and the original posted speed limits were in the 50 to 55 mph range. These speed limits generally remain in that range after the roadway modification to satisfy driver expectancy; however, the driveway density associated with these roadways is high due to the roadside development. High posted speed limits and high driveway densities are two characteristics that, in combination with a curb and gutter cross section, may present several design, operational, and safety problems. In essence, the modified roadways contain design elements that are inherently intended for urban low-speed roadways, creating a possibly unsafe facility when traversed at speeds of 50 or 55 mph.

PROBLEM STATEMENT

Due to the concerns arising from the presence of barrier curb on a high-speed roadway section, the demand for these cost-efficient high-speed barrier curb sections may be in direct conflict with the demand for safety. As of yet, these are concerns that have neither been addressed nor resolved. Currently, no guidelines exist for the design of high-speed curb and gutter sections; however, the American Association of State Highway and Transportation Officials (AASHTO) does state that as a precautionary measure, they should not be used on freeways and are considered undesirable on other high-speed arterials. (1) High-speed design, according to AASHTO, has an established minimum speed of 50 mph.

Designers are thus presented with the need for this type of cross-section; however, there are no design guidelines, other than the recommendations against their use. Adequate drainage, lack of shoulders, clear zone requirements, operating versus design speeds, and vaulting are some concerns that need to be addressed to document the safety and operational trade-offs between curb and gutter and rural drainage ditch cross-sections for use on high-speed suburban multilane highways. With these concerns acknowledged and properly analyzed, certain design guidelines may be established which can balance the urban and rural natures of these roadways in a safe and efficient manner. Some design elements that need to be addressed for these transitional sections

include minimum shoulder requirements, minimum clear zone requirements, lane widths, maximum and minimum grades, maximum degree of curvature, and access control.

RESEARCH OBJECTIVES

The objective of this report was to quantify the safety effects (negative and positive) of barrier curb on high-speed suburban multilane highways through the collection and analysis of accident data about these sections. The research hypothesis was that the type, severity, and quantity of accidents occurring on high-speed suburban multilane highways with barrier curb were different from on high-speed suburban multilane highways with a rural parallel drainage ditch design.

To accomplish the objective and test the research hypothesis, the following five tasks were performed:

1. Review the current state of the art through a literature review;
2. Collect accident and roadway data from state databases;
3. Calculate accident rates for accident types on which barrier curb is expected to have an effect (e.g., run-off-the-road accidents) and for certain roadway conditions (e.g., slick roadway surface) expected to cause changes in the accident rates;
4. Analyze accident rates for significant increases and decreases; and
5. Identify the causal factors leading to these changes to provide ideas in the development of design criteria for this type of highway.

ORGANIZATION

This report is divided into five chapters and includes several appendices to present all aspects of the research. Chapter 1 offers background information and defines the scope of this research through the introduction, problem statement, and research objective.

Chapter 2 is a literature review of the state of the art regarding the design practices and guidelines for high-speed barrier curb roadways, and safety research already conducted in this area. The literature review also identifies possible problems associated with these sections.

Chapter 3 describes the study design of this research emphasizing the data collection and the site selection procedures. The data reduction procedure in which accident rates are calculated is included within this section, along with an introduction to the statistical methods used in the analysis of this research.

Chapter 4 presents a detailed description of the methods used in the data analysis and the results from the analysis. Many roadways in growing suburban areas are in need of capacity expansion but have restricted right-of-way due to roadside commercial and residential development. To add lanes, shoulders are converted to travel lanes, and the roadway's drainage system is converted from a rural parallel drainage ditch to a curb and gutter section. This report investigated the safety effects of barrier curb on high-speed suburban multilane highways through

the collection and analysis of accident data about these sections. Accident data was collected for ten before/after Texas sites and nine matched pair Illinois sites. The data was analyzed with respect to accident rates by type of accidents, accident severity, and accident characteristic frequencies. Special attention was recommended for drainage provisions to prevent storm water ponding on high-speed curb and gutter sections. Another recommendation regarding these sections was to install lights to increase nighttime visibility. Barrier curb is not recommended for use on high-speed suburban multilane highways combining low driveway density with high volumes as it may pose safety problems.

Chapter 5 presents the conclusions drawn from the analysis, and presents recommendations for future research. The appendices contain several pertinent graphs, programs, and data used for analysis and are provided as reference material.

2. REVIEW OF LITERATURE

The standard practice in roadway design is for form to follow function. Depending on the functional classification of the roadway, it must be designed to safely accommodate a design vehicle, speed, and traffic volume. The designs of certain roadway features, including vertical and horizontal curves, intersections, cross-section, and drainage are dependent on the design vehicle, speed, and volume of a roadway. As the design criteria vary, the road design changes so as to accommodate the specific roadway type and not impede the safety of the driver.

This literature review addresses issues relevant to the design of high-speed curb and gutter sections. Current design practices and guidelines concerning barrier curb and high-speed suburban multilane highways are examined first, followed by a discussion of several design elements on which the barrier curb may have an impact. The safety effectiveness of several highway design features is then explored, and finally responses from a Texas Department of Transportation (TXDOT) survey are presented.

CURBS

Curbs, according to AASHTO, serve a combination of the following purposes: drainage control, pavement edge delineation, right-of-way reduction, aesthetics, delineation of pedestrian walkways, reduction of maintenance operations, and assistance in orderly roadside development (*1*). Typically, these desired effects are either not necessary, or are accomplished through other means on high-speed roadways due to the possible hazardous effects of impacting a curb at a high speed. There are two types of curbs: mountable and barrier. Mountable curbs are designed for vehicles to cross over, having a height of four to six inches. Barrier curbs are higher than mountable curbs, and have a steep face, from six to nine inches in height.

The method through which drainage is achieved is one design element which changes as the roadway features change. On rural roadways, parallel drainage ditches are utilized for drainage; however, in urban areas where design speeds are lower and right-of-way is more restrictive, a curb and gutter section is implemented. Curbs are widely used on urban collector roads and highways; however, for high-speed rural roadways (50 mph or greater), curbs are considered undesirable (*1*).

AASHTO's A Policy on Geometric Design of Highways and Streets, (the Green Book), states in three separate instances that barrier curb in combination with high-speed arterials and/or freeways is highly undesirable (*1*). The two reasons listed as the justification for this guideline are that vehicle operators may have increased difficulty in maintaining control of their vehicle when a barrier curb is traversed or impacted at high speeds, and barrier curbs are not adequate to prevent a vehicle from exiting the roadway. In locations where a suburban roadway is in need of expansion and right-of-way is limited, curb and gutter is the only feasible method through which to accomplish drainage control. On these roadways, it is likely that the clear zone requirement is not met due to roadside development, and that a speed limit in excess of 50 mph

is in existence. Therefore, given AASHTO's statements in the Green Book, there is a concern that accident rates and accident severity might be increased.

Studies in the past have addressed these potential problems of redirection and vaulting, and confirmed AASHTO's concerns regarding barrier curb on high-speed roadways. In a study by Olson, Weaver, Ross and Post, it was found that curbs offer no safety benefit on high-speed highways from the standpoint of vehicle behavior following impact (2). This study conducted 18 full-scale vehicle impact tests on four typical curb designs (C, E, H, and X), as well as 30 simulation tests using HVOSM. Evaluation criteria included vehicle path, vehicle attitude, and vehicle acceleration. None of the curbs which were tested redirected the vehicles satisfactorily. They concluded that the omission of curbs along high-speed roadways will enhance safety, and recommended that the use of curbs be discontinued on high-speed roadways. If a barrier curb is needed, this study concluded that a full height barrier curb should be selected for use.

A similar study, also conducted by Ross and Post (3), involved the traversing of certain curb configurations (six and eight inch heights) and sloped medians with regard to vaulting over a barrier behind the curb or in the sloped median. This study, using 14 HVOSM simulations, concluded that traffic barriers should not be placed near curbs. In many cases, vehicles have the potential to vault over the barrier or snag on the barrier. A flat approach to the barrier is highly recommended by Ross and Post; however, the problem can also be mitigated by sloping the median or roadside.

SHOULDERS

Shoulders on high-speed suburban multilane highways are a design feature placed to serve several functions that increase the safety of the roadway. These purposes include mail delivery, passing turning vehicles at intersections, passing slow-moving vehicles, room for reconstruction and maintenance activities, off-tracking buffer, encroachment buffer, pedestrian and bicycle refuge, emergency stopping buffer, errant vehicle buffer, and others. When shoulders are converted to travel lanes, as discussed in Chapter 1, the functions they were intended to serve are no longer performed and therefore may cause the roadway to operate less safely.

In the NCHRP (National Cooperative Highway Research Program) report *Shoulder Geometrics and Use Guidelines* by Downs and Wallace (4), the functional purposes of shoulders were addressed. Based on state policies and previous literature, optimal shoulder widths and acceptable shoulder widths were compiled for a multitude of functional purposes. The acceptable shoulder widths ranged according to the functions above from two to ten feet, and the optimal shoulder widths ranged from four to twelve feet. The majority of the acceptable widths were over six feet, and all but one of the optimal widths were over six feet.

This study indicates that when roadways provide no shoulders or an insufficient shoulder width, many of the functions shoulders are expected to serve can either no longer occur, or cannot occur with the same degree of efficiency and safety (4). There may be an increase in rear-end accidents as vehicles will now slow or stop to turn right in a high-speed lane. As there is no safe refuge for bicyclists, pedestrians, mail trucks, and other slow moving vehicles, there may also be

increases in accidents involving these types of vehicles. With a curb immediately next to a high-speed lane and no shoulder, run-off-the-road accidents may also increase.

SAFETY

It has been shown in past research that several roadway design and operational features have an effect on the accident experience of a roadway (5). These features include median type and width, access control, traffic volume, shoulder and lane width, and roadside features such as clear zone width. These design features will also have an effect on the accident experience on high-speed multilane highways if they are modified. A discussion of research regarding these elements as they relate to roadway safety is presented below.

Medians. In cases where operational and safety problems exist on a high volume two-lane roadway, several options exist which can be used to upgrade the roadway. A study by Harwood (6) investigated the safety aspects of several of these options including a three-lane divided highway with a two-way left-turn lane in the median, a four-lane undivided highway, a four-lane divided highway with a one-way left-turn lane in the median, and a five-lane highway with a continuously alternating left-turn lane in the median. Accident rates based on data from California and Michigan were calculated in accidents per million vehicle miles for the above options, for both commercial and residential locations.

In commercial areas, accident rates experienced by the two four-lane designs (undivided and divided with one-way left-turn lanes in the median) were higher than both the original two-lane design and the five-lane with a continuous one-way left-turn lane in the median. The only alternative to experience a reduction in accident rates, as compared to the original two-lane design, was the three-lane divided highway with a two-way left-turn lane in the median. In residential areas, the original two-lane option had the highest accident rate, the two four-lane options experienced the next highest accident rates, the three-lane design followed with the next highest rate, and the five-lane alternative had the lowest accident rate (6).

Access Control. Several studies have been undertaken to determine the relationship between access and highway safety, with respect to both level of driveway density and access control. Most prominent was a study by Stover (7) which utilized data from over thirty states. This study resulted in submission of a report to Congress concluding that full access control was the most important design factor in accident reduction. Full access control decreased accident rates by approximately 50 percent when compared to rural highways with no access control, and by 33 percent when compared to urban highways with no access control.

A similar study was undertaken by the Bureau of Public Roads (8). This study included data from 40 states, primarily oriented to determine the safety of the interstate system. Results indicated a very strong relationship between access control and accident rate. In addition to full access control lowering accident rates, the study revealed that accident rates increase as the number of access points increases.

A study by Cribbins, Area, and Donaldson (9) conducted in North Carolina suggested that access was one of the most frequent contributory variables to accidents. All accident rates within the study increased with frequency of access points and signalized openings per mile. A study in Indiana at Purdue University conducted by McGuirk (10) experienced similar results in driveway accidents. The accident rates calculated for sites in this study increased with the number of lanes, commercial driveways, intersections per mile, driveways per mile, commercial driveways per mile, and urban area population.

Traffic Volume. Several studies have concluded that accident rates tend to increase with traffic volume. A study by Stover (7) demonstrated that accident rates increase with both traffic volume and driveway density. In the study mentioned by Cribbins, Area, and Donaldson (9), it was found that traffic volume, along with measures of access, was one of the two most significant contributors to accidents. In essence, it is widely accepted that accident rates increase with traffic volume.

Pavement and Shoulder Width. A Federal Highway Administration (FHWA) sponsored study by Zegeer and Deacon (11) analyzed over 5,000 miles of two-lane highway accident data in seven states. This study revealed three accident types related to shoulder and lane width: run-off-the-road accidents, head-on collisions, and sideswipes (both opposing and same direction traffic). Through use of an accident prediction model, expected effects of lane widening and shoulder widening on the three accident types were calculated. These models are appropriate for estimating accident reductions on two-lane roads with traffic volumes of 100 to 10,000 vehicles per day, lane widths of eight to twelve feet, and paved or unpaved shoulder widths of zero to twelve feet.

With respect to the FHWA project, it was determined that for a lane widening project, the percent reduction in related accident rates ranged from 12 percent to 40 percent as the lane increased in width from one to four feet. For a shoulder widening project, the percent reduction in related accident rates for paved shoulders ranged from 16 percent to 49 percent as the shoulder width increased from two feet per side to eight feet per side; and for unpaved shoulders, the percent reduction in related accident rates ranged from 13 percent to 43 percent as the shoulder width increased from two feet per side to eight feet per side (11).

Other studies have revealed similar results, showing that wider shoulders and lanes tend to decrease accident rates. A study by Griffin and Mak (12) was performed on rural, farm-to-market roads in Texas, and indicated that single vehicle accident rates decreased for wider roadway widths and various traffic volume groupings. A before/after study by Rogness, Fambro, and Turner (13) analyzed 30 sections of two-lane roads on which paved shoulders had been added. This study found reductions in single vehicle accidents of 55 percent for traffic volume between 1,000 and 3,000 vehicles per day, 21 percent for traffic volumes between 3,000 and 5,000 vehicles per day, and 0 percent for traffic volumes between 5,000 and 7,000 vehicles per day. These findings indicate greater accident reduction due to shoulder widening at lower traffic volume levels.

Roadside Features. The roadside clear zone is another design element which has a profound effect on the safety of the roadway. The three characteristics often used to describe the roadside are the recovery distance (clear zone), sideslope, and obstacles (5). It was found by

Glennon and Harwood (14) that the clear zone policy had an effect on the single vehicle accident rate. Within various levels of traffic volume, single vehicle accident rates were found to be highest on roadways without a clear zone policy. Accident rates were found to be lower for roadways with a 4:1 clear zone sideslope policy and even lower for roadways with a 6:1 clear zone sideslope policy.

Zegeer and Deacon's (11) study also included accident reduction rates for related accidents due to increasing the roadside clear zone. It was found that with increases of clear zone from five to twenty feet, the percent reduction in related accident rates ranged from 13 percent to 44 percent, respectively. Within this study, it was also found that the ratio of single vehicle accidents to total accidents was highest for sideslopes of 2:1 or steeper. The level of single vehicle accidents drops slightly when the slope is decreased to 3:1, and drops linearly for even flatter slopes.

In a 1978 study by Perchonok et al. (15), several single vehicle crashes were analyzed to determine the percent of injuries and deaths occurring from impacting particular roadside obstacles, leading to a classification of the most dangerous obstacles. The obstacles which had the highest percentages of injuries and deaths are bridge or overpass entrances, trees, field entrances (ditches created by driveways), culverts, embankments, and wooden utility poles.

TEXAS DISTRICTS SURVEY

In January 1993, each TXDOT district was questioned through a survey circulated by the Texas Transportation Institute to acquire information concerning current design practices and problems which the design engineers encounter. The responses confirmed many of the concerns presented in the literature.

The survey responses identified several operational and design concerns regarding high-speed multilane highways. Nearly all of the responses indicated storm water ponding as a potential problem, meaning higher potential for losing control of a vehicle in an outer lane during wet weather. Driveway density was also a concern for engineers due to the high speeds combined with frequent access points and lack of shoulders. Vehicles requiring frequent stops on the roadway (garbage trucks, mail trucks, school buses, and others) are not provided with a safe refuge on high-speed curb and gutter sections. The lack of shoulders also affects pedestrians and bicyclists, forcing them into the traveled way. Another factor indicated on many responses was that clear zone requirements were also not properly satisfied in many cases. Aside from the hazard of collision with a fixed object, there is the difficulty associated with removing vehicles stopped due to an emergency from the travel lanes without a buffer zone.

SUMMARY

Due to the relatively recent need for high-speed multilane curb and gutter sections, no guidelines for their design exist currently. The literature review revealed no research

directly related to the safety of these sections. Several points of interest with regard to these sections, however, can be drawn from the studies reviewed and are summarized as follows:

- Curbs are highly undesirable on high-speed roadways due to the inability of a curb to redirect a vehicle and the possibility of a vehicle vaulting and losing control upon impact of a curb.
- Shoulders provide a variety of functions which help the roadway to maintain safe operations. Minimum shoulder widths recommended for functions a shoulder is typically intended to serve on a high-speed multilane roadway are in excess of six feet. Thus, lack of shoulders for these sections may cause an increase in certain accident types.
- Average daily traffic and driveway density are the two top contributory variables to accident rates. Accident rates typically increase with traffic volume and driveway density. Accident rates decrease with increasing level of access control.

3. STUDY DESIGN

To accomplish the objective presented in Chapter 1, an accident study was designed to determine the differences in the type, rate and severity of accidents occurring on high-speed suburban multilane highways with and without barrier curbs. The study design can be divided into four portions: study type, site identification, data collection, and statistical methods.

STUDY TYPE

The study was designed to examine and analyze accident experience on high-speed suburban multilane highways with a curb and gutter cross section using sites from two states. The study used a before and after structure for Texas sites and a matched pair structure for Illinois sites. Ten sites were studied in Texas, and at least three years of accident data were collected for each site. The sites were recently modified from a rural parallel drainage ditch design to a curb and gutter cross section design. Accident experience before roadway modification was compared with accident experience after roadway modification. Nine matched pairs of sites in Illinois were studied, one with curb and gutter and one without. The sites were matched with respect to traffic volume, number of lanes, median design, and roadside development as closely as possible. Accident experience on the curbed sites was compared with the accident experience on the non-curbed sites.

