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AN INVESTIGATION OF THE
EFFECTIVENESS OF BOULEVARD ROADWAYS

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Salvatore Castronovo

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Thomas L. Maleck
Major professor

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AN INVESTIGATION OF THE EFFECTIVENESS OF BOULEVARD ROADWAYS

By

Salvatore Castronovo

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ABSTRACT

AN INVESTIGATION OF THE EFFECTIVENESS OF BOULEVARD ROADWAYS

By

Salvatore Castronovo

The State of Michigan has been constructing directional cross-overs in the medians of boulevard roadways since the 1960s. These directional cross-overs were constructed to alleviate the congestion and interlocking that were occurring at bidirectional cross-over locations in boulevard roadway sections. The value of these cross-overs has not yet been determined, even though (apparent) improved operations have been observed after the implementation of this design. The objective of this research is the investigation of the safety benefits of divided highway and directional cross-over median designs.

The independent variables that were developed for this research were: roadway cross-section type (i.e., boulevard vs. center lane left-turn); median width; lane width; cross-over type (directional vs. bidirectional) and spacing; speed limits; population density; traffic volumes, percent commercial; intersection density, signal density, and shoulder/curb. The dependent variables that were evaluated are the accident rates and accident types.

A data set of the pertinent state highway facilities was generated utilizing the Michigan Department of Transportation's photo log records and from field reviews. The study segments consisted of 366.3 miles of five-lane roadway, 55.8 miles of seven-lane roadway, and 512 miles of boulevard roadway. Accident data from 1970 to 1990 were retrieved to provide the data necessary to evaluate the dependent variables.

An investigation of the mean accident rates of highways with boulevards, compared to the mean accident rates of highways with continuous center left-turn lanes (CCLTL), revealed that there is a significant difference, with boulevard highways having a lower mean accident rate for those Michigan highways investigated.

The investigation into the difference of the mean accident rate for boulevard highways with medians of different widths provided an indication that roadways with medians greater than 30 feet but less than 60 feet had the lowest mean accident rate of the three median categories investigated. The differences were significant for most accident types when compared to roadways with medians less than or equal to 30 feet and greater or equal to 60 feet.

The investigation of the accident rates for boulevard highways with directional and bidirectional signalized cross-overs, while not conclusive, provided an indication that boulevard highways with directional cross-overs had a lower mean accident rate than boulevard highways with bidirectional cross-overs for signalized roadways.

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I dedicate this dissertation to my wife Joann who provided me support and encouragement, and to my parents Pietro Castronovo and Gaetana Insalaco Castronovo, who emigrated from Sicily to the United States of America and worked many long hours depriving themselves so that their children would receive an education and lead better lives.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION AND RESEARCH BACKGROUND

1.1 HISTORICAL PERSPECTIVE

Divided highways provide a physical separation between opposite directions of vehicular travel. This separation of travel may create problems in accommodating certain traffic movements; such as, left-hand turns, U-turns, and access to property abutting the opposite direction of travel. The design of median openings (cross-overs) was first discussed by the American Association of State Highway Officials (AASHO) in 1954.

A primary concern with this type of highway is the median width needed to accommodate U-turning vehicles. The criterion established in 1954, to allow a passenger vehicle to turn from the outer lane of one roadway to the outer lane of the other roadway or from the inner lane of one roadway to the outer shoulder of the other roadway, was a median width of 20 feet. A 30-foot median width was established for a single unit vehicle to turn from one roadway to the other while encroaching on both shoulders. A 40-foot median width was established to allow a large truck to turn from one roadway to the other while encroaching on both shoulders. A 60-foot median was established as the minimum median width to allow all standard legal vehicles to turn from the inner lane of one roadway to the inner lane of the other roadway (AASHO 1954).

Most early divided highways were designed with one of the above median widths, with one major exception. A four-foot median width, which was considered adequate to allow pedestrians to seek refuge while crossing a roadway, was used as a design criterion where pedestrian traffic was a consideration.

As traffic volumes at these median openings increased, vehicles attempting to negotiate a left turn or U-turn would back up in the inner lane. The vehicle stoppage in the inner or fast lane presented an impediment to the traffic flow, thus increasing the potential for accidents to occur. The immediate solution was to provide a refuge or storage lane in the median. There were three problems with this solution: first, the storage capacity was limited; second, opposing turns became interlocked; and, third, the width of median available to accommodate turns was effectively reduced.

Traffic attempting to cross the intersection would occasionally become trapped in the through lanes because cars waiting to make a left turn were standing in the bidirectional median opening. The congestion worsened when left-turning trucks that were too long for the median opening occupied part of the through lanes. A solution developed by the Michigan Department of Transportation (MDOT) was to provide directional median openings back-to-back at a mid-block location, not opposite another street, and at the same time provide a storage lane for vehicles waiting to make a left turn (Figure 1.1.12). These directional cross-overs would often be used for accommodating left-turning vehicles from nearby signalized intersections.

There are several areas of concern regarding the operation of directional/bidirection mid-block cross-overs. The primary problem is the adverse travel distance required by the vehicles using the cross-overs to make the left-hand turn or reach the destination adjacent to the opposite direction of travel. Another problem is weaving maneuvers the turning vehicle may have to negotiate with thru traffic to reach the desired destination. This includes merging with the higher speed traffic in the inner lane while completing the turning movement. Also, lack of familiarity with the indirect turn procedure may also cause confusion resulting in accidents.

A survey of fifty states and major Michigan counties (as a part of this research) found that only four other states and three Michigan county road commissions are known to provide median cross-overs as a means for making indirect left-turn movements. The questionnaire is shown in Figure 1.1.1 and the aggregated responses are shown in Figure 1.1.2. Because only four states use this geometric feature, the amount of experience with directional median cross-overs is severely limited and subsequently limits the data available for examination.

An advantage of the boulevard cross-section is that left turns are limited to a few locations. The boulevard cross-section also decreases the opportunity for head-on collisions, as well as acting as a refuge area for pedestrians crossing the roadway. Most businesses do not feel there is an access loss and resultant business loss when a boulevard section is used (Metcalf 1989).

STATE RESPONDING: . . . .

CONTACT PERSON NAME: . . . .

STREET ADDRESS: . . . .

CITY: . . . .

STATE: . . . .

ZIP CODE: . . . .

PHONE NO. (   ) . . . .

FAX NO. (   ) . . . .

1. Does your state utilize directional cross-overs in your free-access, median separated roadways? Yes_____ No_____

2. Are these used to accommodate left turns normally accommodated at an intersection? Yes_____ No_____

3. If they are, what is the distance they are spaced from the center of the intersection to the center of the directional cross-over? _____ feet

4. What is the minimum width median in which they are constructed? _________ feet

5. Have you conducted any before and after accident or capacity analysis of roadways where you have used this type of facility? Yes_____ No_____

Figure 1.1.1 Survey of State-of-the-Practice Letter

State/ County	Use Dir Xover	Use Xover for Turns	Xover Spacing ft	Min Median Width ft	Accident Studies	Comments
Alaska	No	No	N/A	N/A	N/A	None
Arizona	No	No	N/A	N/A	No	
Arkansas	No	No	N/A	N/A	No	
California	Yes	No			No	Rarely used, want copy of study
Colorado	No	No	N/A	N/A	No	
Delaware	Yes	Yes	N/A	N/A	No	Recently started using, no criteria individually designed
Florida	Yes	Yes	Per Standard		Yes	Provided standards, determined by districts
Georgia	Yes	No		20	No	Provided median xover policy 1/8 mile urban, 1/4 mile rural, more
Hawaii	Yes	No		10	No	Used for driveway and side street access, provided standard
Idaho	No					
Illinois	Yes	Yes	500-800 feet	60	No	Currently constructing first cross-overs
Iowa	No	No	N/A	N/A	No	
Kansas	No					Could like a copy of the study
Kentucky	No					
Louisiana	No					
Maine	No					
Mississippi	No	No			No	Use at interchanges with local roads, individually designed
Missouri	No				No	
Montana	No	No				
Nebraska	No	No				
New	No	No		40	No	Only on location in the state
Nevada	No					
New Jersey	No	No	N/A	N/A	No	
New York	No				No	
North Carolina	Yes	Yes	Varies	30	No	Used on Case/case basis, wants copy of study, furnished policy
Ohio	No	No	N/A	N/A	No	Provided pertinent portions of location & design manual
Oklahoma	Yes	No		18	Yes	Use green book as STD, use at high accident multiple drive or offset
Pennsylvania	Yes	Normally No		40	No	
South Carolina	Yes	No	N/A/	136-48	No	Rarely used, no standards available
South Dakota	No					
Texas	No	No	N/A	N/A	No	
Utah	No				No	
Vermont	No	No	N/A	N/A	N/A	
Washington	No	No				
West Virginia	No					Included geometric design criteria
Wisconsin	No	No				Included copies of median opening design sheets
Wyoming	No	No	N/A	N/A	N/A	Do not have roads that warrant this treatment
Oakland	Yes	Yes	300	30	No	Constructing currently in Rochester Hills
Wayne	Yes	Yes	Variable	60	No	
Washtenaw	Yes	No		60	No	

Figure 1.1.2 State-of-the-Practice Survey Results

The boulevard cross-section has the potential to reduce system-wide delay, increase roadway capacity, provide safety for pedestrians, create a positive impact upon development, and create a more aesthetically pleasing corridor. Some potential negatives include higher construction costs than for the CCLTL cross-section, reduced local access, weaving and merging with the high-speed lane, and increased travel time for left-turning vehicles (Hartman and Szplett 1989).

The features of various roadway cross-section types can be examined in Figures 1.1.3 through 1.1.8.

A rural roadway with a boulevard cross-section with flush shoulders and residential driveways is shown in Figure 1.1.3. The cross-overs in the median are bidirectional; i.e., the traffic can travel in either direction through the cross-over. The inherent, adverse distance that must be traveled and the weaving that is experienced by residents to access their homes are evident.

An urban roadway with a boulevard cross-section with flush shoulders and directional cross-overs placed at either side of the intersection is shown in Figure 1.1.4. The directional cross-overs are intended for negotiating left turns that are prohibited at the intersection. Drivers traveling from left to right across the photograph wanting to turn left at the crossroad would first travel through the intersection to the directional cross-over, make a U-turn through the cross-over, travel from right to left to the crossroad, and turn right at the crossroad, thus completing the left turn desired. Similarly, a driver desiring to access businesses adjacent to the roadway in the opposite direction would use the cross-overs to change direction and gain access. Evident in these maneuvers is the distance traveled and the weaving that must take place to complete the maneuvers.

Figure 1.1.3 Rural Boulevard Section With Bidirectional Cross-Overs and Residential Drives

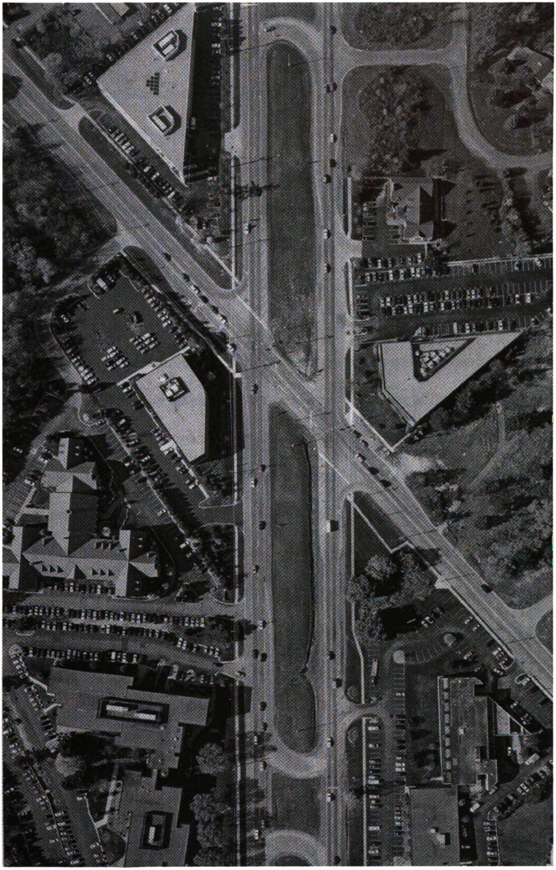


Figure 1.1.4 Urban Boulevard Section With Directional Cross-Overs With Shoulders

An urban boulevard section with curb and gutter and bidirectional cross-overs is shown in Figure 1.1.5. Drivers desiring to access the drives along the opposing direction of travel can use the bidirectional cross-overs to reverse direction and access the driveways. A similar urban roadway with curb and gutter, but with directional cross-overs and intersecting streets that do not cross the median, is shown in Figure 1.1.6. Drivers desiring to access the streets that intersect with the opposite direction of travel must use the directional cross-overs to obtain access. Drivers entering the roadway from the intersecting streets, desiring to travel in the opposite direction, must use a cross-over to obtain access to that direction of travel.