The roads being compared (in Texas before and after modification and in Illinois the matched pairs) were paired samples of two populations of highways. In Texas, accident data before the modification were the control to which accident data after the modification were compared. In Illinois, accident data for the non-curbed sites were the control to which the accident data from the curbed sites were compared. It was assumed that the populations were normal with identical variances.

Three measures of effectiveness were examined to determine if the type, rate, and severity of accidents were different from one population to another. These were accident rate, accident characteristic frequency, and accident severity. Together, the information from these measures of effectiveness provided a comprehensive analysis of the accident experience occurring on these roadway sections.

Accident Rates. The change in accident rates is a strong indicator of the effects of a safety related improvement on a highway. Accident rates are often defined as the number of accidents per mile per year on a section of roadway. Therefore, in this study, accident data was converted to accident rates by accounting for the length of the site and the number of years the data spanned.

Accident Characteristics. One important aspect of an accident study is the underlying cause in the increase in accident rates. This increase or cause can often be determined through examination of the percentage of accidents occurring with a certain characteristic. Accident characteristics examined in this study include wet road surface, inclement weather, and impaired

visibility, each of which were identified by roadway designers as potential causes of increased accident rates on high-speed suburban curb and gutter sections.

Accident Severity. Often, the accident rate of a certain type of accident may remain constant after a roadway modification; however, the severity of those accidents may increase or decrease. If the severity of a group of accidents increases, while the accident rate remains constant, the increase shows that the roadway improvement has caused the road to become less safe.

SITE IDENTIFICATION

The following section discusses the selection of the sites from both Texas and Illinois for the before/after and matched pair studies. In addition, geometric attributes of the sites are listed and discussed.

Texas. Because Texas uses high-speed curb and gutter roadways, maintains a quality accident and roadway data base, and was convenient for site inspection, it was selected as one state to furnish the sites for this study. In January 1993, each TXDOT district was questioned through a survey circulated by the Texas Transportation Institute to determine potential sites for this analysis.

The responses indicated there were 193 high-speed curb and gutter sections scattered in 20 Texas districts. These roadways have a posted speed limit of 50 mph or greater. Completion dates ranged from the 1950s to the 1990s. Several sites used two-way left-turn lanes and raised medians. Most sites did not have shoulders; however, some sites had eight to ten foot shoulders.

In order to compare accident experience at each site before and after curb and gutter was installed, sites were selected that had completion dates allowing at least one year of data before construction started and one year after construction ended. This mandated selection of sites with completion dates of 1990 or earlier. In addition, the accident data base maintained accident reports after and including 1985. Therefore, with elimination of construction time, the earliest completion date for modification of a site was 1987. Of the 193 potential sites identified in the survey, 26 had completion dates between 1987 and 1990.

Accident records for these sites were obtained from LANSER (Local Area Network Safety Evaluation and Reporting) for the years 1985 to 1992. Some of the 26 sites were not accessible, or had no accident data for several years. This initial screening left 10 sites to be analyzed. The sites selected for study encompassed a range of Texas topography. East Texas sites were located in Gregg, Henderson, Rusk, and Smith counties. One west Texas site was located in Tom Green county. Central Texas sites included two sites in Bexar county. Two sites were also located in South Texas in San Patricio and Nueces counties.

The sites varied in length, number of lanes, and driveway density. All of the sites, however, had a minimum of two through lanes in each direction, and a minimum posted speed limit of 50 mph. None of the selected sites included a paved shoulder. Table 3-1 lists the geometric attributes of the 10 sites.

Table 3-1. Geometric Attributes of Texas Study Sites

County	Highway Number	Cross-Section	Speed Limit (mph)	Traffic Volume
Tom Green	RM 584	FLUSH MEDIAN	55	5,900
Smith	SH 155	TWLTL ¹	55	11,200
Henderson	SH 31	TWLTL	50-55	13,000
Rusk	US 79	TWLTL	50-55	5,700
Smith	SH 31	TWLTL	55	11,900
Gregg	Loop 281	TWLTL	55	18,300
Bexar	IH 410 Frontage Road (1 way)	Median	50	16,003
Bexar	IH 410 Frontage Road (1 way)	Median	50	14,920
Nueces	SH 357	LTL ²	50	12,900
San Patricio	SH 35	TWLTL	55	10,900

¹TWLTL - Two Way Left Turn Lane

²LTL - Left Turn Lane at Intersections

Illinois. To identify sites in Illinois, the Highway Safety Information System (HSIS) data base was used. The HSIS data base contains information on roadway characteristics of homogeneous sections of roadway within a state in a Roadlog File. A request to the Federal Highway Administration, who administers the HSIS data base, was made for a file in the form of a Statistical Analysis System (SAS) data set containing information on non-freeway, multilane roadway sections in Illinois that have posted speed limits of 50 mph or greater. The data set contained many variables describing the design and operational characteristics of the roadway sections.

To select matched pairs of sites differing only in their use of curb and gutter, a listing of all roadway sections using curb and gutter was extracted. Seventeen sites that were high-speed curb and gutter sections in Illinois were identified. Out of these 17 sites, only nine exhibited the homogeneity with respect to traffic volume, median design, and number of lanes necessary to perform a comparative accident analysis. The remaining data base of roadway segments that did not use curb and gutter was then searched to find matches for the nine sites. The variables used to match the pairs included traffic volume, number of lanes, median design, inside shoulder width, inside shoulder type, functional class, median width, surface width, driveway density and existing right-of-way.

A constant difference between the pairs with respect to shoulder width was noted. None of the high-speed curb and gutter sections had shoulders, whereas each of the non-curb and gutter sites had eight or ten foot shoulders on each side of the roadway. Each site selected had four lanes. The geometric characteristics of the sites are summarized in Tables 3-2 and 3-3.

ACCIDENT DATA COLLECTION

The data collection procedures are outlined in this section for both the Texas data and the Illinois data.

Texas Data. LANSER is a microcomputer software package that provides access to traffic records data for the State of Texas (16). LANSER was developed by the Texas Transportation Institute (TTI) in cooperation with TXDOT. The accident data entered into LANSER's data base is the same information collected by the Department of Public Safety.

The records in the data base date from 1985 through the beginning of 1992. They are accessed through a process called subsetting. In essence, one searches the entire data base for accidents meeting a certain specification. In this case, certain control sections and milepoints on those control sections were selected as criteria. Once the qualifying records are obtained, LANSER creates a subset of these accident records that have met the required definition. The records within the subset can then be printed or stored in a file. Certain variables can be selected from these records to be placed into a file to be imported into spreadsheet programs or statistical analysis programs. LANSER can also perform frequency distributions on one or two user specified variables contained in the accident report.

Table 3-2. Geometric Attributes of Illinois Curbed Study Sites

Site Number (With Curb and Gutter)	Surface Width ¹ (ft.)	Median Design	Speed Limit (mph)	Traffic Volume
1	48	Curbed	50	25000
2	54	Mountable	55	25000
3	52	Rumble Strip	50	18000
4	48	Unprotected	55	17000
5	52	Rumble Strip	55	26000
6	44	No Median	50	34900
7	48	No Median	50	28700
8	48	No Median	50	20000
9	48	No Median	55	14500

¹There were no shoulders on these roadways.

Table 3-3. Geometric Attributes of Illinois Non-Curbed Study Sites

Site Number (No Curb and Gutter)	Surface Width ¹ (ft.)	Median Design	Speed Limit (mph)	Traffic Volume
1	48	Curbed	55	28800
2	50	Mountable	55	20500
3	48	Rumble Strip	50	20800
4	58	Unprotected	50	17700
5	48	Rumble Strip	50	22600
6	40	No Median	55	34900
7	40	No Median	55	28200
8	48	No Median	50	21000
9	48	No Median	55	15500

¹The surface width does not include shoulder width.

Through LANSER, all of the accident records for the necessary years were accessed using the control section and beginning and ending milepoints for each site to provide two years of before data and two years of after data. If additional years of accident information were available, those years were included in the analysis. Certain variables were extracted from these records and placed into a file usable by SAS, which was manipulated for the data analysis. The variables chosen were subdivided into the following four categories:

1. Identifying Information (date, accident number, time, road class, control/section, mile point for control/section, population group);
2. Accident Data (roadway related, intersection related, other factor, severity of collision, first harmful event, object struck, manner of collision, number of vehicles involved);
3. Geometric Characteristics (road condition, number of lanes, shoulder type, speed limit, surface width); and
4. Other Conditions (light condition, weather, surface condition).

In addition, each site was visited to understand the design and operation of that roadway better. This visual inspection provided information on the driveway density at the site and the adjacent development, and confirmed the information provided in the survey regarding the geometric attributes of the sites.

Illinois Data. The accident file of the HSIS data base was used to obtain the necessary information on accidents occurring on the matched pairs of sites. A request was made to the Federal Highway Administration, concurrent with the request for the information from the Roadlog File, for information on all accidents occurring on high-speed multilane non-freeway roadway sections between 1988 and 1992. The information was requested as a SAS data set. Where possible, the variables requested were similar to those chosen from LANSER. The data set was then divided into several smaller data sets, each containing the accidents occurring on the roadway sections selected as sites from 1988 to 1992.

DATA ANALYSIS

To test each measure of effectiveness previously described, the analysis is divided into three sections, each dealing with one measure of effectiveness.

Accident Rates. To analyze the accident rates, the mean accident rates for each state were calculated for a variety of accident types on which curb and gutter was expected to have an impact, including the total accident rates. These accident rates were calculated for each site and for both before and after the modification for the Texas data. The thirteen accident types that were calculated are listed in Table 3-4.

Table 3-4. Accident Types Studied

Accident Code	Type of Accident
1	TOTAL ACCIDENTS
2	ACCIDENTS NOT DURING DAYLIGHT
3	ACCIDENTS WHEN WEATHER WAS NOT CLEAR
4	ACCIDENTS WHEN RAINING
5	ACCIDENTS WITH IMPAIRED VISIBILITY
6	RUN-OFF-THE-ROAD ACCIDENTS
7	RUN-OFF-THE-ROAD INTO A FIXED OBJECT
8	ACCIDENTS DUE TO VEHICLE EXITING THE
9	ACCIDENTS INVOLVING BICYCLES OR
10	SIDESWIPE ACCIDENTS
11	REAR END ACCIDENTS
12	WET SURFACE ACCIDENTS
13	ACCIDENTS DUE TO STRIKING THE CURB

The mean accident rates for each of these accident types before and after the section modifications were statistically compared to determine increases or decreases in the accident rate, implying a corresponding increase or decrease in the safety of the section. This statistical comparison entailed a t-test to determine if the mean from one population is greater than the mean from another population. In this instance, knowing whether the accident rate increased or decreased is desirable, not merely if it changed. Therefore, a one-sided t-test is appropriate. Because the accident rates were calculated from the same sample of roadways before and after modification, the observations were not independent of each other. A paired t-test is appropriate, and assisted in controlling for the variability arising from differences among the experimental units (the roadways). The t-test is discussed further at the end of this chapter. The same analysis form was used for the Illinois data; however, instead of accident rates on the same roadway before and after modification being compared, accident rates for the two matched groups of roadways were compared. Therefore, the t-test was a two-sample t-test, not a paired t-test. A one-sided t-test was used to determine if the population of roadways with curb had a higher or lower accident rate when compared with roadways without curb.

Although the sites were all high-speed curb and gutter roadway sections, some inherent differences were noted among the sites that may account for some variability in accident rate changes among the sites. For Texas sites, these factors were traffic volume, driveway density, and the site configuration. With the Illinois sites, site configuration is not applicable as all sites have four lanes, and have not been modified; and the driveway density variable was unavailable for study. Essentially,

each of these factors may affect differences in the accident rates. Sites with lower traffic volumes were expected to respond more favorably to curb and gutter than sites with higher traffic volumes. Additionally, sites that experienced addition of lanes and removal of a shoulder when curb was installed were expected to respond less favorably to the modification than those sites whose number of lanes and shoulder width remained the same, or were increased after the curb was installed.

Therefore, these three site variables (traffic volume, driveway density, and site configuration) were examined to determine any relationship between them and the difference in accident rates. As traffic volume is a continuous variable, it was tested using a linear regression model to determine if traffic volume could be used to predict the change in accident rate. Regression analysis is discussed further at the end of this chapter.

The driveway density and change in site configuration are categorical variables containing distinct class levels. Driveway density, as it applies to Texas sites, can be divided into three levels: low, high, and sites on frontage roads. Site configuration change can be divided into two classes for these sites: those that experienced no change in shoulder width and number of lanes, and those that experienced both a lane addition and shoulder width reduction. Table 3-5 lists the driveway density levels and site configuration changes for the Texas sites.

Accident Characteristic Frequency. The proportion of accidents that involved certain characteristics were calculated for each Texas site before and after modification and for each Illinois site. These characteristics were selected to represent many roadway designers' concerns regarding these sections, and are as follows:

- Impaired Visibility (Not clear and not daylight);
- Absence of Light (Not daylight);
- Wet Road Surface (Dry, wet or other); and
- Intersection Type (Intersection, driveway, or none).

The difference in these proportions was tested using a log-linear model, which will be fit to the data to determine if the characteristics occurred in equal proportions in the two accident populations being compared.

Accident Severity. The severity of each accident is categorized in accident reports as shown in Table 3-6. To determine if the accident severity distribution on roads using curb and gutter differs from those not using curb and gutter, two factor log-linear models were used to test for association between severity and the roadway type.

Table 3-5. Driveway Density Levels and Site Configurations for Texas Sites

	Driveway Density Level	Number of Lanes Added	Shoulder
1	Low	2	Yes
2	High	2	Yes
3	High	0	No
4	High	0	No
5	High	2	Yes
6	High	0	No
7	Frontage	0	No
8	Frontage	0	No
9	Low	4	Yes
10	Low	2	Yes

Table 3-6. Accident Severity Definition

Severity Number	Severity Type
1	No injury
2	Possible Injury
3	Non-Incapacitating
4	Incapacitating
5	Fatal

STATISTICAL METHODS

In essence, four basic statistical methods will be used in this data analysis: the t-test, Analysis of Variance, regression, and log-linear modeling. Each of these methods is established and used by a wide range of analysts. Essentially, these tests are performed to determine if a treatment affected a certain measurable variable, or if two factors are associated. For each test used in this report, a significance level of 95 percent was used, as this is a common level used in transportation research.

T-test. The first of these methods, the t-test, generally tests if means of two normally distributed populations are different. The populations are usually subjected to two different levels of a factor or influence. One of these levels can be a control group, and the other can have a certain treatment applied to it. For Texas sites, a before/after type study was used. For Illinois sites, a matched pair structure was used. By testing to see if the two population means are equal, it could be determined, to a certain confidence level, if the treatment (curb and gutter) affected the response variable.

In this study, determining if accident rates were higher or lower for the two different types of cross sections was desirable. The research hypothesis was that the accident rates for the roadways with barrier curb were greater than or less than the accident rates for roadways without barrier curb, depending on the accident type being tested. The determination was based on the difference between the accident rates of the two roadway types. If the difference is positive, the research hypothesis tests that the accident rates for sections with curb and gutter are greater than sections not using curb and gutter. If the difference is negative, the research hypothesis tests that the accident rates for sections using curb and gutter are less than sections not using it.

Two different t-tests were used for this study: the paired t-test and the two-sample t-test. The paired t-test was for Texas data because it came from one sample (ten roads) with a treatment applied to them. The paired t-test uses the sample variance of the differences between the two observations on one experimental unit to conduct the hypothesis test. The two-sample test was used for Illinois data because two separate samples (nine roads with curb and gutter and nine roads without curb and gutter) were compared.

Analysis of Variance. In Analysis of Variance, or ANOVA, the variability in the observations of a dependent variable is subdivided into recognizable sources of variation. These sources of variation included experimental error and independent variables, called class variables. Class variables represent factors or treatments having different levels that may affect the outcome of the dependent variable. Linear models are used to predict the dependent variable as a function of parameters and class variables, with parameters obtained using least squares estimates minimizing the error between the actual and predicted response.

One measure to determine if the means at one level of a treatment are different from another level of treatment is the F-test. The F-test essentially compares the variance attributable to experimental error against the variance attributable to the effect of a class variable. If the variance due to the class variable is much larger than the variance due to experimental error, the class variable significantly affects the dependent variable.

In this research, the dependent variable is the change in accident rates, and the class variables are the driveway density and the site configuration. The research hypothesis was that the dependent variables, driveway density and site configuration, significantly affected the difference in the accident rates between sites with and without curb and gutter.

Regression. Regression basically is the analysis of the relationship between one variable and another set of variables. The first variable is called the response variable. The second set of variables are the regressor variables. The regressor variables and response variables are fit into a linear equation that uses the regressor variables to predict the response variable. The parameters within the equation consist of coefficients for the regressor variables and the variance accounting for the random scatter around the regression line. These parameters are obtained using least squares estimates.

One means by which the measure of fit of the equation is estimated is the coefficient of determination, or R^2 value. Essentially R^2 is an indicator of how much variation in the response variable can be explained by the model of the regressor variables, or in other words, how well the equation fits the data. The R^2 value ranges between zero and one, with zero meaning the regression model explains none of the variation in the response variable values, and one meaning the regression model explains all of the variation in the response variable.

In this research, the regressor variable is the difference in the accident rate between sites with curb and gutter and those without. The regressor variable is the traffic volume of the site. The R^2 value was used to determine if traffic volume explains any variation in the differences in the accident rates.

Log-linear Models. The last method used in this study is a relatively new method that is a part of categorical data analysis. A categorical variable is one for which the measurement scale consists of a set of categories. The accident severity, visibility, road surface and weather are all categorical variables, and therefore, this type of analysis is appropriate. The log-linear model does two things: it measures relative changes in frequencies as opposed to absolute frequencies through a logarithmic transformation, and it assumes a linear relationship between certain factors and the log of the frequencies. This model allows the testing of several hypotheses for one set of variables through the development of an Analysis of Categorical Data (ANOCAT) table. The hypotheses are all tested by the Likelihood Ratio Chi-Squared Statistic. The ANOCAT table lists all of the hypotheses, the sources of association, and the calculated and critical values of the Chi-Squared Statistic; and from this table, the hypotheses are either accepted or rejected. The model can be either a two- or three-factor model.

In a two-factor model, four hypotheses are tested. The first two hypotheses test that the row and column frequencies are equal. The third hypothesis, the total hypothesis, tests that an even distribution among all cells in the table exists. If this total hypothesis is not significant, no association exists within the table. The hypothesis of interest for this study is the last hypothesis, the hypothesis of no interaction. This hypothesis tests that no interaction exists between the two factors being tested.

Since several associations are possible in a three-factor log-linear model, several hypotheses can be tested. The first hypothesis examined is the Mutual Independence Hypothesis. This hypothesis tests that no association exists within the three factors. If this hypothesis is accepted, the analysis is stopped. If it is rejected, the analysis proceeds. Conditional Independence Hypotheses test for no association between two factors at each level of the third factor. If the hypothesis is rejected, this suggests some association between the two factors for at least one level of the third factor. The Two-Factor Interaction tests for no association of two factors when collapsed over the third factor, or ignoring the third factor. This hypothesis of association should be double checked with its corresponding conditional independence hypothesis before being accepted or rejected to ensure validity of the results.

4. RESULTS

This chapter presents the results of the study procedures described in the previous chapter. Tabulated accident rates for various accident types are presented and compared statistically to determine any differences that existed. Accident characteristic frequencies and accident severities are also presented and evaluated in the following sections.

ACCIDENT RATES

Accident rates for both Texas and Illinois sites were calculated by dividing the number of accidents per site by the length of the site and the number of years the data spanned. This information is presented in Appendix A in accidents per mile per year. Table 4-1 summarizes the mean accident rates for Texas sites before and after site modification and the difference between the two accident rates. Table 4-2 summarizes the mean accident rates for Illinois sites with curb and gutter and without curb and gutter, as well as the difference between the accident rates for the matched pairs of sites.

As shown in Table 4-1, Texas sites 1 through 6 experienced a decrease in mean accident rates, whereas Texas sites 7 through 10 experienced an increase in the mean accident rates after site modification to a curb and gutter section. Before site modification, accident rates ranged between 4.85 and 16.58 accidents per mile per year, with an average value of 7.50 accidents per mile per year. After site modification, the average accident rate ranged between 4.52 and 13.69 accidents per mile per year, with an average accident rate of 7.06.. The overall mean accident rate combined for all sites decreased by 0.44 accidents per mile per year.

As shown in Table 4-2, six of the nine curbed Illinois sites had higher mean accident rates than their matching site without a curb. Accident rates ranged between 4.20 and 83.39 accidents per mile per year before site modification. After site modification, accident rates ranged between 3.08 and 256.38 accidents per mile per year. The average accident rate for the nine curbed Illinois sites were 41.54 accidents per mile per year, while the non-curbed sites had a lower average value of 28.79 accidents per mile per year. The average mean accident rate for Illinois curbed sites were 12.75 accidents per mile per year higher than for Illinois non-curbed sites.

Table 4-1. Differences in Mean Accident Rates for Texas Sites

Site Number	Accident Rate Before (Acc/Mi/Yr)	Accident Rate After (Acc/Mi/Yr)	Difference
1	4.85	4.52	-0.33
2	9.61	8.69	-0.92
3	16.58	6.45	-10.13
4	8.79	7.75	-1.04
5	7.67	7.58	-0.10
6	10.57	9.11	-1.45
7	8.25	10.25	2.00
8	5.13	5.75	0.63
9	5.01	9.02	4.01
10	7.91	13.69	5.77
Average	7.50	7.06	-0.44

Table 4-2. Differences in Mean Accident Rates for Illinois Sites

Site Number	Accident Rate Curbed (Acc/Mi/Yr)	Accident Rate Non- Curbed (Acc/Mi/Yr)	Difference
1	4.20	6.77	2.57
2	38.42	37.41	-1.01
3	13.83	36.76	22.93
4	83.39	3.08	-80.31
5	5.83	13.17	7.34
6	39.51	256.38	216.87
7	19.53	110.00	90.47
8	28.57	16.00	-12.57
9	13.67	27.39	13.71
Average	41.54	28.79	-12.75

To determine if the mean accident rates for certain types of accidents were significantly different for sites with and without curb, researchers performed paired one-sided t-tests on the Texas data using the SAS MEANS procedure; and they did two-sample t-tests on the Illinois data using the SAS TTEST procedure. The research hypothesis was that the accident rates for roadways with barrier curb were either greater or less than those for roadways without the barrier curb, depending on the mean accident rate for that accident type.

Table 4-3 is a summary of accident rates for Texas sites before and after roadway modification for the 13 different accident types listed in Chapter 3. Table 4-4 is a summary of those accident rates occurring on Illinois sites with and without curb. Tables 4-3 and 4-4 also list the raw and percent differences in the accident rates, the percentage of sites experiencing a difference with the same sign as the mean difference, and the p-value for the t-tests conducted.

As shown in Table 4-3, the types of accidents that increased were nighttime accidents, inclement weather accidents, impaired visibility accidents, run-off-road accidents, accidents on wet roadway surfaces, and accidents due to striking the curb. The accident rates which experienced a decrease were exiting vehicle accidents, bicycle and pedestrian accidents, sideswipes and rear-end accidents.

Only two types of accident rates experienced a statistically significant increase for the Texas data: run-off-road accidents and run-off-road into fixed object accidents. Although typically 70 percent of the Texas sites showed the same effect of the curb and gutter on a specific accident rate, too much variance appeared in the data for mean accident rates to be significantly different. The p-value for the mean accident rate for Texas sites did not show a statistically significant decrease.

As shown in Table 4-4, the types of accidents showing higher mean accident rates on Illinois curbed sites than on comparable Illinois non-curbed sites include nighttime accidents, impaired weather accidents, impaired visibility accidents, wet weather accidents, run-off-road accidents, accidents due to vehicle entering the roadway, sideswipes, rear-end accidents, and accidents on wet roadway surfaces. The types of accidents that had higher mean accident rates on Illinois sites without curb and gutter than Illinois sites with curb and gutter were bicycle and pedestrian accidents, and accidents due to striking the curb. Only one accident type experiencing a significant change in the Illinois data was noted at the 95 percent confidence level: accidents with impaired visibility experienced a significant increase.

Accident types that had higher mean accident rates with curb than without curb in both Texas and Illinois are nighttime, impaired visibility, run-off-road, run-off-road into fixed object, and wet surface accidents.

To determine if the large variance in the mean accident rates was caused by failing to block for a difference in the nature of the sites, several models were applied to the difference in the accident rates. The three operational and geometric variables examined included the traffic volume, the difference in before and after configurations of Texas sites, and the driveway density.

**Table 4-3. Mean Accident Rates and Descriptive Statistics
by Accident Type for Texas Sites**

Accident Type	Accident Rate (Accidents /mile/year)		Difference		Percent of Sites of	P-Value
	Before	After	Raw	Percent		
All	7.50	7.06	-0.44	-5.89	60	.455
Nighttime	2.25	2.52	0.28	12.27	70	.137
Bad Weather	0.87	1.02	0.15	17.16	80	.426
Raining	0.78	0.88	0.09	11.79	60	.477
Bad Visibility	2.84	3.13	0.29	10.21	90	.455
Run off road	0.28	0.38	0.10	35.03	70	.039
Fixed Object	0.15	0.24	0.09	57.54	60	.025
Exiting Vehicle	0.86	0.74	-0.12	-14.35	40	.463
Bike/Pedestrian	0.10	0.08	-0.12	-24.04	50	.198
Sideswipe	0.96	0.74	-0.23	-23.48	70	.442
Rear-End	0.85	0.68	-0.16	-19.19	70	.443

**Table 4-4. Mean Accident Rates and Descriptive Statistics
by Accident Type for Illinois Sites**

Accident Type	Accident Rate (Accidents/mile/year)		Difference		Percent of Sites	P-Value
	Before	After	Raw	Percent		
All	28.79	41.54	12.76	44.32	60	0.32
Nighttime	8.75	11.16	2.41	27.52	60	0.44
Bad Weather	5.84	12.76	6.92	118.41	70	0.21
Raining	3.85	9.17	5.32	138.40	50	0.19
Bad Visibility	12.24	19.98	7.74	63.20	90	0.01
Run off road	1.07	1.68	0.60	55.94	40	0.37
Fixed Object	0.78	1.10	0.32	430.82	40	0.55
Exiting Vehicle	9.39	12.03	2.63	28.04	60	0.61
Bike/Pedestrian	0.14	0.08	-0.06	-42.03	20	0.67
Sideswipe	2.48	6.00	3.53	142.39	70	0.17
Rear-End	13.38	19.47	6.09	45.53	50	0.30
Wet Surface	6.18	13.18	7.00	113.21	50	0.21

Average Daily Traffic. The traffic volume values for Texas and Illinois sites were tested to determine if they exhibited a linear relationship with the change in the accident rates for all accident types under investigation. Two regression models were run through the SAS REG (regression) procedure using the continuous variable traffic volume to model the difference in accident rate.

The R^2 values resulting from the model for each accident type tested are listed for the Texas data and Illinois data in Table 4-5. The p-values for the F-tests conducted in the REG procedure to determine if the variance among the differences in the accident rates can be explained through the traffic volume are also listed in Table 4-5.

The R^2 values for the Texas data are extremely low, even for studies dealing with accidents. The high p-values associated with the model also show that for those sites, traffic volume was not a good predictor of how accident rates change when curb and gutter is placed on a high-speed suburban multilane roadway. The R^2 values resulting from the model for each accident type for Illinois is reasonably high, especially for studies dealing with accidents that are, in essence, random events. The p-values show that traffic volume significantly contributes to the difference in accident rates in all but those accidents with impaired visibility. The regression results for the Illinois analysis thus indicate that traffic volume is a good predictor of how accident rates will change when curb and gutter is placed on a high-speed suburban multilane roadway.

Figure 4-1 shows how the difference in accident rates between Illinois sites with and without curb varied with traffic volume. The data points shown on the graph are the actual differences in mean accident rates for each site by traffic volume. The regression line shown on the graph illustrates that the difference in accident rates between Illinois sites with curb and Illinois sites without curb increases with traffic volume. Care should be taken when applying this equation, however, as only nine sites were used to perform the regression, and elimination of one extreme data point could alter the outcome of the regression.

A discrepancy in the results from the regression models for Texas and Illinois may be a result of the poor data quality associated with the traffic volume values from the Texas data. The traffic volume values for Texas sites varied a great deal over the years in which accident data were collected due to the modification of the sites. In Illinois, however, sites were selected which had a constant traffic volume over the years in which accident data were collected.

**Table 4-5. Coefficient of Determination (R^2) Values
from Regression Model for Texas and Illinois Sites**

Accident Type	Texas Sites		Illinois Sites	
	R^2 Value	P-Value	R^2 Value	P-Value
All	0.0004	0.9589	0.0089	0.6481
Nighttime	0.0005	0.9514	0.0073	0.6665
Bad Weather	0.0001	0.9732	0.0082	0.6557
Raining	0.0014	0.9196	0.0105	0.6318
Bad Visibility	0.0004	0.9589	0.5250	0.0604
Run-Off-Road	0.0824	0.4214	0.0111	0.6263
Fixed Object	0.0357	0.6010	0.0266	0.5277
Exiting Vehicle	0.0272	0.6491	0.0180	0.5741
Bike/Pedestrians	0.0595	0.4972	0.0119	0.6185
Sideswipes	0.0033	0.8755	0.0057	0.6874
Rear-Ends	0.0478	0.5400	0.0203	0.5604
Wet Surface	0.0098	0.7853	0.0093	0.6434
Strike Curb	0.0117	0.7665	0.0061	0.6822

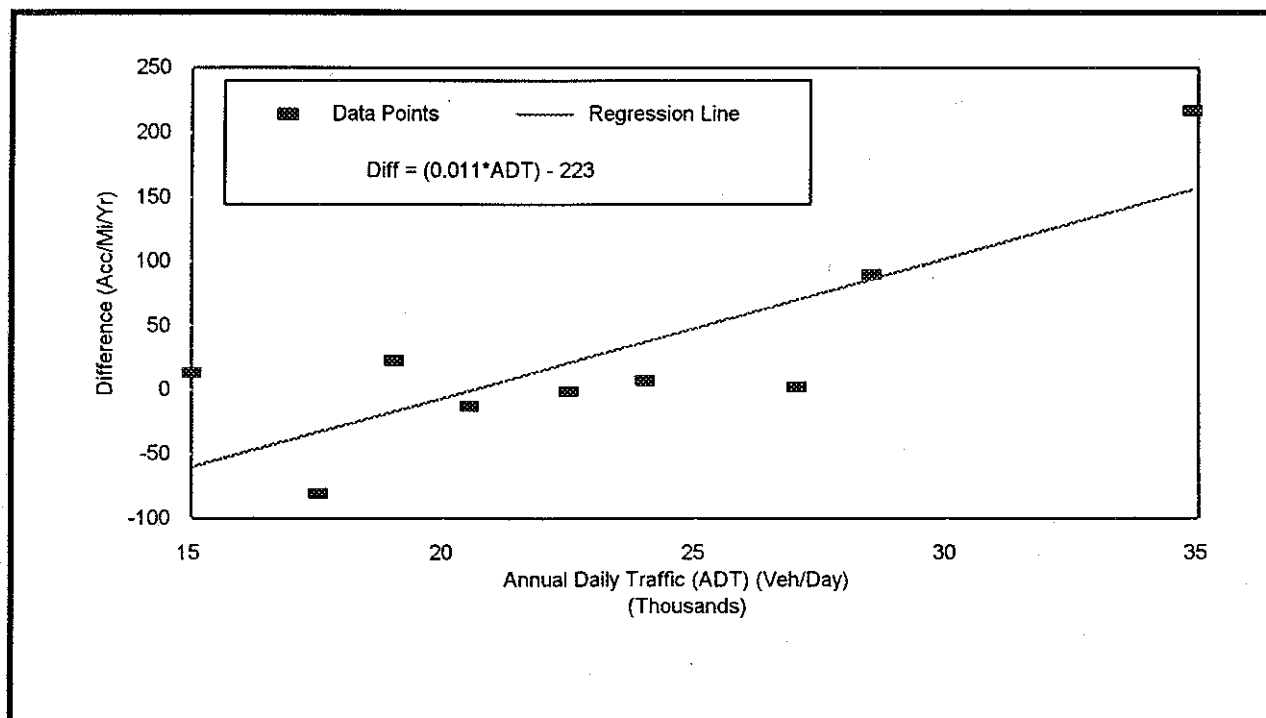


Figure 4-1. Difference in Accident Rates vs. Traffic Volume for Illinois Data

Site Configuration and Driveway Density. Texas sites can be grouped into two distinct types of modifications: those in which the number of lanes and the shoulder width remained the same and those in which lanes were added and the shoulder width was reduced. Driveway density for Texas sites falls into three categories: high, low, and frontage road. General linear models were developed to block for this effect using the GLM (general linear model) procedure in SAS to determine if either of these variables affected the change in the accident rates

A general linear model was run for three accident types: all accidents, run-off-road accidents, and run-off-road into fixed object accidents. The difference between the accident rates from before to after the site was modified was the dependent variable, and the site configuration and driveway density was the independent variable used in the models. The model included the two class variables, site configuration and driveway density, and their interaction.

The three general linear models for the three accident types provided means for the difference between each level of driveway density and each different site configuration change. These means as well as the p-values resulting from the F-tests are listed in Tables 4-6 and 4-7.

From Table 4-6, it appears that the mean accident rate difference increased for sites with low driveway density and decreased for sites with high driveway density. The mean accident rates for run-off-road accidents also increased with low driveway density; however, it increased less with high driveway density. For run-off-road into fixed object accidents, the mean accident rates for sites with low driveway density increased slightly and increased less for sites with high driveway density. For each of the three accident types tested, the mean accident rates for sites with frontage roads increased. According to the model, for all accidents, it can be said that driveway density significantly affects the difference in accident rates only to about a 90 percent confidence level.

Driveway density, nonetheless, appears from this data to be a large factor in determining the effect of placing curb and gutter on a roadway, especially when coupled with the effect of traffic volume. Site 1 had a very low driveway density, and experienced a slight reduction in accident rates upon modification. Sites 2 through 6 had very high driveway densities, and all experienced a decrease in their mean accident rate upon modification to a curb and gutter section. Sites 7 through 10 all had very low driveway densities, with sites 7 and 8 being frontage roads; and all experienced an increase in accident rates upon modification. Site 1 had a very low volume, and Sites 7 through 10 had fairly high volumes. This may explain the reduction in accident rate for Site 1 and the increase in accident rate for Sites 7 through 10, although both had low driveway densities.

The p-values for the site configuration variable were much smaller than those for the driveway density; however, they still were not significant at the 95 percent confidence level. For each of the three accident rates tested, the mean accident rates for those sites that had lanes added and shoulders reduced had either a smaller increase or a decrease than for those sites that remained the same. This finding shows that the addition of lanes and reduction of shoulder width when a site is modified to a curb and gutter section may negatively affect accident rates and the safety of the section.

Table 4-6. General Linear Model Results: Driveway Density

Accident Type and p-value	Driveway Density Level	Mean Difference In Accident Rate
All Accidents p = 0.133	Low	3.16
	High	-2.72
	Frontage	1.32
Run-Off-Road Accidents p = 0.848	Low	0.37
	High	0.19
	Frontage	0.17
Run-Off-Road Into Fixed Object Accidents p = 0.918	Low	0.26
	High	0.17
	Frontage	0.26

Table 4-7. General Linear Model Results: Configuration Change

Accident Type and p-value	Configuration Change	Mean Difference In Accident Rate
All Accidents p = 0.116	No Change	1.69
	Lanes Added	-1.99
Run-Off-Road Accidents p = 0.238	No change	0.36
	Lanes Added	0.12
Run-Off-Road Into Fixed Object Accidents p = 0.234	No Change	0.25
	Lanes Added	0.18

ACCIDENT SEVERITIES

Though the accident rate may remain constant when a site is modified to a high speed curb and gutter section, or when matched pairs of sites are compared, the severity of a certain accident type may be affected. For example, with respect to run-off-road accidents, with curb and gutter in place, regaining control is more difficult for an errant vehicle once leaving the roadway. Therefore, the accident may be more severe.