A five-lane urban roadway with curb and gutter and with a continuous center lane which is intended to accommodate left-turn movements is shown in Figure 1.1.7. Access to driveways adjacent to the opposite direction of travel is obtained by moving into the left-turn lane prior to completing the turn movement. A similar roadway with curb and gutter and seven lanes of pavement, which includes a CCLTL intended to accommodate left-turn movements into a major cross-street, is shown in Figure 1.1.8. The operation is the same as that used in Figure 1.1.7, with vehicles needing access to the major cross-street being accommodated in the center left-turn lane. Heading up the left-turn movements prevents interlocking of left-turning vehicles.

The current MDOT standards for median cross-over designs are shown in Figures 1.1.9 and 1.1.10. The standards that are used for designing bidirectional cross-overs are shown in Figure 1.1.9. The standards that are used for designing directional cross-overs are shown in Figure 1.1.10. Newly proposed MDOT standards for designing directional cross-overs are illustrated in Figures 1.1.11 through 1.1.13.

Figure 1.1.5 Urban Boulevard Section With Bidirectional Cross-Overs

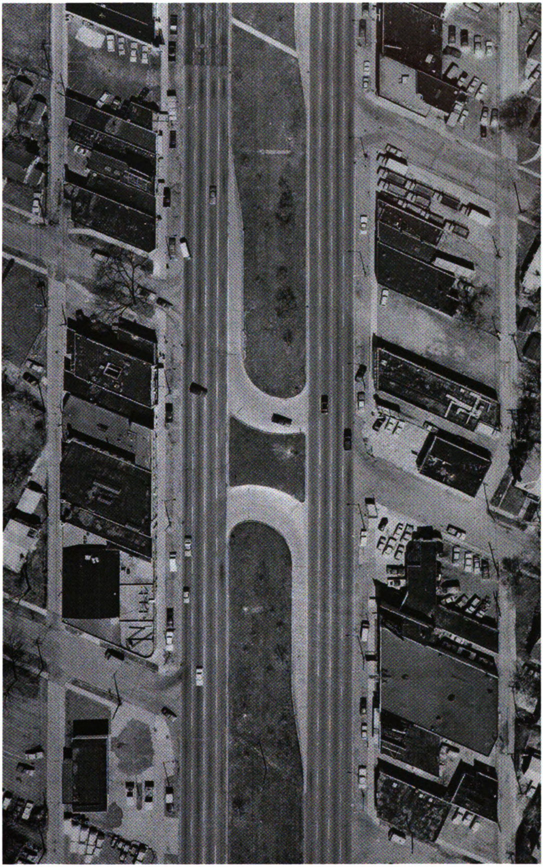


Figure 1.1.6 Urban Boulevard Section With Back-to-Back Directional Cross-Overs

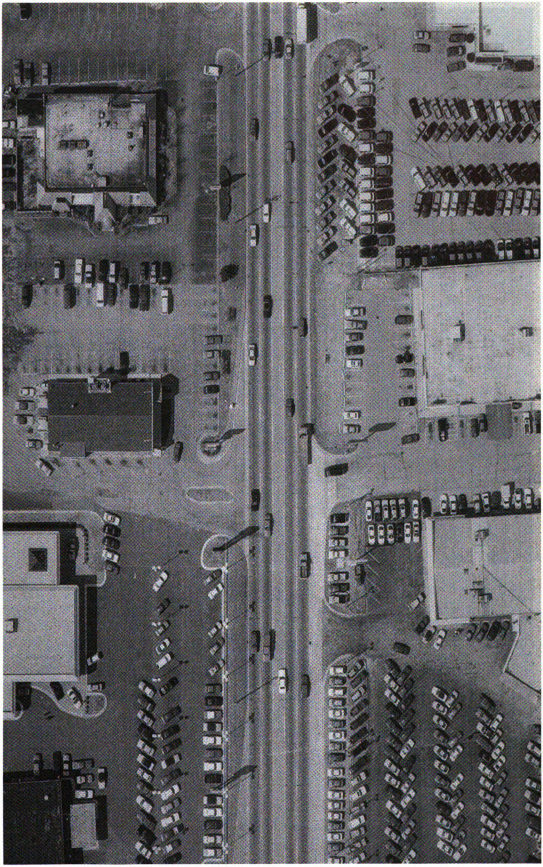


Figure 1.1.7 Urban Five-Lane Center Left-Turn Lane Cross-section

Figure 1.1.8 Urban Seven-Lane Center Left-Turn Lane Cross-section

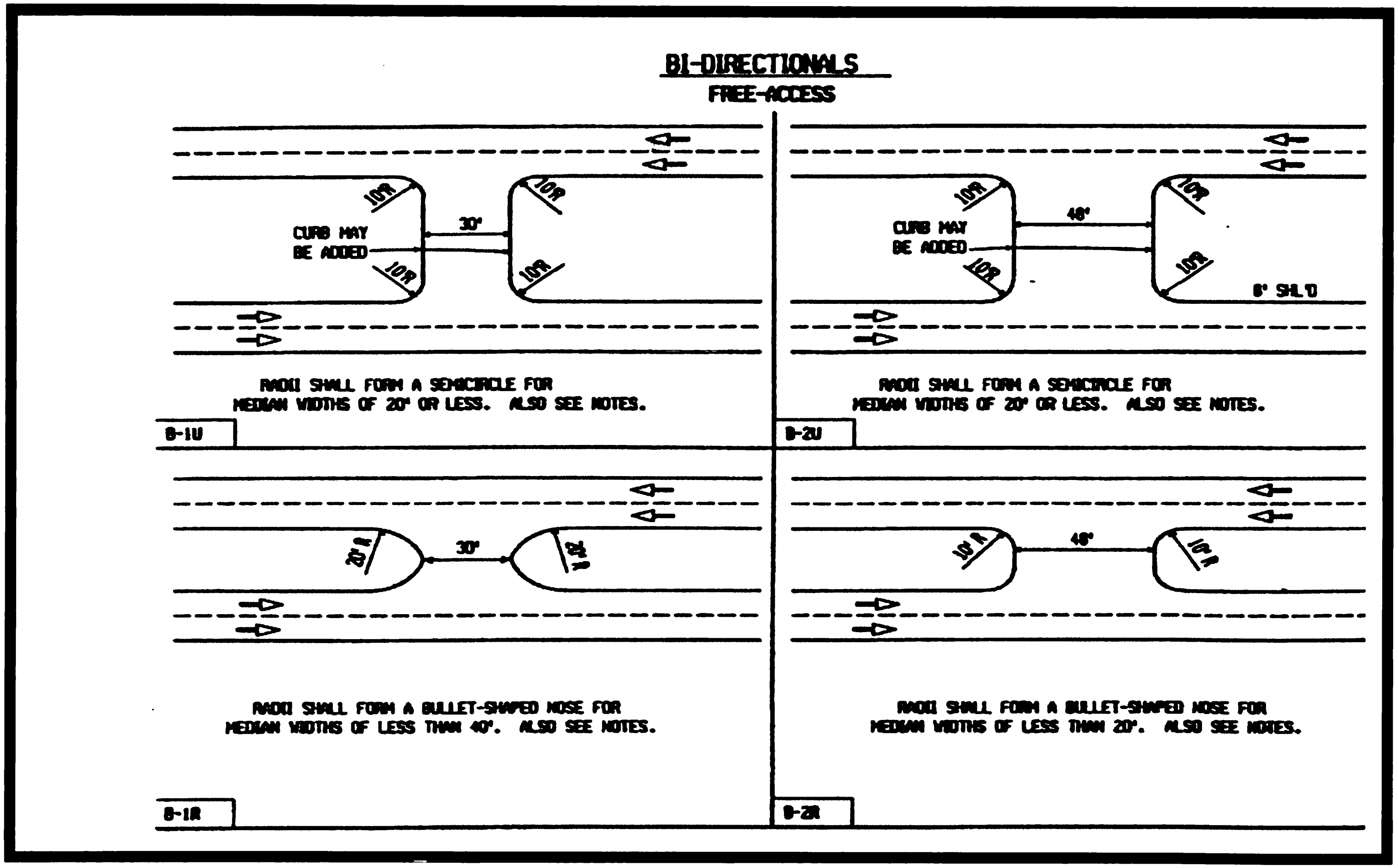


Figure 1.1.9 Michigan Department of Transportation Bidirectional Cross-Over Standard

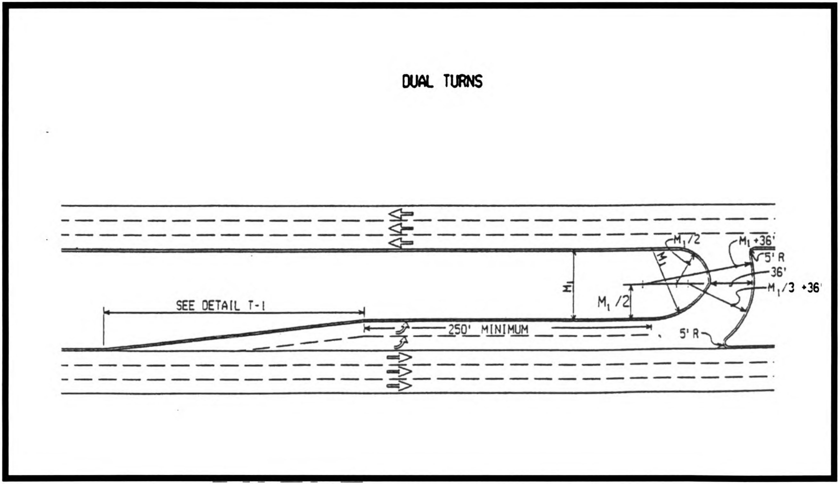
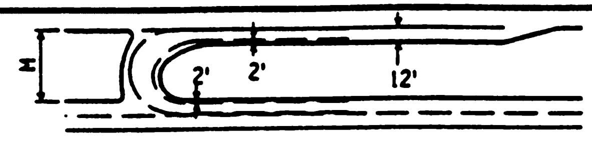
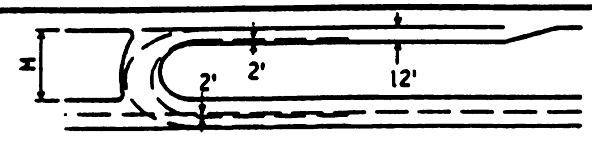
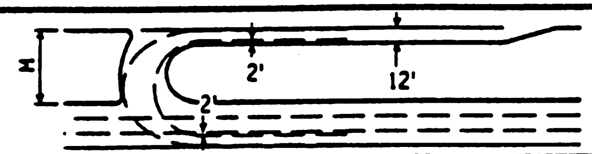


Figure 1.1.10 Michigan Department of Transportation Directional Cross-Over Standard

Minimum Designs for U-Turns

Type of Maneuver		M = Min. width of median - feet for design vehicle				
		P	SU	BUS	WB-50	INTERSTATE
		Length of Design Vehicle				
		19'	30'	40'	55'	70'
Left Lane to Inner Lane		44'	76'	80'	82'	94'
Left Lane to 2nd Lane		32'	64'	68'	70'	82'
Left Lane to 3rd Lane		22'	54'	58'	60'	70'