Relative frequencies were calculated to determine the percentage of accidents at each severity level before and after site modification for Texas sites, and for Illinois curbed and non-curbed sites. These values are listed in Appendix B. Figures 4-2 and 4-3 depict the percentages of accidents with no injuries and with fatalities, respectively, for all accidents and for run-off-road accidents for Texas data. Figure 4-2 illustrates that the percentage of all accidents and run-off-road accidents with no injuries decreased at Texas sites. The percentage of all accidents and run-off-road accidents, however, increased for fatal accidents at Texas sites, as shown in Figure 4-3.

Figures 4-4 and 4-5 depict the percentages of accidents with no injuries and with fatalities, respectively, for all accidents and for run-off-road accidents for Illinois data. Figure 4-4 shows that the percentage of all accidents with no injuries decreased for Illinois sites, while Figure 4-5 illustrates that the percentage of all accidents and run-off-road accidents with fatalities increased for Illinois sites.

Three log-linear models for each state were run using the SAS CATMOD (categorical model) procedure to determine if severity and the type of road interact. The research hypothesis was that interaction between road type and severity exists. The Texas data ANOCAT tables for severity in Appendix C, for each accident type, all accidents, run-off-road accidents, and run-off-road into fixed object accidents, show that the severities of the accidents did not significantly change.

The ANOCAT tables for severity for Illinois data also show that curb and gutter did not significantly affect accident severity for run-off-road accidents and for run-off-road into fixed object accidents. The ANOCAT, however, did show that curb and gutter caused a significant increase in overall accident severity for the Illinois data.

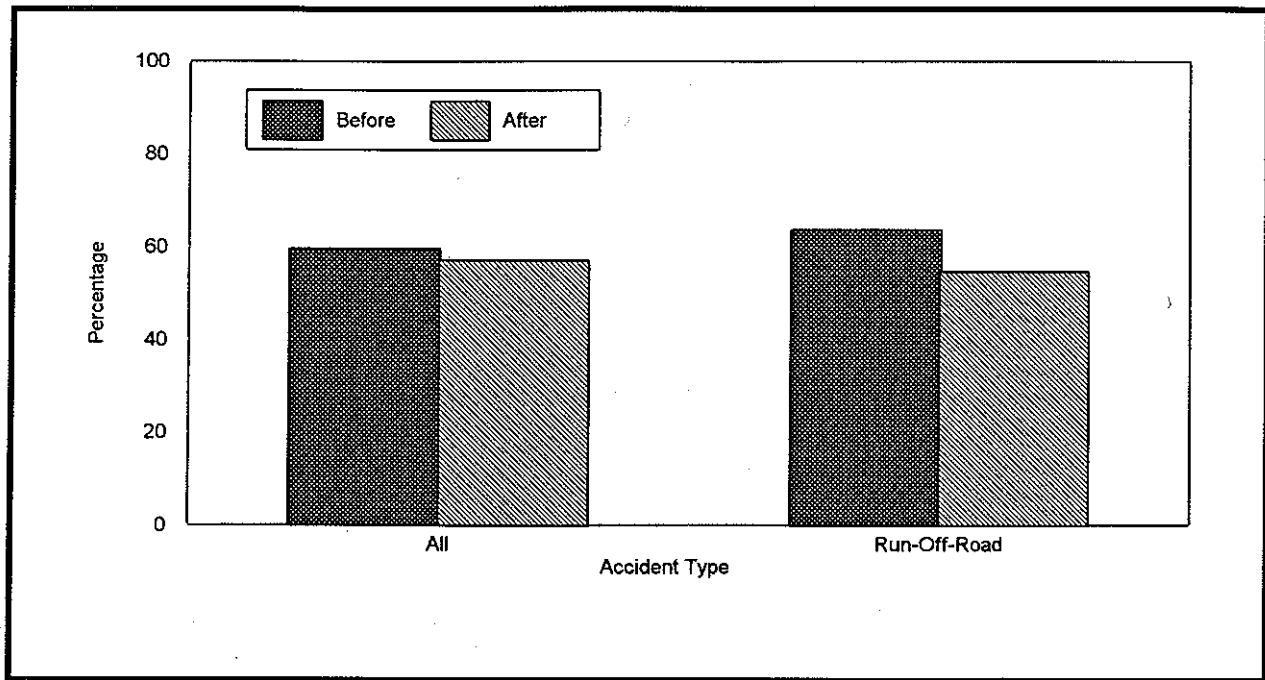


Figure 4-2. Percentage of Accidents with No Injuries for Texas Data

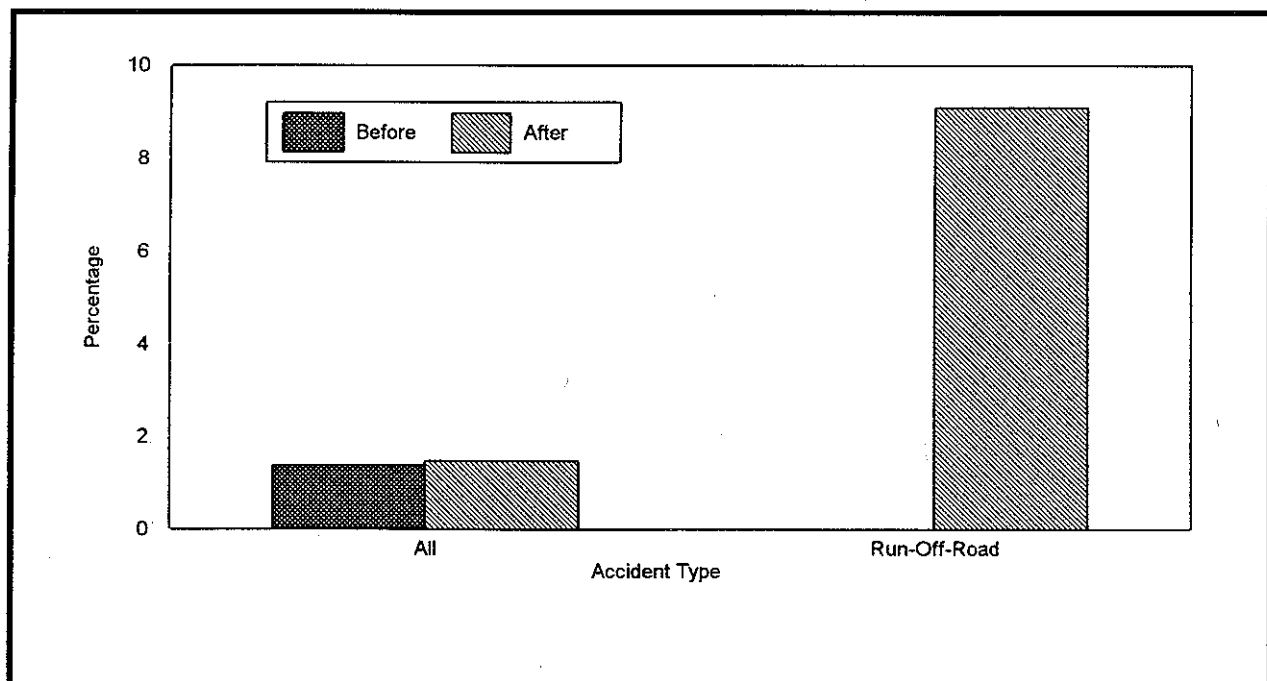


Figure 4-3. Percentage of Accidents with Fatalities for Texas Data

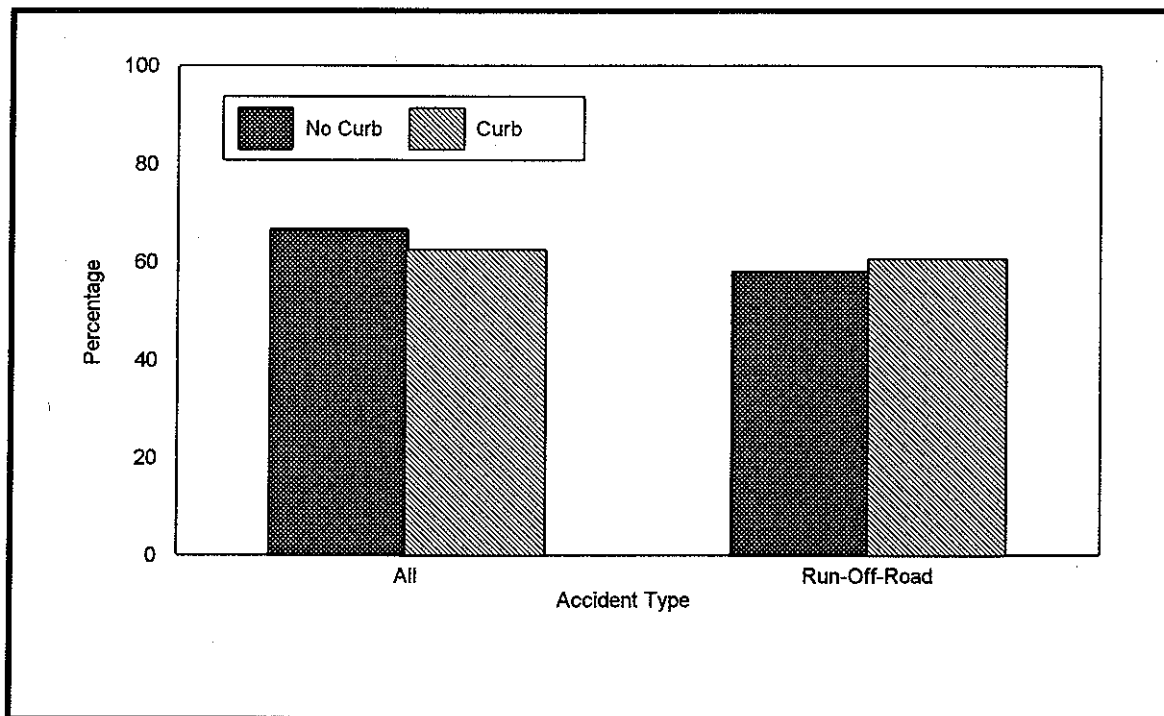


Figure 4-4. Percentage of Accidents with No Injuries for Illinois Data

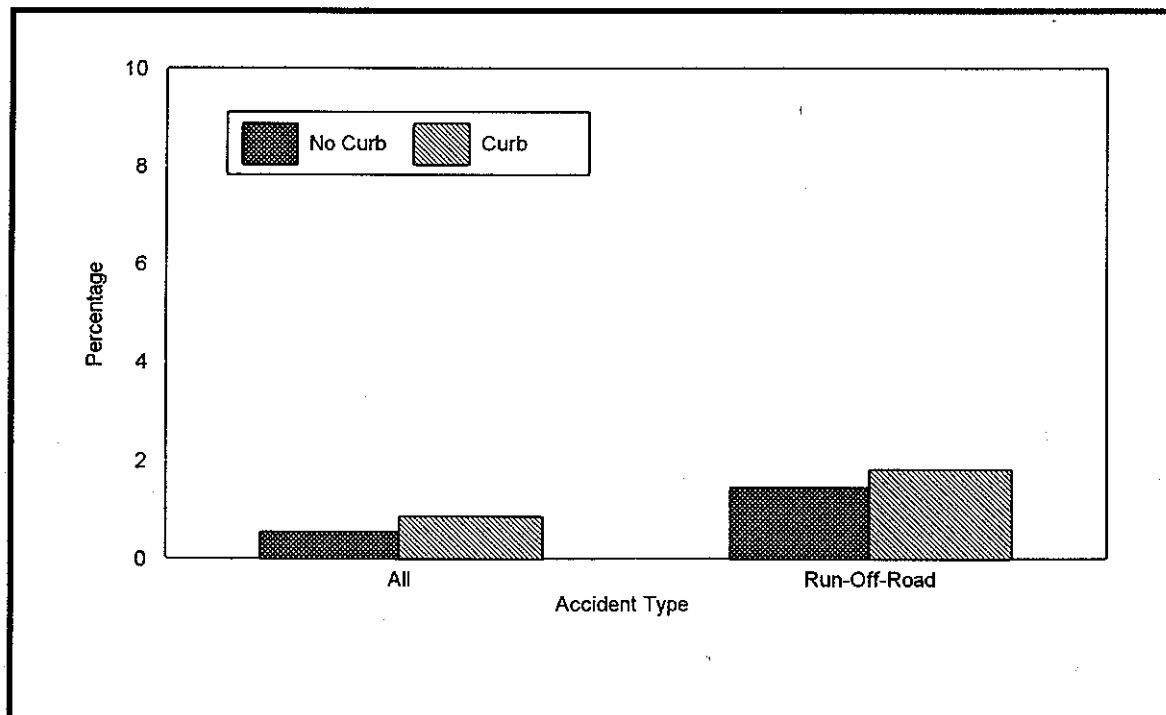


Figure 4-5. Percentage of Accidents with Fatalities for Illinois Data

ACCIDENT CHARACTERISTIC FREQUENCIES

As discussed in Chapter 3, determining the underlying cause of any increase or decrease in accident rates was desirable. The mean accident rates for Texas sites showed that run-off-road accidents experienced a statistically significant increase when curb and gutter was added to the section, and the accident rate for Illinois sites were 12 accidents per mile per year higher for sites with curb than sites without curb. Causes for this increase in accident rates may include storm water ponding, poor curb visibility during nighttime or impaired weather, or intersection related issues.

To determine whether these factors caused an increase in accidents, frequency tables were prepared. The tables included in Appendix B depict the relative frequency distributions of the five variables described in the *Accident Characteristic Frequency* section of Chapter 3 at each site for all accidents and run-off-road accidents. Log-linear models were created and tested for each variable listed to determine if any interaction between that variable and the road type for both Illinois and Texas existed. Three models were run for each variable, one for all accidents, one for run-off-road accidents, and one for run-off-road into fixed object accidents.

Visibility. To determine if drivers unable to see the curb during poor weather or lighting conditions was a problem, the percentage of poor visibility accidents before the roadway modification was compared with the percentage after the modification. The visibility variable was divided into two classes: impaired visibility and non-impaired visibility. Impaired visibility shows that the weather was not clear, that the accident did not occur during daylight, or both. Figure 4-6 depicts the percentage of accidents with impaired visibility for all accidents and for run-off-road accidents for Texas sites both before and after modification. Figure 4-7 depicts the percentage of accidents with impaired visibility for all accidents and for run-off-road accidents for Illinois curbed and non-curbed sites.

Figure 4-6 shows that the percentage of all accidents on Texas sites with impaired visibility increased after modification to a curb and gutter section. Illinois data shows that the percentage of all accidents and of run-off-road accidents with impaired visibility was greater for curbed sites than for non-curbed sites.

For all accidents, log-linear models for both Texas and Illinois data showed that the presence of curb affected the percentage of impaired visibility accidents, but that the curb did not affect the percentage of impaired visibility accidents for run-off-road accidents or for run-off-road into fixed object accidents.

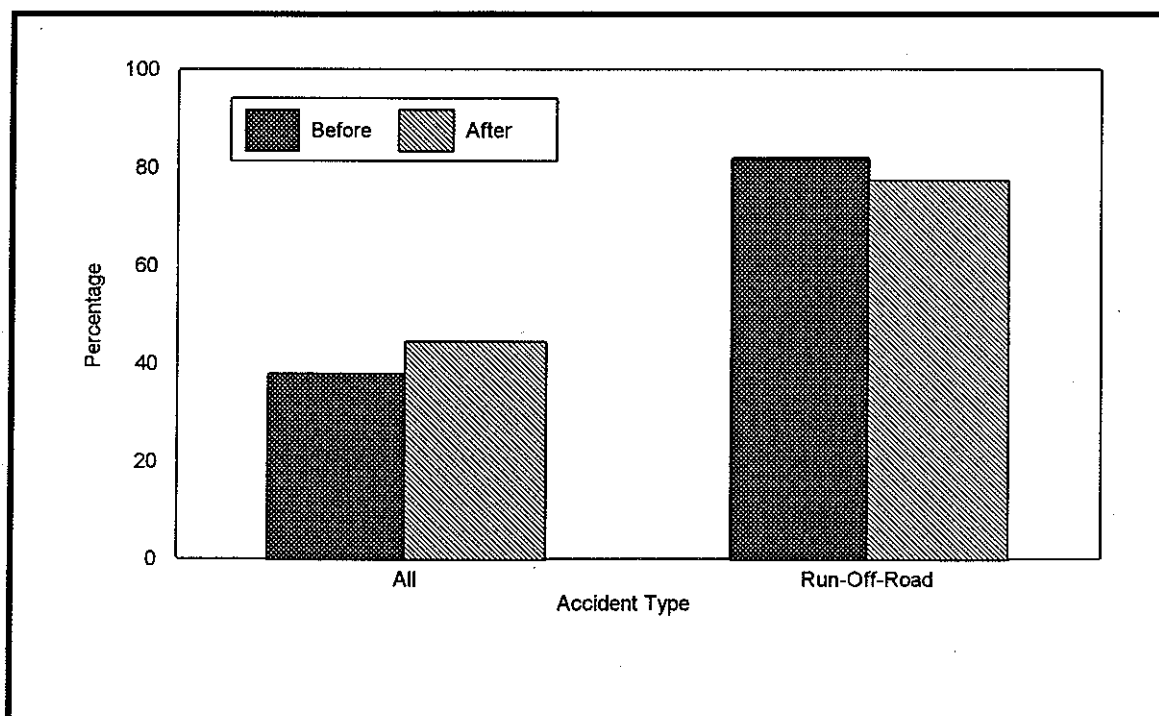


Figure 4-6. Percentage of Accidents with Impaired Visibility for Texas Data

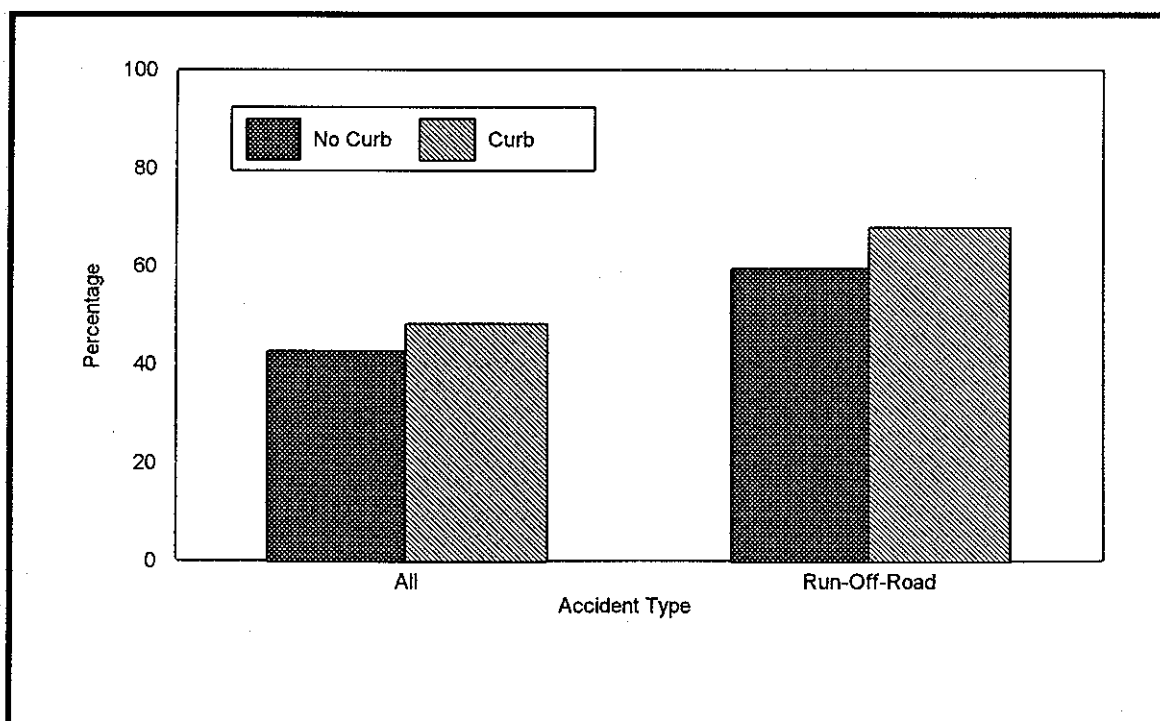


Figure 4-7. Percentage of Accidents with Impaired Visibility for Illinois Data

Lighting. To determine if people are unable to detect the curb specifically due to poor lighting conditions caused problems, a comparison of the percentage of accidents occurring during non daylight hours was made before and after roadway modification for Texas sites and between curbed and non-curbed for Illinois sites. Five categories were used in the accident report for lighting. These five levels were condensed into two for this model: daylight and non-daylight. Figure 4-8 shows the percentage of accidents occurring during non-daylight, or nighttime, for all accidents and for run-off-road accidents at Texas sites before and after modification. Figure 4-9 shows the percentage of accidents occurring during non-daylight conditions for all accidents and for run-off-road accidents at Illinois curbed and non-curbed sites.

Figure 4-8 shows that for Texas sites, the nighttime accident rate increased after modification, and the percentage of accidents occurring at nighttime for Texas sites also increased. The accident rate of nighttime accidents increased after modification for Illinois; however, the percentage of accidents occurring at nighttime decreased slightly.

For all accidents, Texas log-linear models indicted that curb did not affect the percentage of nighttime accidents, but Illinois log-linear models showed that curb did increase the percentage of nighttime accidents. Both Texas and Illinois data showed that curb did not affect the percentage of nighttime run-off-the-road accidents or run-off-the-road into fixed object accidents.

Surface Condition. To investigate the effects of storm water ponding causing safety problems, determining whether most accidents were occurring on a slick or wet surface after the roadway was modified with curb and gutter was desirable. The three categories for surface variables were dry, wet, and other. Other suggested either ice or snow present on the road.

The percentages of wet roadway surface accidents and wet roadway surface run-off-the-road accidents occurring at Texas sites before and after modification is shown in Figure 4-10. The percentages of wet roadway surface accidents and wet roadway surface run-off-the-road accidents occurring at Illinois curbed and non-curbed sites are shown in Figure 4-11.

Figures 4-10 and 4-11 show that the percentage of all accidents occurring on a wet roadway surface was higher for curbed sites than for non-curbed sites in both Texas and Illinois. For run-off-road accidents, the percentage of accidents occurring on a wet roadway surface was lower for Texas sites after modification, and higher for Illinois curbed sites than non-curbed sites. The rate of all accidents occurring on a wet roadway surface was higher in both Texas and Illinois for curbed sites than for non-curbed sites.

Log-linear models showed that for Texas data, the percentage of accidents occurring on wet roadway surfaces was not affected by the presence of curb for all accidents, run-off-road accidents, or run-off-road into fixed object accidents. Illinois data showed that for all accidents, curb increased the percentage of accidents occurring on a wet roadway surface. For run-off-road and run-off-road into fixed object accidents, Illinois data showed that curb and gutter did not affect the percentage of wet roadway surface accidents.

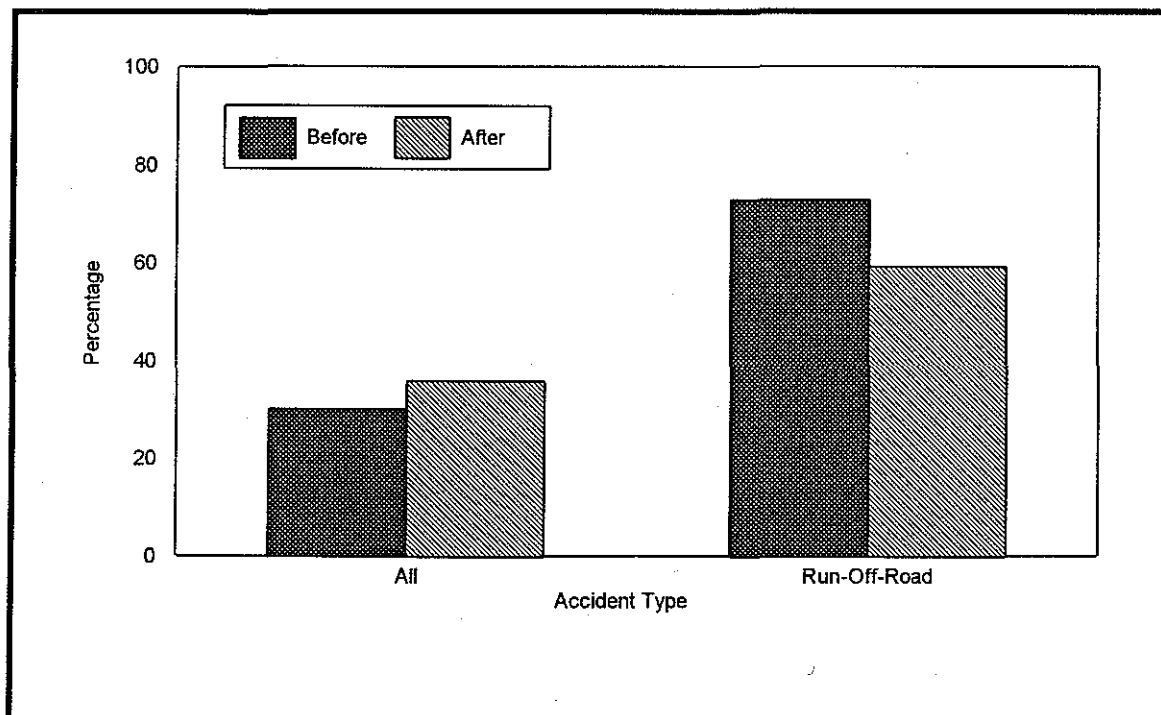


Figure 4-8. Percentage of Accidents During Nighttime for Texas Data

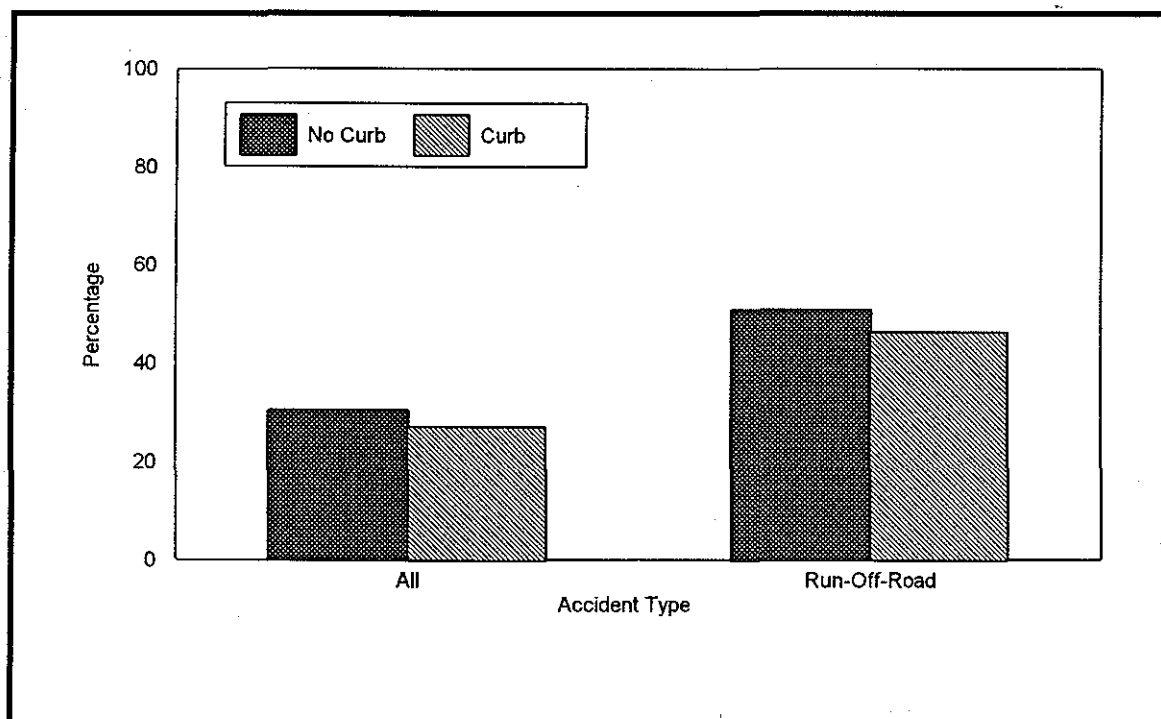


Figure 4-9. Percentage of Accidents During Nighttime for Illinois Data

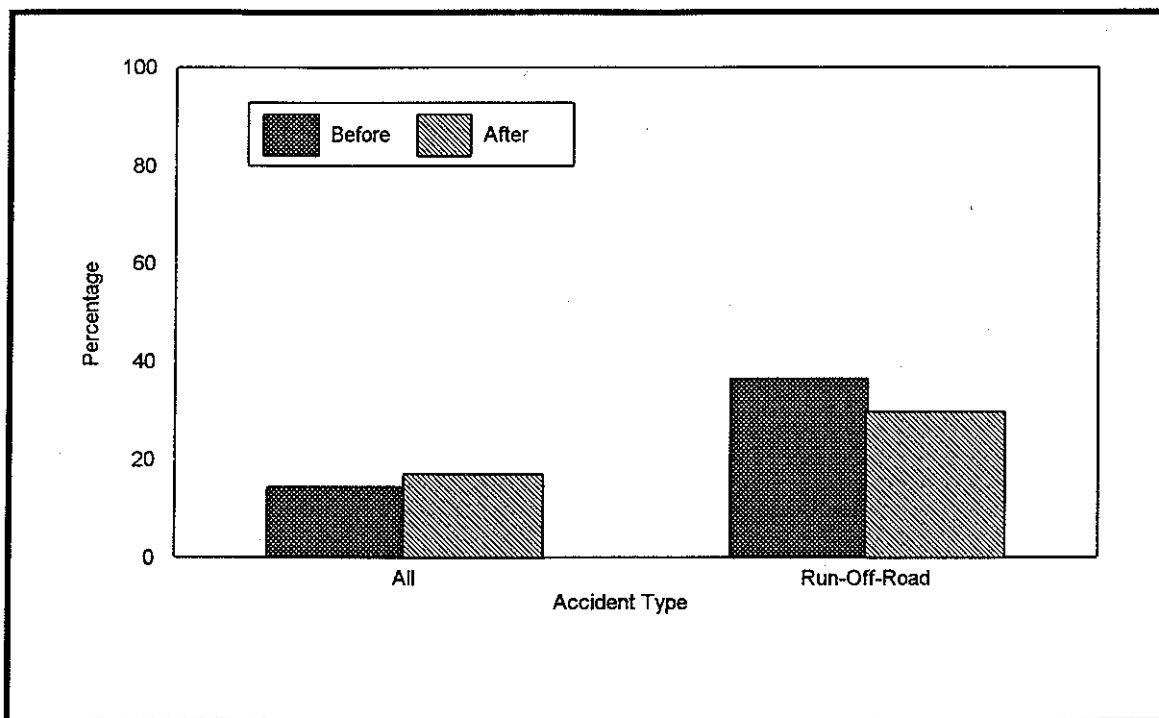


Figure 4-10. Percentage of Accidents on Wet Road Surfaces for Texas Data

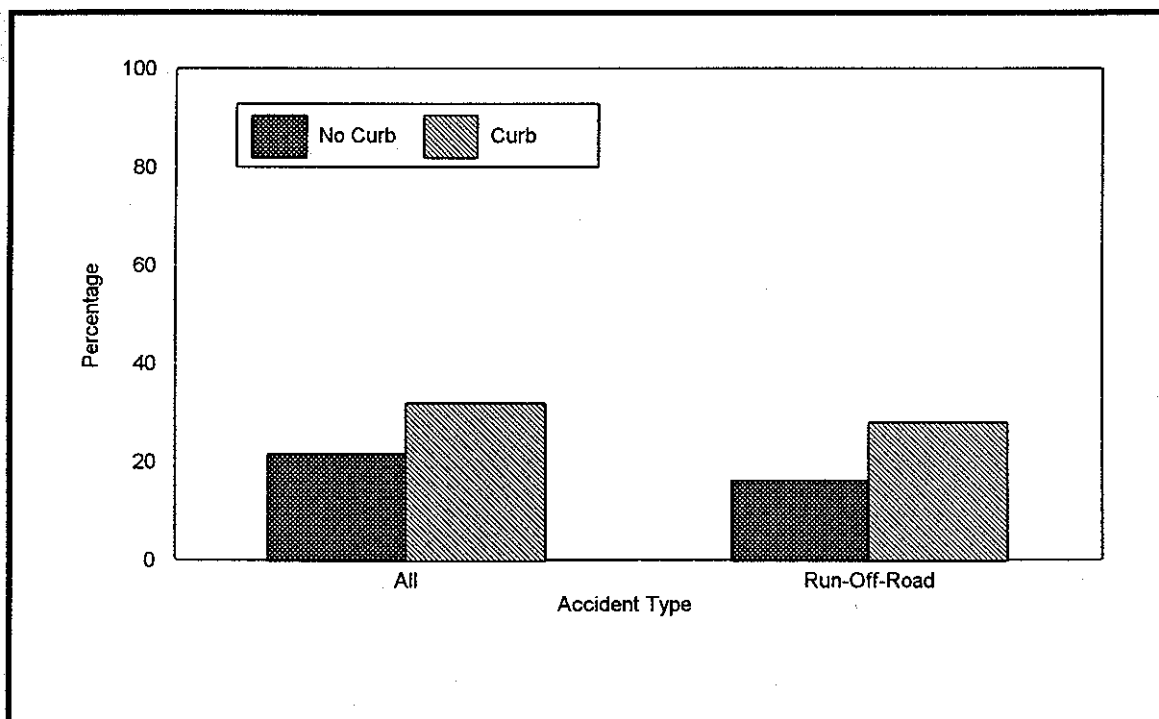


Figure 4-11. Percentage of Accidents on Wet Road Surfaces for Illinois Data

Intersection Related. The percentage of accidents occurring at an intersection was also tested to determine whether a different percentage of accidents occurred at intersections due to the change to curb and gutter. The intersection variable extracted from the accident reports was defined as intersection, intersection related, driveway access, or non intersection. Figure 4-12 portrays the percentage of accidents that were intersection related. This figure indicates that Texas sites show a slight increase in the percentage of intersection-related accidents for all accidents and for run-off-road accidents after roadway modification. Illinois data could not be categorized by intersection-related accidents, and therefore are not presented.

According to log-linear models, for all three accident types tested (all accidents, run-off-the-road accidents, and run-off-the-road into fixed object accidents) curb did not affect the percentage of intersection-related accidents at Texas sites.