P = Passenger
SU = Single Unit Truck
WB-50 = Semi-Truck Medium Size
Interstate = Semi-Truck Large

Figure 1.1.11 Michigan Department of Transportation Proposed Directional Cross-Over Standard

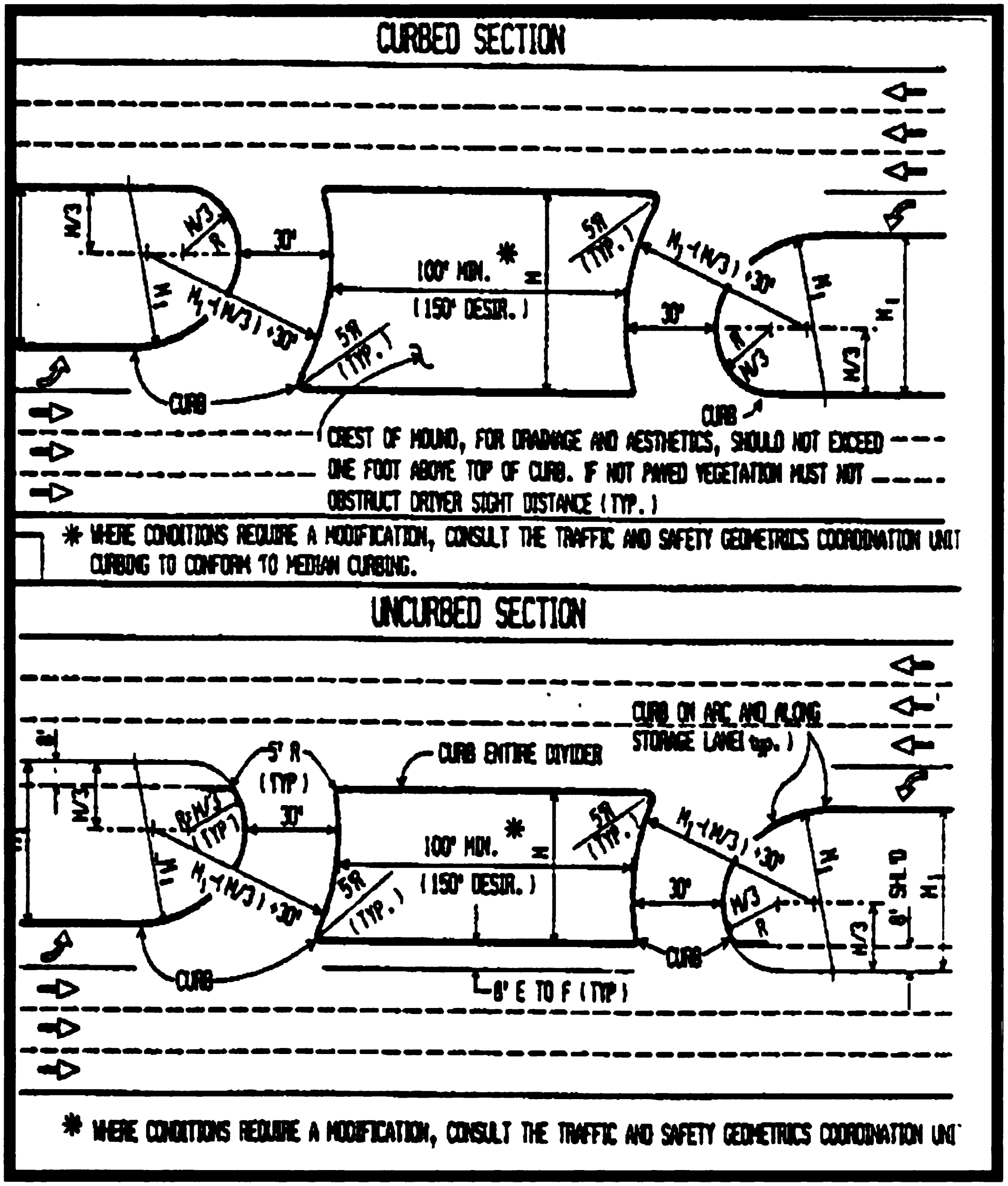


Figure 1.1.12 Michigan Department of Transportation Directional Proposed Cross-Over Standard

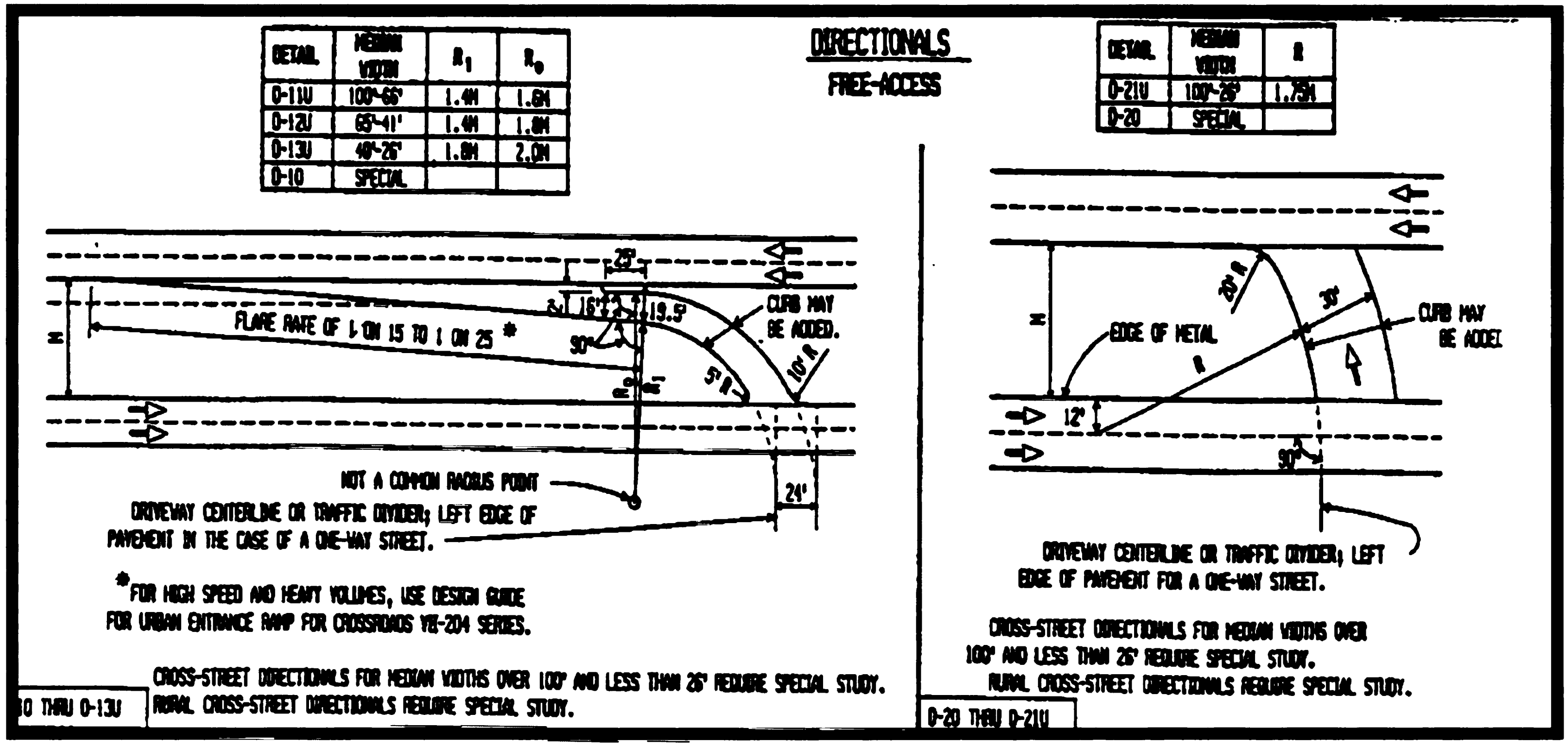


Figure 1.1.13 Michigan Department of Transportation Directional Proposed Cross-Over Standard

1.2 THE PROBLEM

MDOT began constructing boulevard roadways with directional cross-overs after 1960. An examination of the literature pertaining to cross-overs and left-turn movements has not yielded a formal study comparing divided highways featuring directional cross-overs with highways having CCLTL and evaluating the impact of either cross-section on capacity, safety, and level of service.

Roadway construction with a boulevard cross-section is more expensive than a roadway with a CCLTL. The boulevard cross-section requires more right-of-way and traffic signing. There is concern that accidents may occur when vehicles attempt to cross traffic while trying to reach driveway or cross-street destinations adjacent to the opposite roadway. The type of cross-over needed to provide access to the other direction can become a controversial issue, as it may result in businesses becoming concerned with property access for their customers.

For Michigan trunklines, the alternative to a boulevard or divided highway is a multilane highway with a continuous two-way center left-turn lane. This nondivided cross-section is usually provided as a five- or seven-lane facility.

In addition to the acknowledged aesthetic benefits of a divided highway, a need exists to determine whether such construction yields sufficiently fewer accidents to justify the additional costs.

1.3 OBJECTIVE

The objective of this research is to quantify the safety differences between divided highways and multilane facilities with CCLTLs. If there are benefits to be realized from a divided highway, it is important to determine if they are sensitive to the median width. This is important because the right-of-way cost for a divided highway is directly related to the median width. It is also desirable to determine whether factors such as number of driveways, type of median cross-overs, number of intersections, and speed limits significantly affect the decrease or increase in traffic accidents.

1.4 RESEARCH APPROACH

The method for comparing the boulevard cross-sections and the cross-sections is outlined as follows:

1. Review the literature and the two roadway types to determine which features have been reported to have an impact on roadway safety.
2. Conduct a thorough review of Michigan trunklines to establish the location and control section numbers of segments of the two roadway types.
3. Devise a method for data collection.
4. Collect and code the data in a manner suitable for computer analysis.
5. Apply statistical analysis techniques to the data to determine if there is a difference between the two roadway types under consideration and examine roadway features to determine their contribution to any differences detected.
6. Interpret the statistical data, draw inferences, and develop conclusions.
7. Formulate recommendations.

1.5 ORDER OF PRESENTATION

The dissertation consists of the following parts:

1. The literature review and hypothesis are presented in chapter 2.
2. The research approach and the details of the experimental design specifications are presented in chapter 3.
3. The statistical analysis of the collected data and the accident data and their interaction are presented in chapter 4. This includes an evaluation of the independent variables, data type, and accident data.
4. The inferences, conclusions, and suggested subsequent research are presented in chapter 5.
5. The appendices contain the research data and statistical results.

CHAPTER 2

LITERATURE REVIEW

The literature was surveyed to determine what previous investigations have been conducted on boulevard sections and multilane roadways with center left-turn lanes, especially with regard to accident experience. These findings are summarized in the following sections.

2.1 MEDIAN WIDTH

A guide was found for the determination of roadway width and median treatment in semiurban areas. The guide delineated methods of dividing directions of travel which are varied. At one extreme is a pair of parallel one-way streets separated from each other by rows of city blocks. At the other extreme, all that separates the two directions of travel is a double yellow paint line down the middle of the roadway. In between these extremes are medians of varying widths, with and without curb and gutter, and those multilane facilities in which the opposing directions of travel are separated by a flush center lane which is used for left-turning movements only.

Medians that are wider than 30 feet allow for the construction of directional cross-overs which, in effect, limit the number of crossing points. One of the disadvantages with a median is that it results in an increased travel distance for those desiring to reach a property on the opposite side of the median. Similarly, those wanting to make left-hand turns at intersections where turns are prohibited would need to complete the movement using a directional cross-over. A positive aspect is that the left-turn capacity of an intersection that uses a directional cross-over can be nearly double that of a normal turn lane (author unknown 1963).

It further stated that CCLTL roadways with an 11- to 15-foot wide median do not provide the same traffic separation as roadways with wider medians, especially those with curbs. They do provide continuous access to abutting property on either side of the roadway. The author also stated that very high volumes of turns at intersections must be handled by phased signals, with a special phase for left turns to prevent the problem of interlocking. The heading up of this left-turn maneuver is a characteristic of a roadway with a CCLTL. It was reported that a road with a CCLTL provides for left-turning vehicles being stored out of the traffic stream. It does not provide the same security level for pedestrians as a divided roadway. Snow plowing is a consideration, as snow cannot be stored in the center left-turn lane as it can in a wide median (author unknown 1963).