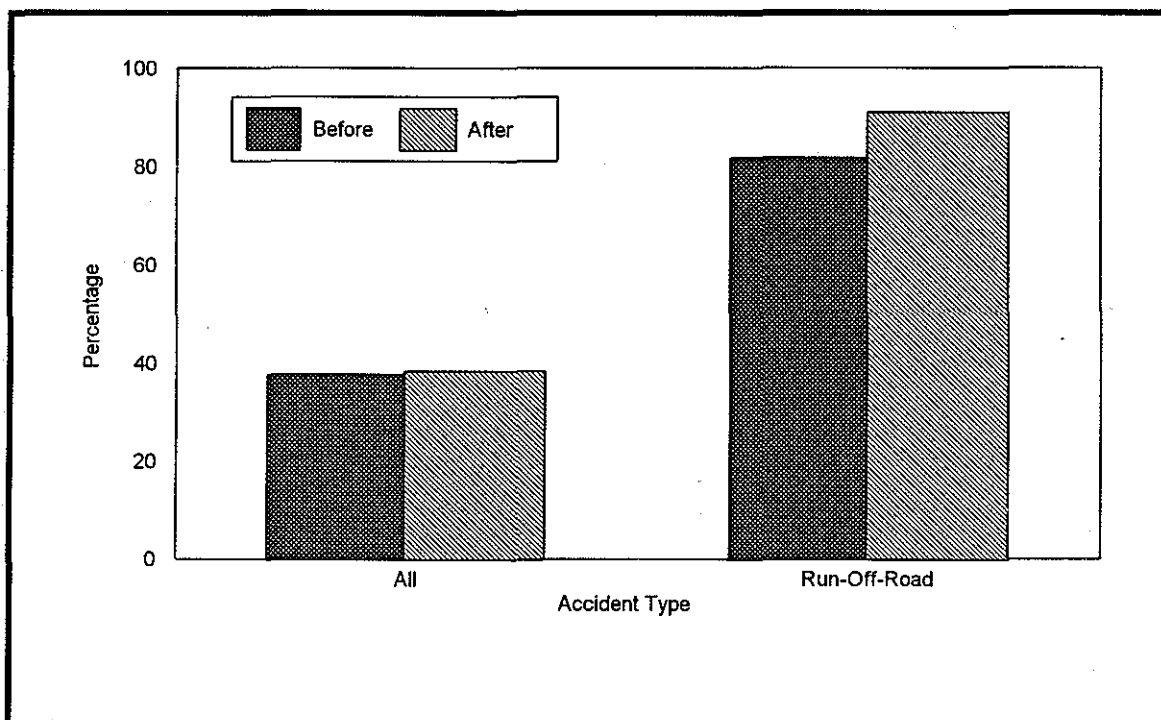


Figure 4-12. Percentage of Accidents Intersection Related for Texas Data

5. CONCLUSIONS AND RECOMMENDATIONS

The research conducted for this report analyzed the safety effects of high speed curb and gutter roadway sections. Researchers analyzed the safety effects through accident rates, accident severities, and accident characteristic frequencies. The sample population included accident data from ten high speed curb and gutter suburban sites in Texas before and after the site was modified to a curb and gutter cross section. Sites in Illinois included nine matched pairs with and without curbs. Research conclusions and recommendations are discussed in this chapter.

CONCLUSIONS

Several conclusions may be drawn based on the limited data available for this study.

- Driveway density appears to affect the safety of high speed curb and gutter sections. With high driveway density, curb and gutter is beneficial. Drivers are aware of roadside development and vehicles entering and exiting the roadway, and thus are more aware of the curb and less likely to strike it. With low driveway density, curb and gutter hinders the safety of the road as drivers are not expecting a curb, but a shoulder. At a low traffic volume, curb and gutter on a road with a low driveway density may not present a problem; however, at a high traffic volume on a road with low driveway density road, curb and gutter causes a safety hazard.
- As traffic volume increases, curb and gutter on a roadway cause increases in accident rates and create a less safe driving environment. A regression model for Illinois indicated that traffic volume significantly affected the difference in accident rates between matched pairs of sites with and without curbs.
- Storm water ponding does present problems for high-speed curb and gutter sections. In both Texas and Illinois, the rate of accidents occurring on a slick roadway surface increased (12 out of 19 sites). Log-linear models for Illinois showed that roadway surface conditions contributed to the difference in accidents between sites with and without curb and gutter.
- Visibility of the curb on high-speed curb and gutter sections also is a problem according to Texas and Illinois data. Both Texas and Illinois show that the proportion of accidents involving impaired visibility were much higher for sites with curb and gutter than without curb and gutter.
- Texas and Illinois data showed that the rate of run-off-the-road accidents increased with the installation of curb and gutter. Both Texas and Illinois data suggested that besides the rate, the severity of these accidents may be worse when using curb and gutter on a high-speed suburban multilane roadway than when using parallel drainage ditches.

RECOMMENDATIONS

It appears that suburban high-speed curb and gutter sections present several safety problems with respect to storm water ponding and visibility. It also appears that traffic volume and driveway density are two indicators of the safety of high-speed curb and gutter sections. Thus, these two operational variables should be considered when modifying a high speed site to a curb and gutter cross-section.

- When driveway density is low and traffic volume is high, curb and gutter may not be a wise option as it may increase accident rates and result in unsafe road conditions. On roadways with high driveway densities, however, curb and gutter may help the road to operate more safely.
- Installation of curb and gutter on a high-speed suburban multilane roadway requires special attention to the design of adequate drainage to prevent storm water ponding. The prevention of storm water ponding would ensure the safety of the section during inclement weather. Including placement of inlets, adequate cross section sloping, and minimum grade requirements may accomplish this.
- Lighting at nighttime to increase the visibility of the section should be considered. This lighting would allow the nighttime driver to see the line of the curb.
- Researchers recommend performing a future study with specific emphasis on the safety concerns addressed above in the conclusions and recommendations. This study may include a thorough examination of thresholds where driveway density and traffic volume show the safety benefits, or lack of safety benefits, that curb and gutter have on a high speed roadway.

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APPENDIX A

ACCIDENT RATE DATA FOR TEXAS AND ILLINOIS STUDIES

Table A-1. Texas Accident Frequencies: Before

Site Type	All	1	2	3	4	5	6	7	8	9	10
Acc1	584	30	89	45	55	40	120	66	82	20	37
Acc2	175	11	22	5	12	16	32	26	36	9	6
Acc3	68	4	9	9	4	3	5	13	11	3	7
Acc4	61	3	8	9	4	3	4	12	10	3	5
Acc5	221	13	27	13	15	18	34	35	44	10	12
Acc6	22	0	3	0	0	1	9	2	6	1	0
Acc7	12	0	1	0	0	1	4	1	4	1	0
Acc8	67	6	5	2	8	4	23	2	5	3	9
Acc9	8	0	1	3	0	1	1	1	0	1	0
Acc10	75	11	11	3	5	1	14	11	13	3	3
Acc11	66	11	11	2	5	1	11	8	11	3	3
Acc12	84	2	11	11	5	5	8	19	13	4	6
Acc13	5	1	1	1	0	1	1	0	0	0	0

Table A-2. Texas Accident Frequencies: After

Site Type	All	1	2	3	4	5	6	7	8	9	10
Acc1	814	42	161	35	97	79	69	123	138	54	16
Acc2	291	20	57	4	22	25	22	50	70	15	6
Acc3	118	2	25	1	15	18	8	22	18	6	3
Acc4	101	2	21	0	14	16	8	21	13	3	3
Acc5	361	21	71	5	34	36	29	60	78	18	9
Acc6	44	0	10	3	3	7	2	8	7	3	1
Acc7	28	0	7	2	3	4	1	6	3	1	1
Acc8	85	7	16	8	17	6	16	3	3	8	1
Acc9	9	3	0	1	0	1	1	0	2	1	0
Acc10	85	4	20	3	9	6	7	9	17	7	3
Acc11	79	4	18	3	7	6	7	9	15	7	3
Acc12	184	2	69	3	18	21	12	29	21	5	4
Acc13	13	0	7	0	2	2	0	1	0	1	0

Table A-3. Texas Accident Rates: Before

Site Type	All	1	2	3	4	5	6	7	8	9	10
Acc1	7.50	4.85	9.61	16.6	8.79	7.67	10.8	8.25	5.13	5.01	7.91
Acc2	2.25	1.78	2.38	1.84	1.92	3.07	2.82	3.25	2.25	2.25	1.28
Acc3	0.87	0.65	0.97	3.32	0.64	0.58	0.44	1.63	0.69	0.75	1.50
Acc4	0.78	0.48	0.86	3.32	0.64	0.58	0.35	1.50	0.63	0.75	1.07
Acc5	2.84	2.10	2.92	4.79	2.39	3.45	2.99	4.38	2.75	2.51	2.57
Acc6	0.28	0.00	0.32	0.00	0.00	0.19	0.79	0.25	0.38	0.25	0.00
Acc7	0.15	0.00	0.11	0.00	0.00	0.19	0.35	0.13	0.25	0.25	0.00
Acc8	0.86	0.97	0.54	0.74	1.28	0.77	2.03	0.25	0.31	0.75	1.92
Acc9	0.10	0.00	0.11	1.11	0.00	0.19	0.09	0.13	0.00	0.25	0.00
Acc10	0.96	1.78	1.19	1.11	0.80	0.19	1.23	1.38	0.81	0.75	0.64
Acc11	0.85	1.78	1.19	0.74	0.80	0.19	0.97	1.00	0.69	0.75	0.64
Acc12	1.08	0.32	1.19	4.05	0.80	0.96	0.70	2.38	0.81	1.00	1.28
Acc13	0.06	0.16	0.11	0.37	0.00	0.19	0.09	0.00	0.00	0.00	0.00

Table A-4. Texas Accident Rates: After

Site Type	All	1	2	3	4	5	6	7	8	9	10
Acc1	7.06	4.54	8.69	6.45	7.75	7.58	9.11	10.3	5.75	9.02	13.69
Acc2	2.52	2.16	3.08	0.74	0.76	2.40	2.91	4.17	2.92	2.51	5.13
Acc3	1.02	0.22	1.35	0.18	1.20	1.73	1.06	1.83	0.75	1.00	2.57
Acc4	0.88	0.22	1.13	0.00	1.12	1.53	1.06	1.75	0.54	0.50	13.69
Acc5	3.13	2.26	3.83	0.92	2.72	3.45	3.83	5.00	3.25	3.01	7.70
Acc6	0.38	0.00	0.54	0.55	0.24	0.67	0.26	0.67	0.29	0.50	0.86
Acc7	0.24	0.00	0.38	0.37	0.24	0.38	0.13	0.50	0.13	0.17	0.86
Acc8	0.74	0.76	0.86	1.47	1.36	0.58	2.11	0.25	0.13	1.34	0.00
Acc9	0.08	0.32	0.00	0.18	0.00	0.10	0.13	0.00	0.08	0.17	2.57
Acc10	0.74	0.43	1.08	0.55	0.72	0.58	0.92	0.75	0.71	1.17	2.57
Acc11	0.68	0.43	0.97	0.55	0.56	0.58	0.92	0.75	0.63	1.17	3.42
Acc12	1.60	0.22	3.72	0.55	1.44	2.01	1.58	2.42	0.88	0.84	0.00
Acc13	0.11	0.00	0.38	0.00	0.16	0.19	0.00	0.08	0.00	0.17	

Table A-5. Difference in Texas Accident Rates

Site Type	All	1	2	3	4	5	6	7	8	9	10
Acc1	-0.4	-0.3	-0.9	-10.1	-1.0	-0.1	-1.5	2.0	0.6	4.0	5.8
Acc2	0.3	0.4	0.7	-1.1	-0.2	-0.7	0.1	0.9	0.7	0.3	3.9
Acc3	0.2	-0.4	0.4	-3.1	0.6	1.2	0.6	0.2	0.1	0.3	1.1
Acc4	0.1	-0.3	0.3	-3.3	0.5	1.0	0.7	0.3	-0.1	-0.3	1.5
Acc5	0.3	0.2	0.9	-3.8	0.3	0.0	0.8	0.6	0.5	0.5	5.1
Acc6	0.1	0.0	0.2	0.6	0.2	0.5	-0.5	0.4	-0.1	0.3	0.9
Acc7	0.1	0.0	0.3	0.4	0.2	0.2	-0.2	0.4	-0.1	-0.1	0.9
Acc8	-0.1	-0.2	0.3	0.7	0.1	-0.2	0.1	0.0	-0.2	0.6	-1.1
Acc9	-0.0	0.3	-0.1	-0.9	0.0	-0.1	0.0	-0.1	0.1	-0.1	0.0
Acc10	-0.2	-1.4	-0.1	-0.6	-0.1	0.4	-0.3	-0.6	-0.1	0.4	1.9
Acc11	-0.2	-1.4	-0.2	-0.2	-0.2	0.4	-0.0	-0.3	-0.1	0.4	1.9
Acc12	0.5	-0.1	2.5	-3.5	0.6	1.1	0.9	0.0	0.1	-0.2	2.1
Acc13	0.1	-0.2	0.3	-0.4	0.2	0.0	-0.1	0.1	0.0	0.2	0.0

Table A-6. Percent Difference in Texas Accident Rates

Site Type	All	1	2	3	4	5	6	7	8	9	10
Acc1	-6	-6	-10	-61	-12	-1	-14	24	12	80	73
Acc2	12	22	30	-60	-8	-22	3	28	30	11	300
Acc3	17	-67	39	-94	88	200	140	13	9	33	71
Acc4	12	-55	31	-100	75	167	200	17	-13	-33	140
Acc5	10	8	31	-81	14	0	28	2	18	17	200
Acc6	35	X	67	X	X	250	-67	167	-22	100	X
Acc7	58	X	250	X	X	100	-63	300	-50	-33	X
Acc8	-14	-22	60	100	6	-25	4	0	-60	78	-56
Acc9	-24	X	-100	-83	X	-50	50	-100	X	-33	X
Acc10	-24	-76	-9	-50	-10	200	-25	-46	-13	56	300
Acc11	-19	-76	-18	-25	-30	200	-5	-25	-9	56	300
Acc12	48	-33	213	-86	80	110	125	2	8	-17	167
Acc13	76	-100	250	-100	X	0	-100	X	X	X	X

Table A-7. Illinois Accident Frequencies: No Curb

Site Type	All	1	2	3	4	5	6	7	8	9
Acc1	1848	21	536	65	246	21	565	207	120	67
Acc2	562	8	163	19	73	12	175	60	28	24
Acc3	375	5	94	8	57	5	99	60	36	11
Acc4	247	5	62	8	29	3	68	37	28	7
Acc5	786	10	218	25	107	15	230	92	59	30
Acc6	69	6	17	1	12	0	13	3	12	5
Acc7	50	6	9	0	9	0	9	3	11	3
Acc8	603	2	154	36	124	0	144	97	29	17
Acc9	9	0	1	1	1	1	4	0	1	0
Acc10	159	2	42	2	20	2	55	16	14	6
Acc11	859	11	296	17	51	16	309	90	54	15
Acc12	397	6	110	10	45	5	110	60	39	12
Acc13	11	0	2	0	1	0	3	1	1	3

Table A-8. Illinois Accident Frequencies: Curb

Site Type	All	1	2	3	4	5	6	7	8	9
Acc1	4090	45	578	204	25	434	1769	715	156	164
Acc2	1099	20	161	39	4	143	493	150	50	39
Acc3	1256	14	159	48	3	143	489	313	42	45
Acc4	903	4	102	29	3	118	356	230	21	40
Acc5	1967	26	261	69	6	239	816	398	78	74
Acc6	165	7	21	6	6	21	43	36	21	4
Acc7	108	6	13	3	3	15	24	26	15	3
Acc8	1184	15	185	47	3	180	531	145	7	71
Acc9	8	0	0	0	0	1	6	1	0	0
Acc10	591	11	84	19	8	57	237	131	26	18
Acc11	1917	4	223	120	4	195	876	358	68	69
Acc12	1298	8	153	42	3	174	512	315	38	53
Acc13	4	0	1	0	0	0	3	0	0	0

Table A-9. Illinois Accident Rates: No Curb

Site Type	All	1	2	3	4	5	6	7	8	9
Acc1	28.79	4.20	38.42	13.83	83.39	5.83	39.51	19.53	28.57	13.67
Acc2	8.75	1.60	11.68	4.04	24.75	3.33	12.24	5.66	6.67	4.90
Acc3	5.84	1.00	10.15	1.70	19.32	1.39	6.92	5.66	8.57	2.24
Acc4	3.85	1.00	6.70	1.70	9.83	0.83	4.76	3.49	6.67	1.43
Acc5	12.24	2.00	23.54	5.32	36.27	4.17	16.08	8.68	14.05	6.12
Acc6	1.07	1.20	1.84	0.21	4.07	0.00	0.91	0.28	2.86	1.02
Acc7	0.78	1.20	0.97	0.00	3.05	0.00	0.63	0.28	2.62	0.61
Acc8	9.39	0.40	16.63	7.66	42.03	0.00	10.07	9.15	6.90	3.47
Acc9	0.14	0.00	0.11	0.21	0.34	0.28	0.28	0.0	0.24	0.00
Acc10	2.48	0.40	4.54	0.43	6.78	0.56	3.85	1.51	3.33	1.22
Acc11	13.38	2.20	31.97	3.62	17.29	4.44	21.61	8.49	12.86	3.06
Acc12	6.18	1.20	11.88	2.13	15.25	1.39	7.69	5.66	9.29	2.45
Acc13	0.17	0.00	0.22	0.00	0.34	0.00	0.21	0.09	0.24	0.61

Table A-10. Illinois Accident Rates: Curb

Site Type	All	1	2	3	4	5	6	7	8	9
Acc1	41.54	6.77	37.41	36.76	3.08	13.2	256.38	110.0	16.00	27.39
Acc2	11.16	3.01	10.42	7.09	0.49	4.34	71.45	23.08	5.13	5.95
Acc3	12.76	2.11	10.29	8.73	0.37	4.34	70.87	48.15	4.31	6.87
Acc4	9.17	0.60	6.60	5.27	0.37	3.58	51.59	35.38	2.15	6.11
Acc5	19.98	3.91	16.89	12.43	0.74	7.25	118.26	61.23	8.00	11.30
Acc6	1.68	1.05	1.36	1.09	0.74	0.64	6.23	5.54	2.15	0.61
Acc7	1.10	0.90	0.84	0.55	0.37	0.46	3.48	4.00	1.54	0.46
Acc8	12.03	2.26	11.97	8.55	0.37	5.46	76.96	22.31	0.72	10.84
Acc9	0.08	0.00	0.00	0.00	0.00	0.03	0.87	0.15	0.00	0.00
Acc10	6.00	1.65	5.44	3.45	0.99	1.73	34.35	20.15	2.67	2.75
Acc11	19.47	0.60	14.43	21.82	0.49	5.92	126.96	55.08	6.97	10.53
Acc12	13.18	1.20	9.90	7.64	0.37	5.28	74.20	48.46	3.90	8.09
Acc13	0.04	0.00	0.06	0.00	0.00	0.00	0.43	0.00	0.00	0.00