In a paper by another unknown author, assumed to be the same author (1963), the following characteristics of various medians were summarized:

1. Widths of 16 to 22 feet are undesirable because U-turns are not feasible. However, these widths provide sufficient room for construction of left-turn lanes.
2. Widths of 23 to 39 feet are undesirable as they do not provide for U-turns. This width provides room to store passenger vehicles crossing an intersection, but it does

not provide adequate room for larger vehicles. (While the author uses the word *vehicles*, it is understood that what is meant is *vehicles in excess of 16 feet in length.*)

3. Widths of 40 to 59 feet cannot accomodate U-turns for all legal-sized vehicles. Only passenger cars and single unit trucks can negotiate the tight U-turns.

4. Widths in excess of 60 feet are most desirable, as the U-turn is feasible for all legal vehicles.

Figure 2.1.1 provides guidelines for street width designs and median treatments. These were produced by the same unidentifiable source, and provide some insight to the thoughts on the subject at the time. It is interesting to note that the various median treatments, in the opinion of the author, do not significantly effect capacity.

Although, the unknown author suggests that the number of accidents increased as the width of the median increased. He suggested in number 4 above that wider medians were more desirable. Cribbins, et al., in their investigation of median widths and openings in North Carolina, found that median widths are one of the factors having the least effect on accidents, although the accident rate for commercial vehicles did decrease as the median width increased. In another study in North Carolina, no correlation between accident rate and median width was found (Cribbins, Horn, Beeson, and Taylor 1966).

The distance between the two stop bars on a minor road crossing of a divided highway was found to be a contributing factor to an increase in accidents (Van Maren 1978). It appears that the increase in exposure experienced, when crossing a longer distance, is a contributing factor to the increase in the accident rate.

Median Treatment	Remarks	Left Turns at Intersection	Approximate Capacity* (Vehicles/Lane/Hour)	Access to Driveways Between Intersections
One-way Streets	Provides maximum flexibility in signal progression.	Direct at Intersection.	700 vpl/hr. - use 30' curb-to-curb roadway for two-lane, one-way facility **	Direct.
Medians 60' or wider		Left turns off crossroad usually turn right - make U-turn. Left turns off divided highway - direct at intersection or via U-turn maneuver.	650 vpl/hr. including left turns.	Go beyond and U-turn except in case of large generators when direct access can be provided.
11' - 12' (flush or mountable (center lane for left turn)	Left turns may have to be prohibited at heavier volume signalized intersections.	Direct at intersection from center lane. Capacity limited by gaps in oncoming traffic or by yellow phase of signal.	600 vpl/hr. plus left-turn capacity.	Direct at driveways. Left turns to or from development have use of center lane.
Flush or mountable medians 4' - 6' wide	Left turns will often be prohibited at all signalized intersections plus some unsignalized intersections.	Direct at intersection from left thru lane. Capacity limited by gaps in oncoming traffic or by yellow phase of signal.	550 vpl/hr. minus correction in left lanes for left turns. Where left turns minimize use of this lane, its capacity will be 0 for thru traffic and be limited to left-turn capacity.	Direct at driveways - special provision for left turns to or from development not possible.
Undivided multilane facility	Does not provide for pedestrian refuge. Left turns will often be prohibited at all signalized intersections plus some unsignalized intersections.	Direct at intersection from left thru lane. Capacity limited by gaps in oncoming traffic or by yellow phase of signal.	550 vpl/hr. minus correction in left lanes for left turns. Where left turns minimize use of this lane, its capacity will be 0 for thru traffic and be limited to left turn capacity.	Direct at driveways - special provision for left turns to or from development not possible.
40' - 59' median	Is a less desirable treatment in that U-turn maneuver is tight for passenger cars.	Left turns off crossroad usually turn right - make U-turn. Left turns off divided highway - direct at intersection or via U-turn maneuver.	600 vpl/hr. theoretical. However, where appreciable U-turn movements exist, actual capacity is less than 600 vpl/hr.	U-turns are more restrictive. This treatment not suitable where there is considerable development.

Figure 2.1.1 Guide for Determination of Street Widths and Median Treatment (Author Unknown, 1963)

Median Treatment	Remarks	Left Turns at Intersection	Approximate Capacity* (Vehicles/Lane/Hour)	Access to Driveways Between Intersections
One-way Streets	Provides maximum flexibility in signal progression.	Direct at Intersection.	700 vpl/hr. - use 30' curb-to-curb roadway for two-lane, one-way facility **	Direct.
23' - 39' median	See detailed criteria. Undesirable except under very special circumstances. U-turns too tight- left-turn capacity limited.	Slots not workable. Left turns take place as interlock situations. Capacity limited by storage space available. Where capacity exceeded, left turns lock up blocking thru lanes and cross traffic.	600 vpl/hr. including left turn but subject to left turns blocking thru lane.	By very restrictive U-turn maneuver -because of this limitation cannot be used where more than minimum traffic generation will be served between intersections - especially if in combination with large thru volumes.
16' - 22' barrier	Undesirable where development must be served between intersections.	Via left-turn slots at intersections - storage space in slots extremely limited in closely spaced blocks. Capacity limited by gaps in oncoming traffic or by yellow phase of signal.	600 vpl/hr. plus left-turn capacity.	Left-turn ingress or egress impossible except where special openings or slots can be provided. Therefore, this treatment cannot be used where development between intersections must be served directly.
4' to 15' barrier	Undesirable where development must be served between intersections.	Direct at intersection from left-thru lane. Capacity limited by gaps in oncoming traffic or by yellow phase of signal.	550 vpl/hr. minus correction in left lanes for left turns. Where left turns minimize use of this lane, its capacity will be 0 for thru traffic and be limited to left-turn capacity	Left-turn ingress or egress impossible except where special openings can be provided. Therefore, this treatment cannot be used where development between intersections must be served directly.

Figure 2.1.1 (Continued)

As a result of several years of study, the State of Illinois adopted a median width of 40 feet for rural highways and a median width of no less than 6 feet in urban areas where turns are allowed (Hutchinson 1966).

Hakkert and Ben-Yakov raised the issue of pedestrian delay at signalized intersections. They state that the issue is important because, as pedestrian delay increases, the pedestrians increase the amount of crossing on red signals, thus decreasing pedestrian safety. They propose that when the signal cycle length is minimized the pedestrian delay can generally be reduced. They also recommend that for divided highway sections the minimum green period be extended to allow the crossing pedestrian to begin the second leg when the phase is still green (Hakkert and Ben-Yakov 1958). As previously noted the divided or boulevard cross-section does provide a refuge for the pedestrian in the median, thus allowing the pedestrian to cross the roadway in stages during more than one signal cycle.

A median accident study was conducted on several sections of highway in Long Island, New York, to determine the effect of median design on accident rates for urban, multilane, and free-access highways with average daily traffic (ADT) volumes up to 44,000 vehicles. The median designs were classified as either deterring types or nontraversable types. A deterring median was defined as one which discouraged deliberate crossing by obstructions; such as flush and raised with intermittent shrubbery, mountable double curb, or earth medians with flat cross slopes. A nontraversable median was defined as one which prevented crossing from one roadway to the other by obstructions; such as, concrete posts or earth medians with steep cross slopes and guardrail. The results of the study are as follows:

1. The ratio of night-to-day accident rates between intersections averaged 3.5 to 1 for the nontraversable group and 2.0 to 1 for the deterring group of medians. The night traffic volume was determined to be 25 percent of the 24-hour traffic volume.
2. The accident rates between intersections increased linearly with traffic volumes for deterring-type medians. For deterring-type medians, there appears to be no correlation between median width and accident rates even though the accident rate peaked for the 15-foot median with medians less than 15 feet and more than 15 feet having a lower accident rate. The authors did not have sufficient data to determine the relationship between median width and accident rate for nontraversable medians (Figure 2.1.2).
3. The overtaking type of accident accounted for more than 70 percent of accidents between intersections for both deterring and nontraversable median types. In the deterring-type median, the grass-flush median had the lowest rate for all accidents between intersections; the curbed-type median had the highest rate. When the effect of volume was taken into account, the results did not change.
4. In the deterring group, both the earth and miscellaneous features median had the smallest percentage of severe accidents. For the nontraversable type, the double guardrail had the smallest percentage of severe accidents, while the concrete posts had the highest percentage of severe accidents. The accident rate, property damage frequency, and severity of accidents were all much higher for medians with concrete posts.
5. The frequency of all accidents involving the median was higher for the nontraversable type than the deterring type. On highways with deterring curbed

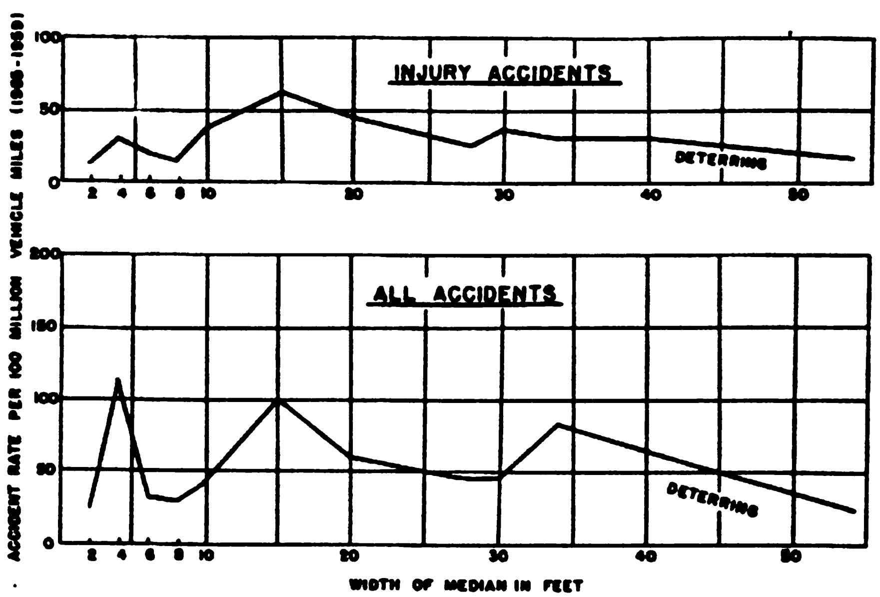


Figure 2.1.2 Relationship of Median Widths to Accident Rates (Billion and Parsons 1953)

medians and nonillumination, the nighttime accident rate at intersections was twice that of the day rate; whereas on highways with illumination, the night and day intersection accident rates were the same. The study also investigated the accident rate between intersections with and without illumination; and it was found that illumination apparently has no effect on accident rate between intersections (Billion and Parsons 1953).

In a California median study, Telford, et al., investigated traversable, deterring and nontraversable medians. They found that the accident rate for traversable and deterring-type medians did not vary much for medians above 10 feet in width. The accident rate for nontraversable medians increased at a rather uniform rate, as the median width increased for medians greater than 25 feet. It was also found that there was no relationship between accident severity and median width (Telford, et al. 1953).

In both the Long Island, New York, and the California median studies, the significance of the difference in accident rates for the various median widths was not discussed.

In a synthesis prepared by the Transportation Research Board, it was reported that "The median width is unrelated to the accident rate." (Transportation Research Board 1978).

2.2 CROSS-OVER TYPES

As stated in the AASHTO design guides, highway efficiency, safety, speed, operation cost, and capacity depend on the general highway intersection design. The main objective of intersection design is to reduce the number of accidents and to provide a more convenient route of travel. Human factors, traffic considerations, physical elements, and economic factors must be considered when designing at-grade intersections (AASHTO 1990).

MDOT studied the effects of replacing a bidirectional cross-over with a pair of directional cross-overs at the intersection of US-10 and Opdyke Road. US-10, a major route in Michigan, intersects at a tee with Opdyke Road. At this intersection, US-10 was four lanes in each direction separated by a 40-foot median with cars traveling at 50 miles per hour (mph). Opdyke Road is a two-lane, two-way roadway with a speed limit of 35 mph.

The following changes were made to the intersection between May 1, 1967, and September 1, 1967. The existing bidirectional median cross-over which was aligned with Opdyke Road was closed. Improvements to the intersection included the construction of two directional, median cross-overs northwest and southeast of the intersection and the construction of median, deceleration lanes for northbound US-10 traffic at both cross-overs. An additional lane was also provided for northbound US-10 traffic exiting at Opdyke Road and for channelizing the intersection.

Accident data for the year following the improvements were compared with accident data from the year before the improvements. Total accidents decreased 62 percent, from 34 to 13, and injuries decreased 70 percent, from 20 to 6. Median accidents were completely eliminated. There were no far-side, right-angle accidents at the north cross-over and only two right-angle accidents at the south cross-over.

The project met its goal of reducing the accident hazard, especially median and far-side patterns. It also increased the efficiency of lane usage on northbound US-10. The cost of the improvements was $67,000. The benefit for the first year alone was calculated to be $47,300 (Hoffman, et al. 1960).

The accident data for this example were limited to one year, but they did provide a view of the results of one of the first directional cross-overs constructed in conjunction with other improvements in Michigan.

2.3 CROSS-OVER SPACING

A study performed in California found that the lower-volume crossroads had a higher accident rate than higher-volume crossroads. The author concluded that increasing the crossroad spacing within reason, which in effect reduces the total crossroads so that volumes that would be concentrated at the remaining crossroads would be beneficial (McDonald 1953). This indicates that it may be beneficial to limit the number of cross-overs; therefore, increasing the volumes on the cross-overs. It should be noted that the accident count was accidents per year, not accidents per million vehicle miles. Cribbins, et al., in a study that surveyed median cross-over spacings, that varied from 1 cross-over per mile to 27 cross-overs per mile, found that as the median cross-over spacing increased the accidents increased. The North Carolina median placement policy is to space median cross-overs at a minimum of 1,300 feet (Cribbins, et al. 1966). It was also concluded in this work that a precise optimum median cross-over spacing could not be determined.

A Federal Highway Administration publication on the Safety Effectiveness of Highway Design Features, published in November 1992, cited a report to the United States Congress that addressed access control. The report to Congress, which analyzed accident data from 30 states, concluded that full access control was the most important single design factor for accident reduction. This conclusion was sustained by the results of comparing interstate performance with performance on primary highways that allow free-access. Many of the findings agree with those of other studies, that the frequency of median openings directly affects the accident rate. The authors conclude in this work that access should be minimized wherever possible (Cirillo 1992).

2.4 DRIVEWAYS

It was found in a study by Cribbins, et al., that, as access points in North Carolina increased, the number of median openings had a significant effect on accident potential. It was also determined that, as access points increased, all types of accidents increased (Cribbins, et al. 1966).

The literature concerning the relationship between accidents and driveways for roadways with boulevard cross-sections is limited. The balance of this section reviews literature concerning driveways on arterial and two-lane highways. While these findings may not be directly applicable, they do give an indication of what might occur to roadway operations and accident history as a result of this roadway feature.

Schoppert found that the driveways and intersections were directly related to the number of accidents at all ADT levels (Schoppert 1957).

In a work by Box, it was recommended that criteria be established for driveway radii and driveway design for one-way and two-way operations. Since the publication of the article 27 years ago, many of the criteria have become part of state and local standards (Box 1969).

In another study in 1969, Box compared driveway street connections to intersections, suggesting that most driveways can be considered as very minor intersections. Using the rationale that 83 percent of all driveway accidents occurred on major streets, Box carried out a two-year study (1961 and 1962) on 39.7 miles of major streets. Box's research found an advantage to roads that have barriers (medians) as opposed to those without barriers in terms of frequency and severity of accidents. Since 60 percent of the accidents involved left-turning movements, this statistic would explain the lower accident rates when barriers (or medians) were used. Commercial driveways represented the primary hazards (Box 1969).

In a 1970 Louisiana study, a correlation was found between accident rates and pavement cross slopes and conflicts per mile, the conflicts being defined as drives and intersections (Dart and Mann 1970). The variation in accident rates for pavement cross slopes was small with no test for significance being provided.

It was found that driveway accidents accounted for 4.2 percent to 13 percent of the accidents reported, in a report by Uckotter. The purpose of Uckotter's research project was to determine the significance of driveway accidents on commercial arterial highways; to examine roadway, driveway, and land use characteristics related to driveway accidents; and to determine which factors had significant effects on driveway accidents.

Data for the study were collected from 14 roadway sections. Accident data during a three-year period from January 1, 1969, to December 31, 1972, were obtained from the Indiana State Police accident records. Stepwise regression analysis was performed to measure the level of interaction among factors used to predict driveway accidents. A model was then developed to predict the number of driveway accidents per mile per year of a roadway section. The ADT, the number of medium plus high volume driveways per mile, and the driveway volume per mile explained 82.6 percent of the variability of driveway accidents per mile per year.

Driveway accidents were found to represent one-third of all traffic accidents on those sections of arterial highways serving commercial land uses. Driveway accident rates were notably higher at driveway volumes between 250 and 800 vpd. Above 800 vpd, driveway accident rates were lower than those driveways with lower volumes. It was postulated that the main reason for a lower accident rate at higher volume driveways was that the entrances and exits were better designed (Uckotter 1974).

In a report of a study by J. C. Glennon, et al., an outline for use by highway agencies concerned with controlling direct access on arterial highways was developed. A discussion of the problems that are associated with control of direct access and the circumstances around driveway conflicts was given. Some driveway accident statistics from 1970 were included in the report and were broken down into several different classifications. The legal aspects and current practices used for direct access control were also discussed.

The second part of the Glennon, et al., report was intended to orient the user to the identification and analysis of access control techniques. First, the techniques were identified and classified; there were over 70 classifications. Multiple evaluations then followed, such as legal, technical, economic, operational effectiveness, cost effectiveness, and development of warrants for implementation (Glennon, et al. 1975).

McGurick and Satterly stated that full access control is not the solution to reducing the number of accidents that occur on urban arterial highways, as access must be provided. The report identified some of the characteristics of driveway accidents and driveway-related accident occurrence to various physical and environmental features of the roadway and traffic characteristics. A statistical analysis of the accident data showed that the driveway accident rate tends to decrease as the spacing between two driveways increases and the spacing between a driveway and an adjacent intersection increases. Multiple regression analyses identified the following relationships: the driveway accident rate decreased as the number of commercial driveways per kilometer (km) decreased, as the number of through lanes decreased, as the number of total intersections per km increased, as the number of total driveways per km decreased, and as the traffic volume on the arterial highway decreased. This study was intended to give the public official or engineer a tool to better understand the circumstances related to driveway accidents, to predict driveway accident rates, and to estimate the effectiveness of measures to reduce driveway-related accidents (McGurick and Satterly 1976).

In a study addressing driveway access control to arterial streets, Bochner stated that some of the long-term effects of poor access management are a high accident frequency and erosion of roadway capacity. Bochner's work represents an ordinance-based approach to arterial driveway access control.

Bochner stated that "the capacity of a four-lane arterial street with a 45 mph speed limit will be reduced by over one percent for every two percent of the traffic that turns between the right lane and driveways at unsignalized driveway locations." Statistics for several accident types that were introduced by the conflicting traffic movements of driveways were presented. Included in Bochner's report was a table showing the recommended minimum driveway separation for different speed limits on arterial roads. There are several factors that should be considered in ordinance provisions, they included: corner clearance, number of driveways, number of lanes per driveway, prohibition of turns, and left-turn lanes. The author concluded that each ordinance provision would require technical justification as the legislative process is used to adopt ordinance provisions (Bochner 1978).

A National Cooperative Highway Research Program synthesis of studies on the cost and safety of highway design elements resulted in the following conclusions:

1. "As the presence of roadside features increases, the intersection accident rate increases."
2. "As the total width of driveways within 200 feet of the intersection increases, the intersection accident rate increases." (Transportation Research Board 1978).

In a Texas study based on accident data from 1975 to 1977, Rogness and Richards found that 16 percent of all traffic accidents were driveway-related. It was suggested that a significant proportion of accidents are influenced by driveway design features, vehicle operating characteristics, and uncontrolled traffic movements at driveways. Approximately 95 percent of the driveway-related accidents occurred in urban areas. The severity was found to be 34 fatal accidents in every 10,000 driveway-related accidents. Motorcycle and truck accidents made up 72 percent of all fatal driveway accidents (Rogness and Richards 1981).

2.5 TURN-RELATED ISSUES

Left-turn accidents at driveways comprised the largest percentage of driveway accidents. It was reported that conflicts from entering vehicles caused those accidents (Box 1970).

Before-and-after accident information for isolated intersections where directional cross-overs were constructed were evaluated by Savage. The construction of directional cross-overs appeared to have a significant effect in reducing the number of accidents, particularly right-angle accidents. It was recommended, however, that directional cross-overs be used only where there are significant operational problems that need to be corrected (Savage 1974).

A National Cooperative Highway Research Program synthesis consisting of studies on the cost and safety of highway design elements, produced the following conclusions:

1. "The presence of left-turn lanes at two-phase signalized intersections can increase the accident rate."
2. "The accident frequency at divided highway grade intersections is inversely proportional to the median width." (Transportation Research Board 1978).

In a study by Higgins, et al., where the objective was to identify the safety and operational impacts of median acceleration and storage lanes and to assess the cost-effectiveness of current design applications, the following aspects were considered: geometric design practices, effects on traffic operations, safety impacts, driver understanding and acceptance of the designs, and costs. The categories that were closely examined were: median deceleration, storage, acceleration lanes, and CCLTLs. A survey of highway and traffic agencies in Canada and the United States was conducted. Among the survey results was the conclusion that median acceleration lanes were not extensively used in Canada or the United States. However, the CCLTLs were found to be used extensively in the United States and were also quite popular in Canada.

In CCLTL design, the speed limit ranged from 25 to 60 mph, and 12 feet was clearly the most popular width. There was a marked decrease in accidents where CCLTLs were implemented. Accidents involving left turns from the main road decreased by 36 percent.

Accidents involving left turns onto the main road decreased by 22 percent. Accidents involving a vehicle turning off with one turning on decreased by 36 percent. It should be noted that total accidents, not accident rates, were cited in the research. According to the data obtained from the survey, there was a decrease in delay and congestion in areas where CCLTLs were implemented. Some guidelines for CCLTL usage suggested that they were best suited for strip development but required effective signing and marking to reduce the vehicle operator's misunderstanding, indecision, and misuse (Higgins, et al. 1984).

AASHTO's 1990 edition of the Geometric Design of Highways and Streets provides a national guideline for accommodating turning movements. The median width needed to provide for efficient and safe indirect left-turns/U-turns depends on the required turning paths of the design vehicles. If a road has a small median, a jug-handle type ramp or a loop design can be used to improve efficiency and safety around the turns. Highways without medians must use local streets with interconnecting patterns, special median openings, jug-handle type ramps, or an at-grade loop to make indirect left-turns or indirect U-turns. Highways with wide medians that use a cross-over for these turns can be confusing, but do reduce congestion. U-turn median cross-overs are used for left turns in high traffic areas. CCLTLs should only be used in urban settings with low speeds and no more than two lanes in each direction. Median left-turn lanes are auxiliary lanes for storage or speed changes. They are necessary in reducing accidents, inconvenience, and lost efficiency in high traffic or high speed areas (AASHTO 1990).

2.6 TRAFFIC VOLUME

Cribbins, et al., in a study conducted in 1966 in North Carolina, concluded that "in the development of a predictive equation for accidents that ADT and roadside access combined with the number and type of median openings are the most important predictors of accident rates."