Table A-11. Difference in Illinois Accident Rates

Site Type	All	1	2	3	4	5	6	7	8	9
Acc1	12.8	2.6	-1.0	22.9	-80.3	7.3	216.9	90.5	-12.6	13.7
Acc2	2.4	1.4	-1.3	3.1	-24.3	1.0	59.2	17.4	-1.5	1.1
Acc3	6.9	1.1	0.1	7.0	-19.0	3.0	64.0	42.5	-4.3	4.6
Acc4	5.3	-0.4	-0.1	3.6	-9.5	2.8	46.8	31.9	-4.5	4.7
Acc5	7.7	1.9	-6.7	7.1	-35.5	3.1	102.2	52.6	-6.1	5.1
Acc6	0.6	-0.2	-0.5	0.9	-3.3	0.6	5.3	5.3	-0.7	-0.4
Acc7	0.3	-0.3	-0.1	0.6	-2.7	0.5	2.9	3.7	-1.1	-0.2
Acc8	2.6	1.9	-4.7	0.9	-41.7	5.5	66.9	13.2	-6.2	7.4
Acc9	-0.1	0.0	-0.1	-0.2	-0.3	-0.3	0.6	0.2	-0.2	0.0
Acc10	3.5	1.3	0.9	3.0	-5.8	1.2	30.5	18.6	-0.7	1.5
Acc11	6.1	-1.6	-17.5	18.2	-16.8	1.5	105.4	46.6	-5.9	7.5
Acc12	7.0	0.0	-2.0	5.5	-14.9	3.9	66.5	42.8	-5.4	5.6
Acc13	-0.1	0.0	-0.2	0.0	-0.3	0.0	0.2	-0.1	-0.2	-0.6

Table A-12. Percent Difference in Illinois Accident Rates

Site Type	All	1	2	3	4	5	6	7	8	9
Acc1	44	61	-3	166	-96	125	549	463	-44	100
Acc2	28	88	-11	75	-98	30.2	484	308	-23	22
Acc3	118	111	1	413	-98	212	924	751	-50	206
Acc4	138	-40	-1	210	-96	330	985	914	-68	327
Acc5	63	96	-28	134	98	74	635	6	43	85
Acc6	56	-12	-26	413	-82	X	586	1847	-25	-40
Acc7	41	-25	-13	X	-88	X	453	1313	-41	-25
Acc8	28	464	-28	12	-99	X	664	144	-90	212
Acc9	-42	X	-100	-100	-100	-89	210	X	-100	X
Acc10	142	314	20	711	-86	211	793	1235	-20	124
Acc11	46	-73	-55	503	-97	33	488	549	-46	244
Acc12	113	0	-17	259	-98	280	865	756	-58	230
Acc13	-76	X	-70	X	-100	X	107	-100	-100	-100

APPENDIX B

ACCIDENT FREQUENCY DATA FOR TEXAS AND ILLINOIS DATA

Table B-1. Texas Accident Frequencies Before (By Site)

Severity	1	2	3	4	5	6	7	8	9	10	Total
1	21	48	35	29	19	71	41	56	12	15	347
2	3	21	5	13	6	14	5	14	3	10	94
3	2	11	2	9	8	23	16	8	3	8	90
4	3	8	3	4	4	11	2	4	2	4	45
5	1	1	0	0	3	1	2	0	0	0	8
Total	30	89	45	55	40	120	66	82	20	37	584

Table B-2. Texas Accident Frequencies After (By Site)

Severity	1	2	3	4	5	6	7	8	9	10	Total
1	31	91	19	61	43	38	71	70	26	14	464
2	4	34	7	16	16	13	25	27	19	0	161
3	6	27	8	12	12	12	13	30	3	2	125
4	1	7	1	7	7	4	10	9	5	0	52
5	0	2	0	1	1	2	4	2	1	0	12
Total	42	161	35	79	79	69	123	138	54	16	814

Table B-3. Texas Accident Frequencies Before (By Accident Type)

Severity	1	2	3	4	5	6	7	8	9	10	11	12	13
1	347	103	43	38	347	14	9	42	0	37	30	53	3
2	94	20	13	12	94	2	0	12	0	20	19	16	0
3	90	31	10	9	90	5	3	6	3	8	7	13	2
4	45	17	1	1	45	1	0	6	4	4	4	1	0
5	8	4	1	1	8	0	0	1	1	0	0	1	0
Total	584	175	68	61	584	22	12	67	8	69	60	84	5

Table B-4. Texas Accident Frequencies After (By Accident Type)

Severity	1	2	3	4	5	6	7	8	9	10	11	12	13
1	464	147	66	59	464	24	15	49	0	36	31	82	8
2	161	44	29	24	161	3	1	18	0	26	26	31	3
3	125	64	20	17	125	9	7	13	5	17	16	22	1
4	52	29	2	0	52	4	2	5	4	4	4	1	1
5	12	7	1	1	12	4	3	0	0	2	2	2	0
Total	814	291	118	101	814	44	28	85	9	85	79	138	13

Table B-5. Texas Accident Frequencies Before (By Site)

Light	1	2	3	4	5	6	7	8	9	10	Total
0	19	67	40	43	24	88	40	46	11	31	409
1	0	1	0	0	0	1	0	2	0	0	4
2	5	17	0	9	12	12	18	27	7	3	110
3	5	4	4	2	3	18	8	6	2	3	55
4	1	0	1	1	1	1	0	1	0	0	6
Total	30	89	45	55	40	120	66	82	20	37	584

Table B-6. Texas Accident Frequencies After (By Site)

Light	1	2	3	4	5	6	7	8	9	10	Total
0	22	104	31	75	54	47	73	68	39	10	523
1	1	0	1	0	2	1	3	1	0	0	9
2	2	37	1	9	20	2	30	55	11	1	168
3	16	19	2	12	2	19	12	13	4	5	104
4	1	1	0	1	1	0	5	1	0	0	10
Total	42	161	35	97	79	69	123	138	54	16	814

Table B-7. Texas Accident Frequencies Before (By Accident Type)

Light	1	2	3	4	5	6	7	8	9	10	11	12	13
0	409	0	46	42	409	6	2	53	7	49	42	55	2
1	4	4	1	1	4	2	1	0	1	0	0	1	0
2	110	110	13	10	110	9	7	6	0	13	12	17	2
3	55	55	8	8	55	5	2	7	0	5	4	11	1
4	6	6	0	0	6	0	0	1	0	2	2	0	0
Total	584	175	68	61	584	22	12	67	8	69	60	84	5

Table B-8. Texas Accident Frequencies After (By Accident Type)

Light	1	2	3	4	5	6	7	8	9	10	11	12	13
0	523	0	70	60	523	18	11	61	7	57	53	80	6
1	9	9	2	2	9	3	2	1	1	0	0	2	0
2	168	168	31	24	168	18	12	9	1	14	12	33	6
3	104	104	14	14	104	4	2	14	0	13	13	21	1
4	10	10	1	1	10	1	1	0	0	1	1	2	0
Total	814	291	118	101	814	44	28	85	9	85	79	138	13

Table B-9. Texas Accident Frequencies Before (By Site)

Visibility	1	2	3	4	5	6	7	8	9	10	Total
1	17	62	32	40	22	86	31	38	10	25	363
2	1	0	1	1	1	2	0	3	0	0	9
3	4	15	0	8	11	11	15	24	6	3	97
4	4	3	3	2	3	16	7	6	1	2	47
5	2	5	8	3	2	2	9	8	1	6	46
6	0	1	0	0	0	0	0	0	0	0	1
7	1	2	0	1	1	1	3	3	1	0	13
8	1	1	1	0	0	2	1	0	1	1	8
Total	30	89	45	55	40	120	66	82	20	37	584

Table B-10. Texas Accident Frequencies After (By Site)

Visibility	1	2	3	4	5	6	7	8	9	10	Total
1	21	90	30	63	43	40	63	60	36	7	453
2	2	1	1	1	2	1	6	2	0	0	16
3	2	29	1	8	14	2	25	47	8	1	137
4	15	16	2	10	2	18	7	11	4	5	90
5	1	14	1	12	11	7	10	8	3	3	70
6	0	0	0	0	1	0	2	0	0	0	3
7	0	8	0	1	6	0	5	8	3	0	31
8	1	3	0	2	0	1	5	2	0	0	14
Total	42	161	35	97	79	69	123	138	54	16	814

Table B-11. Texas Accident Frequencies Before (By Accident Type)

Visibility	1	2	3	4	5	6	7	8	9	10	11	12	13
1	363	0	0	0	363	4	2	49	7	46	40	14	2
2	9	9	0	0	9	1	1	1	0	2	2	0	0
3	97	97	0	0	97	7	5	6	0	10	10	6	2
4	47	47	0	0	47	5	2	6	0	4	4	3	1
5	46	0	46	42	46	2	0	4	0	3	2	41	0
6	1	1	1	1	1	1	0	0	0	0	0	1	0
7	13	13	13	10	13	2	2	0	1	3	2	11	0
8	8	8	8	8	8	0	0	1	0	1	0	8	0
Total	584	175	68	61	584	22	12	67	8	69	60	84	5

Table B-12. Texas Accident Frequencies After (By Accident Type)

Visibility	1	2	3	4	5	6	7	8	9	10	11	12	13
1	453	0	0	0	453	10	6	52	6	54	50	16	5
2	16	16	0	0	16	4	3	1	0	1	1	1	0
3	137	137	0	0	137	15	10	5	1	13	11	8	5
4	90	90	0	0	90	4	2	13	1	12	12	7	0
5	70	0	70	60	70	8	5	9	1	3	3	64	1
6	3	3	3	3	3	0	0	0	0	0	0	3	0
7	31	31	31	24	31	3	2	4	0	1	1	25	1
8	14	14	14	14	14	0	0	1	0	1	1	14	1
Total	814	291	118	101	814	44	28	85	9	85	79	138	13

Table B-13. Texas Accident Frequencies Before (By Site)

Weather	1	2	3	4	5	6	7	8	9	10	Total
0	26	80	36	51	37	115	53	71	17	30	516
1	3	8	9	4	3	4	12	10	3	5	61
2	0	0	0	0	0	0	0	0	0	0	0
3	0	1	0	0	0	0	1	0	0	2	4
7	1	0	0	0	0	1	0	1	0	0	3
Total	30	89	45	55	40	120	66	82	20	37	584

Table B-14. Texas Accident Frequencies After (By Site)

Weather	1	2	3	4	5	6	7	8	9	10	Total
0	40	136	34	82	61	61	101	120	48	13	696
1	2	21	0	14	16	8	21	13	3	3	101
2	0	1	0	0	1	0	0	0	0	0	2
3	0	1	1	0	1	0	1	5	3	0	12
7	0	2	0	1	0	0	0	0	0	0	3
Total	42	161	35	97	79	69	123	138	54	16	814

Table B-15. Texas Accident Frequencies Before (By Accident Type)

Weather	1	2	3	4	5	6	7	8	9	10	11	12	13
0	516	153	0	0	516	17	10	62	7	62	56	23	5
1	61	19	61	61	61	5	2	4	1	7	4	60	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4	2	4	0	4	0	0	1	0	0	0	1	0
7	3	1	3	0	3	0	0	0	0	0	0	0	0
Total	584	175	68	61	584	22	12	67	8	69	60	84	5

Table B-16. Texas Accident Frequencies After (By Accident Type)

Weather	1	2	3	4	5	6	7	8	9	10	11	12	13
0	696	243	0	0	696	33	21	71	8	80	74	32	10
1	101	41	101	101	101	10	7	11	1	4	4	98	1
2	2	0	2	0	2	0	0	0	0	1	1	0	1
3	12	7	12	0	12	1	0	2	0	0	0	7	1
7	3	0	3	0	3	0	0	1	0	0	0	1	0
Total	814	291	118	101	814	44	28	85	9	85	79	138	13

Table B-17. Texas Accident Frequencies Before (By Site)

Inter.	1	2	3	4	5	6	7	8	9	10	Total
0	10	20	21	17	10	29	11	19	5	10	152
1	3	31	6	13	4	19	14	19	1	12	122
2	3	12	10	16	7	24	0	2	4	12	90
3	14	26	8	9	19	48	41	42	10	3	220
Total	30	89	45	55	40	120	66	82	20	37	584

Table B-18. Texas Accident Frequencies After (By Site)

Inter.	1	2	3	4	5	6	7	8	9	10	Total
0	11	46	11	32	10	16	45	37	18	7	223
1	4	46	6	20	10	8	18	33	6	6	157
2	4	23	10	27	14	18	1	1	13	2	113
3	23	46	8	18	45	27	59	67	17	1	311
Total	42	161	35	97	79	69	123	138	54	16	814

Table B-19. Texas Accident Frequencies Before (By Accident Type)

Inter.	1	2	3	4	5	6	7	8	9	10	11	12	13
0	152	33	11	11	152	0	0	8	2	2	1	13	0
1	122	34	17	15	122	3	1	11	1	11	9	19	1
2	90	18	11	10	90	1	1	29	0	9	8	14	0
3	220	90	29	25	220	18	10	19	5	47	42	38	4
Total	584	175	68	61	584	22	12	67	8	69	60	84	5

Table B-20. Texas Accident Frequencies After (By Accident Type)

Inter.	1	2	3	4	5	6	7	8	9	10	11	12	13
0	233	60	21	19	233	0	0	4	3	5	5	26	1
1	157	57	22	21	157	3	2	7	0	24	45	31	2
2	113	27	17	12	113	1	0	50	0	7	22	16	1
3	311	147	58	49	311	40	26	24	6	49	7	65	9
Total	814	291	118	101	814	44	28	85	9	85	79	138	13

Table B-21. Texas Accident Frequencies Before (By Site)

Rd. Rel.	1	2	3	4	5	6	7	8	9	10	Total
0	23	82	41	53	26	104	37	57	18	35	476
1	7	4	3	2	12	7	26	17	1	1	80
2	0	3	1	0	2	9	3	8	1	1	28
Total	30	89	45	55	40	120	66	82	20	37	584

Table B-22. Texas Accident Frequencies After (By Site)

Rd. Rel.	1	2	3	4	5	6	7	8	9	10	Total
0	31	137	31	84	60	61	81	93	47	14	639
1	11	14	1	10	12	6	32	36	4	1	127
2	0	10	3	3	7	2	10	9	3	1	48
Total	42	161	35	97	79	69	123	138	54	16	814

Table B-23. Texas Accident Frequencies Before (By Accident Type)

Rd. Rel.	1	2	3	4	5	6	7	8	9	10	11	12	13
0	476	119	43	38	476	0	0	65	8	62	58	55	0
1	80	38	19	17	80	0	0	2	0	5	1	20	5
2	28	18	6	6	28	22	12	0	0	2	1	9	0
Total	584	175	68	61	584	22	12	67	8	69	60	84	5

Table B-24. Texas Accident Frequencies After (By Accident Type)

Rd. Rel.	1	2	3	4	5	6	7	8	9	10	11	12	13
0	639	204	73	62	639	0	0	79	9	78	78	86	1
1	127	59	32	27	127	0	0	6	0	6	1	37	12
2	48	28	13	12	48	44	28	0	0	1	0	15	0
Total	814	291	118	101	814	44	28	85	9	85	79	138	13

Table B-25. Texas Accident Frequencies Before (By Site)

Surface	1	2	3	4	5	6	7	8	9	10	Total
0	26	78	34	50	33	111	47	67	15	31	492
1	2	11	11	5	5	8	19	13	4	6	84
2	0	0	0	0	0	0	0	0	1	0	1
4	1	0	0	0	0	0	0	0	0	0	1
5	1	0	0	0	2	1	0	2	0	0	6
Total	30	89	45	55	40	120	66	82	20	37	584

Table B-26. Texas Accident Frequencies After (By Site)

Surface	1	2	3	4	5	6	7	8	9	10	Total
0	40	131	32	78	54	57	93	117	48	12	662
1	2	23	3	18	21	12	29	21	5	4	138
2	0	0	0	0	0	0	0	0	0	0	0
4	0	7	0	1	4	0	1	0	1	0	14
5	0	0	0	0	0	0	0	0	0	0	0
Total	42	161	35	97	79	69	123	138	54	16	814

Table B-27. Texas Accident Frequencies Before (By Accident Type)

Surface	1	2	3	4	5	6	7	8	9	10	11	12	13
0	492	145	3	0	492	14	8	62	7	60	54	0	4
1	84	29	61	60	84	8	4	5	1	8	5	84	0
2	1	0	0	0	1	0	0	0	0	0	0	0	0
4	1	1	1	0	1	0	0	0	0	0	0	0	0
5	6	0	3	1	6	0	0	0	0	1	1	0	1
Total	584	175	68	61	584	22	12	67	8	69	60	84	5

Table B-28. Texas Accident Frequencies After (By Accident Type)

Surface	1	2	3	4	5	6	7	8	9	10	11	12	13
0	662	226	5	0	662	31	20	71	8	76	71	138	10
1	138	58	106	98	138	13	8	14	1	7	6	0	2
2	0	0	0	0	0	0	0	0	0	0	0	0	0
4	14	7	7	3	14	0	0	0	0	2	2	0	1
5	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	814	291	118	101	814	44	28	85	9	85	79	138	13

Table B-29. Illinois Accident Frequencies Before (By Site)

Severity	1	2	3	4	5	6	7	8	9	Total
1	15	352	44	180	16	385	129	62	45	1228
2	1	44	2	7	0	28	12	9	10	113
3	2	49	4	19	2	38	17	25	5	161
4	3	91	15	37	3	110	49	23	5	336
5	0	0	0	3	0	4	0	1	2	10
Total	21	536	65	246	21	565	207	120	67	1848

Table B-30. Illinois Accident Frequencies After (By Site)

Severity	1	2	3	4	5	6	7	8	9	Total
1	34	350	139	19	282	1121	404	98	104	2551
2	5	69	13	4	26	157	85	23	25	407
3	2	45	14	0	38	188	80	15	13	395
4	4	108	35	0	85	296	135	18	21	702
5	0	6	3	2	3	7	11	2	1	35
Total	45	578	204	25	434	1769	715	156	164	4090

Table B-31. Illinois Accident Frequencies Before (By Accident Type)

Severity	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1228	377	263	166	528	40	33	403	0	123	563	279	9
2	113	29	19	15	38	7	5	35	3	8	37	20	1
3	161	68	30	17	86	13	7	62	4	12	58	24	0
4	336	81	63	49	127	8	5	101	1	16	201	71	0
5	10	7	0	0	7	1	0	2	1	0	0	3	1
Total	1848	562	375	247	786	69	50	603	9	159	859	397	11

Table B-32. Illinois Accident Frequencies After (By Accident Type)