In a boulevard intersection accident study performed in California, McDonald found that divided highway roadways with less than 5,500 ADT were unusual, and the roadways with the lower volume were removed from the study (McDonald 1953). Accidents on lower volume roads with less than 5,000 ADT were found to have little correlation with any roadway element (Schoppert 1957). It was found that accident predictions were more accurate for roadways with 3,000 ADT or greater (Schoppert 1957).

2.7 RAISED MEDIANS

In a California study performed by Telford, et al., it was found that traversable medians had a lower accident rate than deterrent medians (curbed being included in this category) for traffic volumes less than 15,000 ADT. When the traffic volumes exceeded 15,000 ADT, the nontraversable median proved to be more effective. This was generally true for all levels of severity (Telford, et al. 1953).

Metcalf discussed the pros and cons of both raised and flush medians which are paraphrased in the next two paragraphs.

Raised medians are permanent, and this permanence has both positive and negative aspects. For instance, if the left-turn lane is too short for the required storage, it is costly to correct the problem by lengthening the turn lane. With flush medians, correction can be made by repainting. Raised medians also separate traffic flows reducing, but not eliminating, the possibility of head-on collisions. Raised medians force left-turn movements at predetermined locations, thus helping in access management. They can be made much more aesthetically pleasing and provide a safe location for both pedestrian crossing, traffic signal and light poles, and other traffic signs. Improper placement of signs on raised medians, however, can be a maintenance nightmare. Adjacent businesses often do not like raised medians because they feel they are being "cut off", which is not necessarily true. A raised median will not discourage the motorists from making the necessary movements to go where they want to go.

Flush medians cannot completely control left turns; they are not "self-enforcing" like raised medians. Flush medians are not aesthetically pleasing. Although flush medians are more economical to install, the concern for maintenance and the safety of the maintenance crews should be considered. Flush medians are difficult to see in rain or snow, or when covered with dirt or sand from snow removal and ice control operations.

Metcalf concluded that flush medians are probably best in rural areas and raised medians are best in urban settings where speeds are lower (Metcalf 1989).

2.8 CCLTLs

Ohio State University carried out a project to evaluate the effectiveness of CCLTLs as an access control measure. Results of a nationwide expert opinion survey and field studies were included in this report. The following is a brief summary of the report:

CCLTLs included in this project were mostly common in commercial land use areas. Positive effects of these left-turn lanes on traffic operation were evident throughout the 8,000 to 31,000 ADT range. Once CCLTLs were installed, reductions in accident rates were observed. The speed limit ranged from 25 to 45 mph. One, two, or three through-lanes in each direction were found acceptable, with the five-lane section most common. These findings are consistent with the 1990 AASHTO Policy on Geometric Design of Highways and Streets, except that AASHTO does not recommend a center left-turn application for situations with three lanes in each direction. The recommended width was that of a normal left-turn lane. CCLTLs could extend directly up to minor intersections, but separate left-turn lanes should be placed at major intersections. Total accidents and injury accidents decreased after the addition of CCLTLs, especially rear-end, side-swipe, and mid-block left-turn collisions. Also, CCLTLs have not been shown to lead to an increase in head-on collisions.

Seventy traffic engineers with practical experience with CCLTLs responded to the survey. They reported that CCLTLs significantly increased the traffic flow quality and reduced accidents. Fears that the lane would produce severe head-on collisions had been proven unfounded. Public reaction was favorable. The effectiveness of CCLTLs increased with the appropriate signing and was also enhanced by a positive effort to educate the public. General guidelines called for operating with 10- to 15-foot lanes, with an optimum width of 12 feet. The use of CCLTLs was applicable in residential, as well as commercial areas, and cross-turn storage was considered a proper function of CCLTLs.

Three sites were used in the field study. US-20 between Painseville and Mentor was changed from a four-lane to a three-lane roadway. The beneficial effects of the CCLTL in terms of traffic flow were offset by the elimination of one traffic lane in each direction. Travel time increased along with weaving, and there was a reduction in accidents. S.R. 264 in Cincinnati was changed from a four-lane to a five-lane highway. Travel speeds didn't change significantly, but at higher volumes the benefits of the CCLTL were more obvious. Braking conflicts were reduced. US-42 north of Mansfield changed from a two-lane to a three-lane highway. Average total travel times and average delays were reduced. There were improvements in running speeds, as well as a reduction in accidents. Braking conflicts were reduced 37 percent and weaving was reduced 80 percent.

The Ohio State University study demonstrated that the two-way, left-turn median lane is effective in improving traffic flow and in reducing left-turn-related accidents. It also lessens the severity of accidents (Nemeth 1976).

In a 1983 paper, David P. McCormick and Eugene M. Wilson compared the operational effects of roadways having continuous two-way, left-turn lanes with four-lane sections and five-lane, Z-pattern sections. The purpose of their work was to determine under which circumstances a particular alternative would produce the best possible results from the standpoint of movement efficiency and safety. A rather small sample size of seven locations was used.

In their conclusions, McCormick and Wilson state that CCLTLs had a substantially lower mean conflict rate than either the four-lane or the Z-pattern treatment. U-turns were virtually eliminated with the use of the CCLTLs. The recommendation of McCormick, et al., for use of the CCLTLs along strip development agrees with other studies (McCormick and Wilson 1983).

2.9 ROADWAY GEOMETRY

Cribbins, et al., determined that in North Carolina: 1) accident rates could be accurately predicted for boulevard roadways; 2) the number of rear-end accidents is less where storage lanes are provided; 3) rear-end accidents occur more frequently at unsignalized intersections than at signalized intersections; and 4) 35 percent of accidents between intersections involve median openings (Cribbins, Avey and Donaldson 1967).

An accident analysis was conducted by B. Beukers and J.H. Jenezon on three types of intersections in the Netherlands. The three types of intersections are:

Type A: An intersection where the main road is not divided by any median and does not provide a left-turn bay.

Type B: An unsignalized intersection where the main road is divided by a median and has left-turn bays.

Type C: Same as Type B except the intersection has a traffic light at the intersection.

The accident analysis, which included 18 intersections of Type A, 20 intersections of Type B, and 13 intersections of Type C, was performed over a period of two years. The ADT for the intersections were 7,500, 8,000, and 19,000 vehicles for Types A, B, and C, respectively.

For the 24-hour periods studied, Type B intersections had the highest percentage (69.5 percent) of collisions that involved crossing or oncoming traffic, while Type A and C intersections had 46.9 percent and 41.4 percent, respectively. As expected, the ratio of rear-end collisions were highest at Type C intersections with 35.1 percent. There were 26.0 percent and 7.6 percent at Type A and B intersections, respectively. However, when the lights were turned on to the flashing mode for Type C intersections, rear-end collisions dropped to 18.8 percent and collisions at the intersections involving crossing or oncoming traffic increased to 55.0 percent (Beukers and Jenezon 1972).

A study was conducted in the early 1970s to determine the relationship between roadway geometry and accidents. Kentucky rural accident and traffic volume data from 1970 to 1972 were collected. The highway sections studied were divided into the following categories: two-lane, three-lane, four-lane undivided, four-lane divided (no access control), and interstate and parkway. The following observations were made:

1. Four-lane undivided highways had the highest accident, injury, and fatality rates. This was attributed to the higher volumes and number of conflict points associated with this roadway type. When the highway was divided, the accident rate dropped sharply and injury and fatality rates declined. This was attributed to the fewer conflict points that exist on this roadway type. When access and at-grade intersections were eliminated, such as on interstates and parkways, the accident rate reached a minimum.
2. The critical accident rate is defined as that rate above which a hazardous situation is believed to exist. Two-lane highways had the highest critical rate in terms of million vehicle miles (MVM) of travel. Four-lane undivided highways had the highest critical rate in terms of accidents per mile per year.
3. Rear-end or same-direction sideswipe accidents were the most frequent types of accidents for all highways as a group. For three-lane, four-lane divided, and four-lane undivided highways, rear-end accidents were most common. Single-vehicle and rear-end accidents were most common on two-lane roads as well as on interstate routes and parkways. Interstate routes and parkways had a significant number of head-on and sideswipe accidents, while four-lane divided and undivided highways had a significant percentage of angle accidents (Agent, et al. 1975).

A 1979 investigation by R. J. Taylor cited accident statistics for a highway which had been converted to a CCLTL roadway. The total number of accidents was reduced by 35.9 percent. Rear-end accidents declined 45 percent; left-turn 20 percent; head-on 67 percent; opposite-direction sideswipe 100 percent; parking 79 percent; angle 40 percent; same-direction sideswipe 50 percent; pedestrian/bicyclist 30 percent; and fixed objects 65 percent. The run-off-the-road accidents increased by 86 percent and backing-related, 125 percent.

2.10 LITERATURE SEARCH SUMMARY

The literature search found general agreement among researchers on the subject of boulevard roadway operation. There was agreement that the median width did have an effect on the accommodation of vehicles making U-turns through median cross-overs. The authors differed on how to group median widths for analytical purposes, but generally it was at 0 to 30 feet, 30 to 60 feet, and over 60 feet of median width.

There was disagreement as to whether accident rates increased or decreased as median width increased. In two studies, opposing results were obtained. One study found that the accident rate increased with increasing median width and the other found that the accident rate decreased with increasing median width.

One study reported that the directional cross-overs were effective in reducing accidents, but the study that indicated these results had only two years of data, which may be insufficient to support that conclusion.

The use of CCLTLs appeared to improve the operation of urban arterials. The use of the boulevard roadway section with indirect left turns appeared to improve operations. No comparison between the two roadway types was found in the literature.

The studies examined also indicated that roadways with curbed medians had a higher accident rate than roadways with uncurbed medians for traffic volumes under 15,000 ADT. On roadways with higher traffic volumes, the roadways with curbed medians had a lower accident rate.

No published research was found which compared the Michigan-designed boulevard with five- and seven-lane CCLTL facilities.

Studies where low traffic volumes were used resulted in unreliable statistics. The definition of low traffic volume was 3,000 ADT in one study and 5,500 ADT in another study.

Several studies dealt with the relationship between signals and accidents. The general conclusion is that the stop-go signals did not reduce accidents, but merely changed the type of accident that occurred at the intersection.

2.11 RESEARCH OBJECTIVES

The literature reviewed in sections 2.1 through 2.9 suggests that there may be a difference between the accident rates of roadways with a boulevard cross-section and those of roadways with CCLTLs.

The research hypotheses to be tested in this study are formulated as follows:

1. The accident rate for a roadway with a boulevard is different than the accident rate for a roadway with a CCLTL.
2. The accident rate for roadways with a boulevard cross-section is influenced by geometric features and roadway environment; i.e., median width, posted speed, and average daily traffic.
3. There is a difference in the accident rate for a boulevard with directional cross-overs and a boulevard with bidirectional cross-overs.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 THE VARIABLES OF INTEREST

This dissertation is part of a cooperative research effort between Michigan State University and MDOT. MDOT was interested in investigating the safety aspects of divided highways with respect to the geometric design features. MDOT was also interested in the ability to predict accident rates for boulevard highways as a function of the geometric features so that they could develop cost-effective designs.

The literature search revealed extensive research and investigation of roadway features that attempt to explain the difference between the accident experience on roadways with CCLTLs and that on roadways with a boulevard cross-section, but information on the Michigan design was limited to only one location studied in the 1960s. The conclusions of the researchers were not always in agreement even when the same roadway features were the subject of the research.

The hypotheses regarding the safety aspects of a boulevard cross-section will be tested by examining the relationship between the roadway elements and the accident data. As there are several roadway features that could affect the accident rate, multivariate analyses will be performed to test the relationship of the independent variables with respect to the dependent variables. The analyses require four types of data: 1) the physical roadway features; 2) the accident data as recorded by the local jurisdictional authorities or Michigan State Police; 3) traffic data; and 4) traffic control data. The details of the proposed analyses are found in section 3.8.

3.2 THE RESEARCH DATA

Roadway data were obtained from the MDOT roadway inventory. The records for all five-lane, seven-lane, and boulevard roadways in the State of Michigan were obtained. The values of the independent variables present on each of the roadway sections were obtained from the following: MDOT photo-log system, plan of record, Planning and Traffic and Safety data files, and a field check combining video tape and measurements.

The published official traffic volumes and information concerning presence of a curb were obtained from the MDOT Sufficiency Rating manual dated 1990. The Michigan county population figures were obtained from the State of Michigan Library compact disc records of the 1990 Census of Population and Housing.

3.2.1 DATA INDEX

MDOT uses a numerical system to inventory the state highways. Each control section is further subdivided into mile points which are measured in hundredths of a mile and the numbering increases from south to north and from west to east. The state roadway inventory shows the control sections of the state highways that fall into the CCLTL and boulevard categories.

MDOT photographs all of the state highways on a periodic basis (until recently). The original 35 mm film process has been upgraded to a videotape process and all records are now saved on an optical disk. These records, with additional videotaping and field measurements, were used to define the roadway features in this research. The equipment and procedures are described in section 3.6.

The accident data are formatted with standard data fields by year. The method of categorizing the different routes has been to assign a (MALI) prime number to each roadway segment. The prime numbers and mile points may or may not correlate with the photolog mile points. The values used to report accidents are derived from maps and other horizontal measurements, while data derived from the photolog are based on driven distances. Thus a small error is introduced and the error accumulates as the distance from the origin increases. To resolve this discrepancy, the English name of each intersection is coded from the photolog and subsequently matched with the corresponding name from the MALI. A simple linear transformation is used to provide each accident with a photolog-based mileage point.

The data were assembled into working computer files while data collection was proceeding. Each data set was inspected and errors that were detected were verified on the photolog or in the field and then corrected.

The accident data, obtained from the University of Michigan Transportation Research Institute, were converted from a tape format to a compact disk format. This enabled quick access to the data via a desktop computer which was especially convenient for both statistical analyses and plotting. The roadway data were then merged with the accident data into one computer file for ease of inspection and analysis.

3.2.2 ROADWAY FEATURES

The following roadway features have the potential to affect the accident potential of roadways with CCLTLs and boulevard cross-sections and can be a practical consideration in a roadway design:

1. **Intersection density:** The number of intersections per mile of roadway.
2. **Signal/no signal:** The presence or absence of stop-go traffic signals.
3. **Signal density:** The number of signals per mile of roadway.
4. **Driveway type:** The classification of the driveway, generally defining its primary use such as residential or commercial.
5. **Driveway density:** The number of driveways per mile.
6. **Lane width:** The width of the individual traveled lane measured in feet.
7. **Shoulder/curb:** The method of treating the area beyond the edge of pavement either with a curb or a shoulder.
8. **Median width:** The width of the median measured from edge of metal to edge of metal.
9. **Cross-over type:** The type of cross-over provided in the median. Directional cross-overs permit travel only in one direction from one roadway to the other. Bidirectional cross-overs permit travel in either direction from one roadway to the other or across the median.
10. **Cross-over density:** The number of cross-overs occurring per mile.

3.2.3 TRAFFIC CONTROL DATA

The following traffic data have the potential of affecting the accident potential of CCLTL and boulevard roadways:

1. **Traffic volumes:** The number of vehicles on a particular roadway could directly represent the increased potential of conflict between vehicles which are traveling along, attempting to enter or perform some other maneuver on that same roadway.
2. **Percent commercial vehicles:** The percentage of commercial vehicles represents a portion of the motor traffic which requires certain accommodations, such as adequate turning radii, to participate in the traffic stream. Commercial vehicles include all buses, single-unit trucks, and truck combinations except for light delivery trucks.
3. **County population:** The population of the county in which a roadway is located. This may be a surrogate measure of development intensity that is present along roadways in a particular geographic area, which in turn could reflect the cross-street volumes. Data on cross-street volumes are not available.
4. **Speed limits:** Speed limits are traditionally based on the 85th percentile running speed of the roadway in question. Speed limits may also be a surrogate measure of developmental density and/or traffic congestion.

3.2.4 THE ACCIDENT DATA

The accident data were furnished on magnetic tape by the University of Michigan Transportation Research Institute. The data furnished were for 1970 through 1991.

The accident types are described as follows:

1. **Head-on:** The collision of two vehicles traveling in opposite directions with the fronts of the two vehicles impacting.

2. **Head-on left:** The collision of two vehicles when one of the vehicles is turning left and the front end of both vehicles impact.

3. **Angle-straight:** The collision of two vehicles traveling at 90 degrees to each other prior to the time of impact.

4. **Rear-end:** The collision of two vehicles traveling in the same direction with the front of the trailing vehicle impacting the rear of the leading vehicle.

5. **Rear-end right:** The collision of two vehicles traveling in the same direction with the front of the trailing vehicle impacting the rear of the leading vehicle when the leading vehicle turns right.

6. **Rear-end left:** The collision of two vehicles traveling in the same direction with the front of the trailing vehicle impacting the rear of the leading vehicle when the leading vehicle turns left.

7. **Angle-turn:** The collision of two vehicles traveling in opposite directions when the turning vehicle turns into the path of the other vehicle.

8. **Sideswipe same direction:** The collision of two vehicles traveling in the same direction with one of the vehicles impacting the side of the other vehicle with the side of the vehicle.

9. **Sideswipe opposite direction:** The collision of two vehicles traveling in opposite directions with one of the vehicles impacting the side of the other vehicle with the side of the vehicle.

10. **Angle-drive:** The collision of two vehicles when one vehicle is turning into a driveway or out of a driveway with the front end of one vehicle impacting the side or front of the other vehicle.

11. **Rear-end drive:** The collision of two vehicles traveling in the same direction with the front of the trailing vehicle impacting the rear of the leading vehicle when the leading vehicle turns into a driveway.

12. **Dual left-turn:** The collision of two vehicles traveling in the same direction and turning left along side of each other with the side of one vehicle impacting the side of the other vehicle.

13. **Dual right-turn:** The collision of two vehicles traveling in the same direction and turning right along side of each other with the side of one vehicle impacting the side of the other vehicle.

14. **Other accidents:** Other accidents not categorized above, which include accidents such as deer, pedestrian, and parking-related accidents.

Accident severity is defined as follows:

1. **Type "A" injury:** An incapacitating injury, any injury, other than fatal, which prevents the injured person from walking, driving, or normally continuing the activities which he/she was capable of performing prior to the traffic accident.

2. **Type "B" injury:** A nonincapacitating injury, other than fatal and incapacitating, which is evident to any person at the scene of the accident.

3. **Type "C" injury:** A possible injury reported or claimed which is not a fatal, incapacitating, or nonincapacitating evident injury.

4. **Type "K" injury:** A fatal injury that results in death within 90 days of the accident.

3.5 SITES OF INVESTIGATION

The project includes all five-lane, seven-lane, and boulevard highways in the State of Michigan, representing a variety of sites that include urban and rural settings. These locations are distributed around the state and consist of 366.3 miles of five-lane highways, 55.8 miles of seven-lane highways, and 512 miles of boulevard highways. A complete listing of these roadway sections is provided in Appendix Table A1 with the control section, common state route number, and limits of data acquisition indicated. A State of Michigan map showing MDOT Districts is shown in Figure A1.

3.6 EXECUTION OF THE EXPERIMENT

The highway data for the experiment were collected on the basis of the features listed in Section 3.2.2. All the data were collected during the period from January 1994 to October 1994.

The forms shown in Figures A4 to A9 and A13 were designed for ease of use by the data collectors. A set of instructions in Figures A2, A3, and A10-A12 was developed by the author for use by the individuals collecting the data. It was determined that multiple viewing passes of the photolog would be made, with similar data being collected during each pass. Information identifying the control section (location of the data being collected), the date that the video or film was recorded, the direction of travel, the variable being collected, and the mile point were common to all data sets collected. The forms also provided a location for recording the common given route number, the name of the individual recording the data, the name of the individual verifying the data, and the sheet number.

The data were collected in MDOT offices located in Lansing, Jackson, and Kalamazoo.

The equipment consisted of the following units:

1. Sony optical disk player (Figures 3.6.1 to 3.6.4)
2. Bell and Howell 35 mm film viewing machine
3. Sharp Slim Cam video camera
4. Canon AE1 35 mm camera
5. Distance measuring device

Field measurements were performed using a measuring wheel and a video camera to field-check data acquired from the photolog video player and the 35 mm projection screen and to obtain certain other ground data. Separate instructions were developed for the field verification and collection of additional data.

Space was provided for any unusual circumstances or observations that may have been noted during the data acquisition and field verification phase.

The forms and their corresponding data are as follows:

1. Form A: number of lanes
2. Form B: intersection mile points and names
3. Form C: cross-over types and mile points
4. Form D: drive mile points and characteristics
5. Form E: unusual features such as lunes or bus turn-outs
6. Form F: type of roadway
7. Form G: median width, lane width, and speed limit

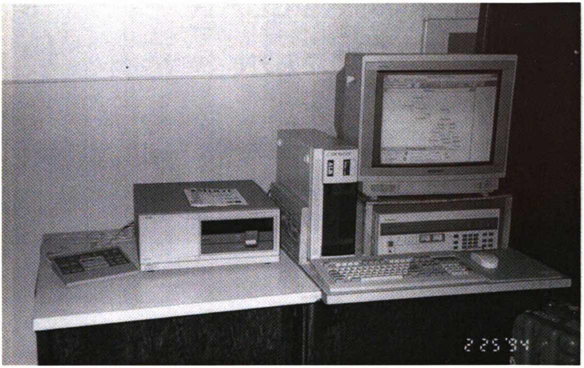


Figure 3.6.1 Photolog Equipment

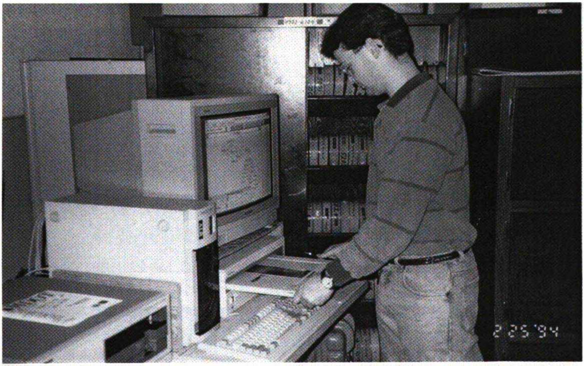


Figure 3.6.2 Loading Optical Disk Into Photolog Machine

Figure 3.6.3 Operating Photolog Equipment

Figure 3.6.4 Photolog Image of Road Section

8. Form K: parking restrictions; not used in the study

9. Form L: turn restrictions; not used in the study

3.7 DATA INSPECTION

A visual inspection was made of the data set utilizing scatter diagrams and histograms. This was performed so that any obvious coding errors, correlations, or trends could be recognized.

3.8 UNIT OF ANALYSIS

The unit of analysis is a section of highway with a unique control section with beginning and ending mile points (the basic MDOT referencing system). Originally the segments of highway were divided into unique element for every change in the number of lanes, median width, lane width, curb and gutter/shoulder, and/or speed limit. However, the control sections did not exhibit a change in element as often as anticipated which resulted in a number of segments of considerable length. Thus, a uniform segment length of one quarter mile was chosen. Segments less than one quarter mile in length were not used in the statistical analysis.

3.9 STATISTICAL ANALYSIS

Discriminate analysis was utilized to determine which independent variables explained the difference in accident rates for boulevard and CCLTL roadways. A branching process was the applied utilizing discriminate analysis. The discriminate analysis was continued until a sample size of 30 values or larger was no longer available or no significant difference was indicated at the 0.95 significance level.

The statistics computed include the mean, standard error, maximum, and minimum for seven accident types. These statistics were obtained for all segments, unsignalized segments, and signalized segments.

The Student's *t*-test was then utilized to determine if the difference between the means for boulevard vs. CCLTL data sets were significant.

The one-way analyses of variance (ANOVA) utilizing Tukey's B was performed for the following data sets:

- three categories of boulevard widths.
- three categories of boulevard posted speeds.
- three categories of boulevard ADT.
- three boulevard median widths for two cross-over types.
- three categories of CCLTL posted speeds.
- three categories of CCLTL ADT.