Severity	1	2	3	4	5	6	7	8	9	10	11	12	13
1	2551	712	784	539	1239	100	73	737	0	411	1155	788	4
2	407	97	131	99	190	22	9	120	4	58	144	127	0
3	395	129	111	79	201	19	9	125	3	59	164	118	0
4	702	148	221	179	315	21	14	195	1	54	452	255	0
5	35	13	9	7	22	3	3	7	0	9	2	10	0
Total	4090	1099	1256	903	1967	165	108	1184	8	591	1917	1298	4

Table B-33. Illinois Accident Frequencies Before (By Site)

Surface	1	2	3	4	5	6	7	8	9	Total
0	0	8	0	2	0	0	0	3	0	13
1	14	373	55	173	11	422	128	69	46	1291
2	6	110	10	45	5	110	60	39	12	397
4	1	43	0	26	5	33	19	9	5	141
5	0	0	0	0	0	0	0	0	0	0
6	0	2	0	0	0	0	0	0	4	6
Total	21	536	65	246	21	565	207	120	67	1848

Table B-34. Illinois Accident Frequencies After (By Site)

Surface	1	2	3	4	5	6	7	8	9	Total
0	0	2	5	0	2	11	4	0	2	26
1	26	354	135	22	230	1098	321	100	99	2385
2	8	153	42	3	174	512	315	38	53	1298
4	11	69	21	0	28	146	73	18	10	376
5	0	0	1	0	0	0	0	0	0	1
6	0	0	0	0	0	2	2	0	0	4
Total	45	578	204	25	434	1769	715	156	164	4090

Table B-35. Illinois Accident Frequencies Before (By Accident Type)

Surface	1	2	3	4	5	6	7	8	9	10	11	12	13
0	13	2	0	0	2	0	0	1	0	2	11	0	0
1	1291	353	6	0	355	38	26	422	8	99	612	0	8
2	397	121	261	245	311	11	9	149	0	26	193	397	1
4	141	86	108	2	118	20	15	31	1	32	41	0	2
5	0	0	0	0	0	0	0	0	0	0	0	0	0
6	6	0	0	0	0	0	0	0	0	0	2	0	0
Total	1848	562	375	247	786	69	50	603	9	159	859	397	11

Table B-36. Illinois Accident Frequencies After (By Accident Type)

Surface	1	2	3	4	5	6	7	8	9	10	11	12	13
0	26	8	0	0	8	0	0	3	0	4	17	0	0
1	2385	576	9	1	582	78	46	738	7	316	1095	0	1
2	1298	356	990	900	1086	46	33	390	1	169	676	1298	1
4	376	1558	257	2	290	41	29	53	0	102	15	0	2
5	1	1	0	0	1	0	0	0	0	0	0	0	0
6	4	0	0	0	0	0	0	0	0	0	4	0	0
Total	4090	1099	1256	903	1967	165	108	1184	8	591	1917	1298	4

Table B-37. Illinois Accident Frequencies Before (By Site)

Weather	1	2	3	4	5	6	7	8	9	Total
0	4	8	0	5	0	0	0	3	0	20
1	12	434	57	184	16	466	147	81	56	1453
2	5	62	8	29	3	68	37	28	7	247
3	0	23	0	24	2	28	23	4	3	107
4	0	4	0	4	0	0	0	2	1	11
5	0	5	0	0	0	3	0	2	0	10
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
Total	21	536	65	246	21	565	207	120	67	1848

Table B-38. Illinois Accident Frequencies After (By Site)

Weather	1	2	3	4	5	6	7	8	9	Total
0	0	0	5	0	2	13	6	0	2	28
1	31	419	151	22	289	1267	396	114	117	2806
2	4	102	29	3	118	356	230	21	40	903
3	10	34	15	0	22	109	63	21	5	279
4	0	9	4	0	3	17	18	0	0	51
5	0	10	0	0	0	7	0	0	0	17
6	0	1	0	0	0	0	2	0	0	3
7	0	3	0	0	0	0	0	0	0	3
Total	45	578	204	25	434	1769	715	156	164	4090

Table B-39. Illinois Accident Frequencies Before (By Accident Type)

Weather	1	2	3	4	5	6	7	8	9	10	11	12	13
0	20	4	0	0	4	3	3	3	0	2	13	1	0
1	1453	407	0	0	407	47	32	469	8	107	689	135	10
2	247	66	247	247	247	4	4	95	0	22	121	245	0
3	107	72	107	0	107	12	8	28	1	26	34	11	1
4	11	8	11	0	11	1	1	6	0	2	0	5	0
5	10	5	10	0	10	2	2	2	0	0	2	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1848	562	375	247	786	69	50	603	9	159	859	397	11

Table B-40. Illinois Accident Frequencies after (By Accident Type)

Weather	1	2	3	4	5	6	7	8	9	10	11	12	13
0	28	10	0	0	10	0	0	4	0	4	21	4	0
1	2806	701	0	0	701	93	53	862	7	358	1303	304	1
2	903	228	903	903	903	31	22	255	1	140	467	900	1
3	279	127	279	0	279	35	29	36	0	79	97	36	2
4	51	20	51	0	51	4	3	18	0	8	20	44	0
5	17	13	17	0	17	1	1	9	0	2	4	4	0
6	3	0	3	0	3	1	0	0	0	0	2	3	0
7	3	0	30	3	0	0	0	0	0	0	3	3	0
Total	4090	1099	1256	903	1967	165	108	1184	8	591	1917	1298	4

Table B-41. Illinois Accident Frequencies Before (By Site)

Light	1	2	3	4	5	6	7	8	9	Total
0	0	0	0	0	0	1	0	0	0	1
1	13	373	46	173	9	389	147	92	43	1285
2	0	7	0	0	0	12	0	2	2	23
3	0	23	5	6	0	21	13	4	0	72
4	2	40	10	17	10	99	24	16	18	231
5	6	93	4	50	2	43	23	6	4	231
Total	21	536	65	246	21	565	207	120	67	1848

Table B-42. Illinois Accident Frequencies After (By Site)

Light	1	2	3	4	5	6	7	8	9	Total
0	0	1	0	0	0	2	0	0	0	3
1	25	416	165	21	291	1274	565	106	125	2988
2	1	16	4	0	2	23	16	1	0	63
3	0	15	4	0	18	40	19	1	4	101
4	16	71	23	2	75	305	75	45	17	629
5	3	59	8	2	48	125	40	3	18	306
Total	45	578	204	25	434	1769	715	156	164	4090

Table B-43. Illinois Accident Frequencies Before (By Accident Type)

Light	1	2	3	4	5	6	7	8	9	10	11	12	13
0	1	0	0	0	0	1	0	0	0	0	0	0	0
1	1285	0	224	181	224	33	24	446	3	110	609	279	6
2	23	23	4	4	23	0	0	4	0	0	14	20	0
3	72	72	18	13	72	0	0	20	2	8	38	24	1
4	236	236	63	23	236	26	18	49	2	20	99	3	0
5	231	21	66	26	231	9	8	84	2	21	99	3	0
Total	1848	562	375	247	786	69	50	603	9	159	859	397	11

Table B-44. Illinois Accident Frequencies After (By Accident Type)

Light	1	2	3	4	5	6	7	8	9	10	11	12	13
0	3	0	0	0	0	0	0	0	0	0	2	0	0
1	2988	0	868	675	868	89	57	896	2	406	1501	942	4
2	63	63	33	21	63	5	4	14	0	12	22	29	0
3	101	101	42	32	101	5	3	26	0	12	58	38	0
4	629	629	205	116	629	52	33	148	6	113	228	193	0
5	306	306	108	59	306	14	11	100	0	48	106	96	0
Total	4090	1099	1256	903	1967	165	108	1184	8	591	1917	1298	4

Table B-45. Illinois Accident Frequencies Before (By Site)

Visibility	1	2	3	4	5	6	7	8	9	Total
1	11	318	40	139	6	335	115	61	37	1062
2	0	25	3	2	0	29	8	4	2	73
3	2	31	10	8	8	72	11	16	15	173
4	3	68	4	40	2	30	13	3	2	165
5	2	55	6	34	3	55	32	31	6	224
6	0	5	2	4	0	4	5	23	0	22
7	0	9	0	9	2	27	13	0	3	63
8	3	25	0	10	0	13	10	3	2	66
Total	21	536	65	246	21	565	207	120	67	1848

Table B-46. Illinois Accident Frequencies After (By Site)

Visibility	1	2	3	4	5	6	7	8	9	Total
1	19	317	135	19	195	953	3117	78	90	2133
2	0	17	6	0	9	39	15	1	2	89
3	11	50	12	2	56	203	45	33	12	424
4	1	35	3	1	31	85	25	2	15	198
5	6	100	30	2	96	323	248	28	35	868
6	1	14	2	0	11	24	20	1	2	75
7	5	21	11	0	19	102	30	12	5	205
8	2	24	5	1	17	40	15	1	3	108
Total	45	578	204	25	434	1769	715	156	164	4090

Table B-47. Illinois Accident Frequencies Before (By Accident Type)

Visibility	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1062	0	0	0	0	28	20	365	3	82	506	86	6
2	73	73	0	0	73	0	0	14	2	6	41	10	0
3	173	173	0	0	173	15	9	33	2	12	79	17	4
4	165	165	0	0	165	7	6	60	1	9	76	23	0
5	224	0	224	181	224	6	4	81	0	28	103	190	0
6	22	22	22	17	22	0	0	10	0	2	11	17	1
7	63	63	63	23	63	11	9	16	0	8	20	27	0
8	66	66	66	26	66	2	2	24	1	12	23	27	0
Total	1848	562	375	247	786	69	50	603	9	159	859	397	11

Table B-48. Illinois Accident Frequencies After (By Accident Type)

Visibility	1	2	3	4	5	6	7	8	9	10	11	12	13
1	2123	0	0	0	0	53	30	673	2	259	1062	212	1
2	89	89	0	0	89	4	2	28	0	8	38	7	0
3	424	424	0	0	424	31	16	101	5	64	151	61	0
4	198	198	0	0	198	5	5	64	0	31	73	28	0
5	868	0	868	675	868	36	27	223	0	147	441	730	3
6	75	75	75	53	75	6	5	12	0	16	42	60	0
7	205	205	205	116	205	21	17	47	1	49	77	132	0
8	108	108	108	59	108	9	6	36	0	17	33	68	0
Total	4090	1099	1256	903	1967	165	108	1184	8	591	1917	1298	4

APPENDIX C

ANOCAT TABLES FOR LOG-LINEAR ANALYSIS OF TEXAS AND ILLINOIS DATA

Table C-1.

ANOCAT TABLE FOR TEXAS DATA: All Accident Types				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	38.01	3.84	Reject
Severity	4	1256.46	9.49	Reject
Interaction	4	3.77	9.49	Accept
Total	9	1298.24	16.92	Accept

Table C-2.

ANOCAT TABLE FOR TEXAS DATA: Accident Type = 6				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	5.3	3.84	Reject
Severity	4	46.59	9.49	Reject
Interaction	3	0.65	7.81	Accept
Total	8	52.54	15.51	Reject

Table C-3.

ANOCAT TABLE FOR TEXAS DATA: Accident Type = 7				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	2.98	3.84	Accept
Severity	4	24.33	9.49	Reject
Interaction	1	0.18	3.84	Accept
Total	6	27.49	12.59	Reject

Table C-4.

ANOCAT TABLE FOR TEXAS DATA: All Accident Types				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	38.02	3.84	Reject
Visibility	1	39.36	3.84	Reject
Interaction	1	5.94	3.84	Reject
Total	3	83.32	7.81	Reject

Table C-5.

ANOCAT TABLE FOR TEXAS DATA: Accident Type = 6				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	23.29	3.84	Reject
Visibility	1	7.48	3.84	Reject
Interaction	1	0.18	3.84	Accept
Total	3	30.95	7.81	Reject

Table C-6.

ANOCAT TABLE FOR TEXAS DATA: Accident Type = 7				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	15.42	3.84	Reject
Visibility	1	6.58	3.84	Reject
Interaction	1	0.12	3.84	Accept
Total	3	22.12	7.81	Reject

Table C-7.

ANOCAT TABLE FOR TEXAS DATA: All Accidents				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	158.34	3.84	Reject
Lighting	1	38.01	3.84	Reject
Interaction	1	5.15	3.84	Reject
Total	3	201.50	7.81	Reject

Table C-8.

ANOCAT TABLE FOR TEXAS DATA: Accident Type = 6				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	4.97	3.84	Reject
Lighting	1	7.47	3.84	Reject
Interaction	1	1.21	3.84	Accept
Total	3	13.65	7.81	Reject

Table C-9.

ANOCAT TABLE FOR TEXAS DATA: Accident Type = 7				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	5.01	3.84	Reject
Lighting	1	6.59	3.84	Reject
Interaction	1	2.11	3.84	Accept
Total	3	13.71	7.81	Reject

Table C-10.

ANOCAT TABLE FOR TEXAS DATA: All Accident Types				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	38.01	3.84	Reject
Surface	2	1629.33	5.99	Reject
Interaction	2	2.05	5.99	Accept
Total	5	1669.39	11.07	Reject

Table C-11.

ANOCAT TABLE FOR TEXAS DATA: Accident Type = 6				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	7.48	3.84	Reject
Surface	1	8.93	3.84	Reject
Interaction	1	0.31	3.84	Accept
Total	3	16.72	7.81	Reject

Table C-12.

ANOCAT TABLE FOR TEXAS DATA: Accident Type = 7				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	6.58	3.84	Reject
Surface	1	6.58	3.84	Reject
Interaction	1	0.09	3.84	Accept
Total	3	13.25	7.81	Reject

Table C-13.

ANOCAT TABLE FOR TEXAS DATA: All Accident Types				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	38.02	3.84	Reject
Intersection	3	172.39	7.81	Reject
Interaction	3	1.84	7.81	Accept
Total	7	212.25	14.07	Reject

Table C-14.

ANOCAT TABLE FOR TEXAS DATA: Accident Types = 6				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	7.48	3.84	Reject
Intersection	2	87.27	5.99	Reject
Interaction	2	1.08	5.99	Accept
Total	5	95.83	11.07	Reject

Table C-15.

ANOCAT TABLE FOR TEXAS DATA: Accident Type = 7				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	7.67	3.84	Reject
Intersection	2	37.15	5.99	Reject
Interaction	1	0.04	3.84	Accept
Total	5	44.86	11.07	Reject

Table C-16.

ANOCAT TABLE FOR TEXAS DATA: All Accident Types				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	38.02	3.84	Reject
Road Rel.	2	1333.92	5.99	Reject
Interaction	2	1.99	5.99	Accept
Total	5	1373.93	11.07	Reject

Table C-17.

ANOCAT TABLE FOR ILLINOIS DATA: All Accident Types				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	867.86	3.84	Reject
Severity	4	64.71	9.49	Reject
Interaction	4	29.92	9.49	Reject
Total	9	962.49	16.92	Reject

Table C-18.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 6				
Source	Df	L.R. X ²	SIG X ²	Decision
Road Type	1	40.57	3.84	Reject
Severity	4	207.29	9.49	Reject
Interaction	4	2.36	9.49	Accept
Total	9	250.22	16.92	Reject

Table C-19.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 7				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	19.94	3.84	Reject
Severity	4	158.54	9.49	Reject
Interaction	3	1.38	7.81	Accept
Total	8	179.86	15.51	Reject

Table C-20.

ANOCAT TABLE FOR ILLINOIS DATA: All Accident Types				
Source	Df	L.R.X ²	SIG X ²	Decision
Road Type	1	867.86	3.84	Reject
Visibility	1	31.46	3.84	Reject
Interaction	1	15.87	3.84	Reject
Total	3	915.19	7.81	Reject

Table C-21.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 6				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	40.57	3.84	Reject
Visibility	1	22.52	3.84	Reject
Interaction	1	1.52	3.84	Accept
Total	3	64.61	7.81	Reject

Table C-22.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 7				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	21.80	3.84	Reject
Visibility	1	21.80	3.84	Reject
Interaction	1	2.31	3.84	Accept
Total	3	45.91	7.81	Reject

Table C-23.

ANOCAT TABLE FOR ILLINOIS DATA: All Accident Types				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	867.86	3.84	Reject
Lighting	1	1193.00	3.84	Reject
Interaction	1	7.85	3.84	Reject
Total	3	2068.71	7.81	Reject

Table C-24.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 6				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	0.62	3.84	Accept
Lighting	1	40.58	3.84	Reject
Interaction	1	0.42	3.84	Accept
Total	3	41.62	7.81	Reject

Table C-21.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 6				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	40.57	3.84	Reject
Visibility	1	22.52	3.84	Reject
Interaction	1	1.52	3.84	Accept
Total	3	64.61	7.81	Reject

Table C-22.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 7				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	21.80	3.84	Reject
Visibility	1	21.80	3.84	Reject
Interaction	1	2.31	3.84	Accept
Total	3	45.91	7.81	Reject

Table C-23.

ANOCAT TABLE FOR ILLINOIS DATA: All Accident Types				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	867.86	3.84	Reject
Lighting	1	1193.00	3.84	Reject
Interaction	1	7.85	3.84	Reject
Total	3	2068.71	7.81	Reject

Table C-24.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 6				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	0.62	3.84	Accept
Lighting	1	40.58	3.84	Reject
Interaction	1	0.42	3.84	Accept
Total	3	41.62	7.81	Reject

Table C-25.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 7				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	21.80	3.84	Reject
Lighting	1	0.10	3.84	Accept
Interaction	1	0.31	3.84	Accept
Total	3	22.21	7.81	Reject

Table C-26.

ANOCAT TABLE FOR ILLINOIS DATA: All Accident Types				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	867.86	3.84	Reject
Surface	2	2756.93	5.99	Reject
Interaction	2	78.98	5.99	Reject
Total	5	3703.77	11.07	Reject

Table C-27.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 6				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	61.15	3.84	Reject
Surface	2	27.14	5.99	Reject
Interaction	2	3.71	5.99	Accept
Total	5	92.00	11.07	Reject

Table C-28.

ANOCAT TABLE FOR ILLINOIS DATA: Accident Type = 7				
Source	Df	L.R. X^2	SIG X^2	Decision
Road Type	1	21.80	3.84	Reject
Surface	2	10.20	5.99	Reject
Interaction	2	2.94	5.99	Accept
Total	5	34.94	11.07	Reject