3.10 CHAPTER SUMMARY

The independent variables determined to be relevant to the validity of the hypothesis are: traffic volumes, percent commercial vehicles, county population, speed limits, intersection density, signal density, driveway type and density, lane width, shoulder and curb, median width, cross-over type and density.

The dependent variables were selected to be: accident rate expressed as accidents per hundred million vehicle miles of travel and accident severity.

The data for the project were collected through the use of photolog techniques and field measurements. These were merged with available records and were then converted into computer data files for input in computer-supported analyses.

The analytical unit of analysis was a quarter-mile section of highway with uniform roadway features.

CHAPTER 4

DATA ANALYSIS

4.1 INTRODUCTION

The distribution of the data is presented in Section 4.2. The frequency distributions present an indication of which independent variables have a relationship with the dependent variables described in Chapter 3.

The results of discriminate analyses utilized to determine which independent variables explained the difference in accident rates for boulevard and CCLTL roadways are presented in Section 4.3. In section 4.4 accident statistics for seven accident categories are developed for the independent variables that appeared to be important. The Student's *t*-test and ANOVA with Tukey-b test were utilized to determine whether there was a significant difference between the means for the groupings that were being compared.

The conclusions drawn from the data analysis are discussed in Chapter 5.

4.2 DATA INSPECTION

The frequency distributions of the data for the independent and dependent variables were investigated. These frequency distributions provided an indication of distribution types (normal, uniform, or Poisson) skewed data, coding errors, and outliers. These frequency distributions are presented in Figures 4.2.1 to 4.2.15.

The occurrence of different types of accidents and their distribution for boulevard and CCLTL highways are of interest. Figure 4.2.1 illustrates the accident data distribution as a function of the accident types for boulevard and CCLTL highway segments. Thirteen accident types are shown with the remaining accident types (such as, animal-related accidents) being grouped into the "other" category.

Boulevard highway segments were found to have a higher percentage of rear-end and angle-straight accidents than the CCLTL highways. Rear-end and angle-straight accidents are associated with intersection conflicts. CCLTLs had higher percentages of other, angle-drive, rear-end drive, and head-on, left-turn accident types.

It is not surprising that divided (boulevard) highways have a relatively lower percentage of head-on accidents as the directions are separated by a median. This reduces the number of potential head-on accidents. Other than vaulting the median, this type of accident would only occur if a wrong-way movement takes place. It is not intuitive that a boulevard should have a relatively lower percentage of driveway-related accidents. However, as will be seen later on Figure 4.2.9, the driveway density is generally greater for highway segments with CCLTLs.

Rear-end accidents represent the largest component of accidents--accounting for 34,021 or 56 percent of the boulevard accidents and 29,582 or 47 percent of the CCLTL accidents. The second most frequent accident type was the angle-straight accident accounting for 8,784 or 14 percent of the boulevard accidents and 5,442 or 9 percent of the

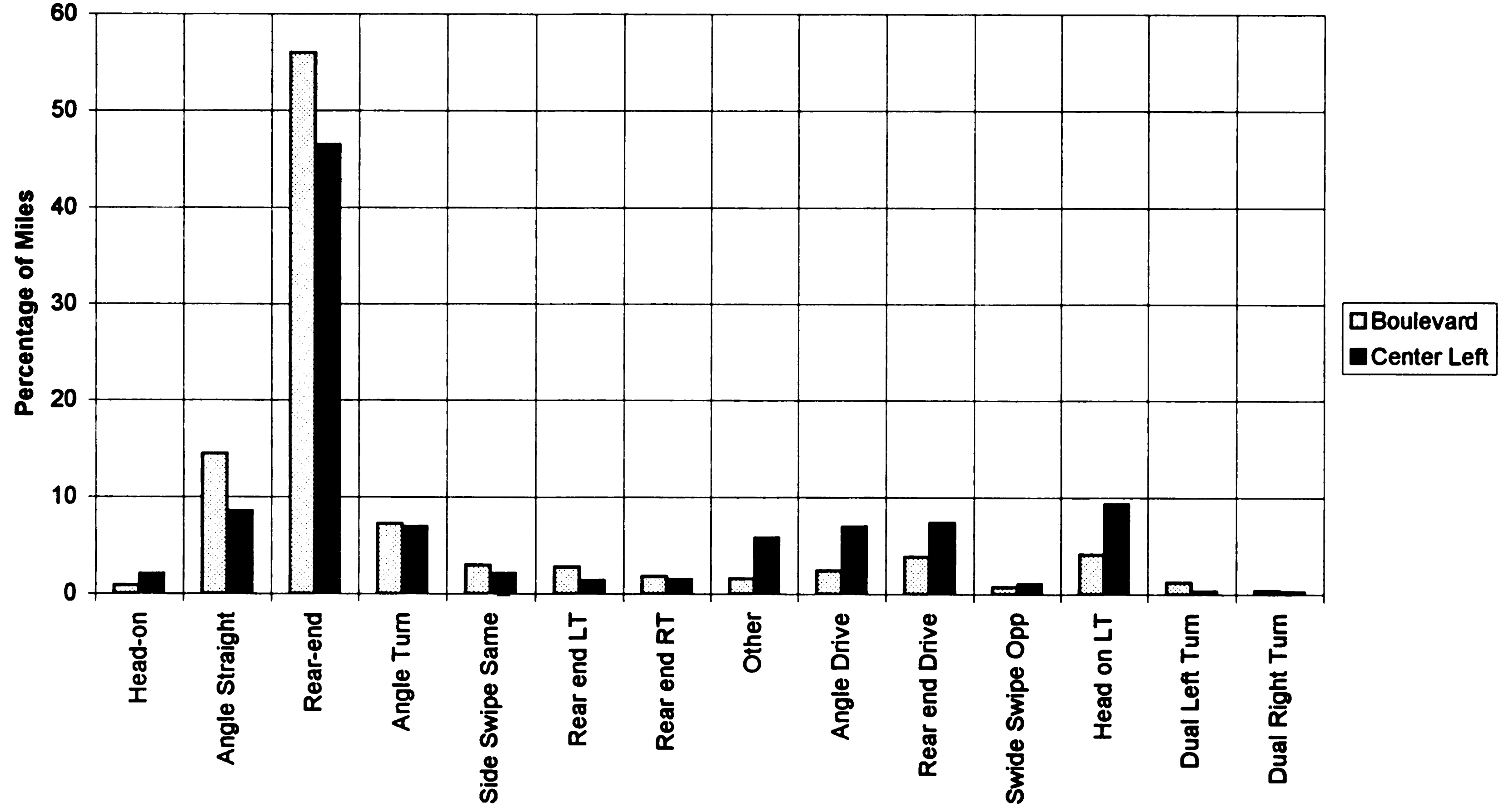


Figure 4.2.1 : Accident Percentage for each Type of Accident, All Segment Lengths

CCLTL accidents. Head-on left- and angle-turn were the next most frequent accident types.

Severity is a measure of the seriousness of the injuries sustained by individuals involved in an accident. In Figure 4.2.2 the distribution of accident data is illustrated as a function of accident severity for boulevard and CCLTL highway segments for four levels of accident severity. The classification of the level of accident severity is as follows: Type A represents accidents where disabling injuries occurred; Type B represents accidents where nondisabling injuries occurred; Type C represents accidents where no visible injuries occurred but complaints of injury were voiced; and Fatalities represents those accidents where deaths occurred.

The bar chart indicates that there is no apparent difference between the boulevard and the CCLTL highway segments for the four severity categories. It might have been expected that a higher percentage of severe injury accidents and fatalities would be associated with the CCLTL segments as the direction of travel is not physically separated. The Type C accident was the most common accident type for both roadway types with 9,581 or 64 percent of the boulevard injury accidents and 13,112 or 63 percent of the CCLTL injury accidents occurring in this category. The interesting observation is that the percentage of each injury type is almost identical for each roadway type.

Traffic volumes vary for individual highways, depending on the location and the demand for highway use. Figure 4.2.3 illustrates the distribution of total miles as a function of traffic volumes for boulevard and CCLTL highway segments.

Twenty-six categories of ADT volumes, ranging from 4,000 vehicles per day to over 104,000 vehicles per day in increments of 4,000, are provided in the bar chart.

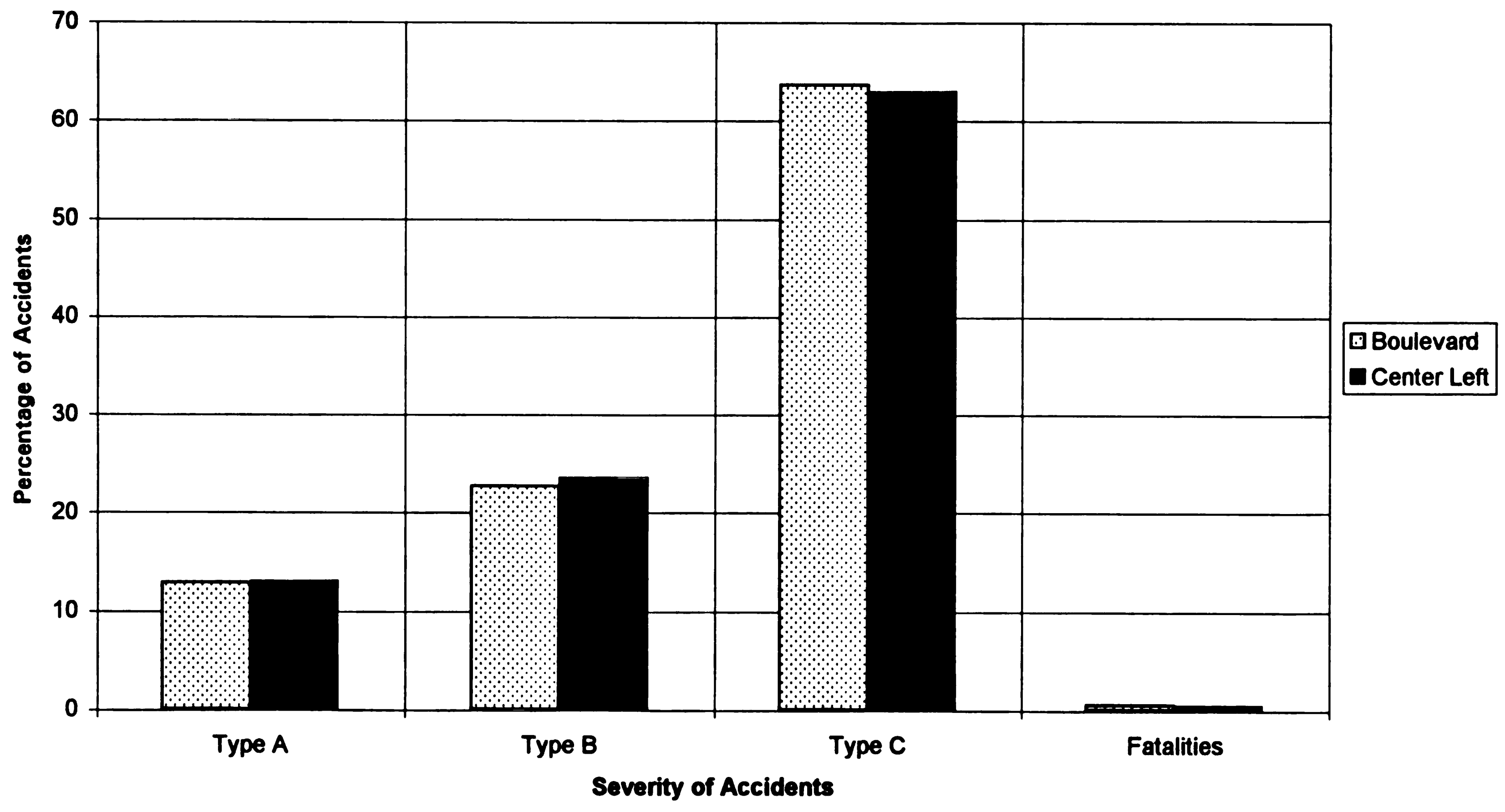


Figure 4.2.2 : Accident Severity Percentage for All Accidents

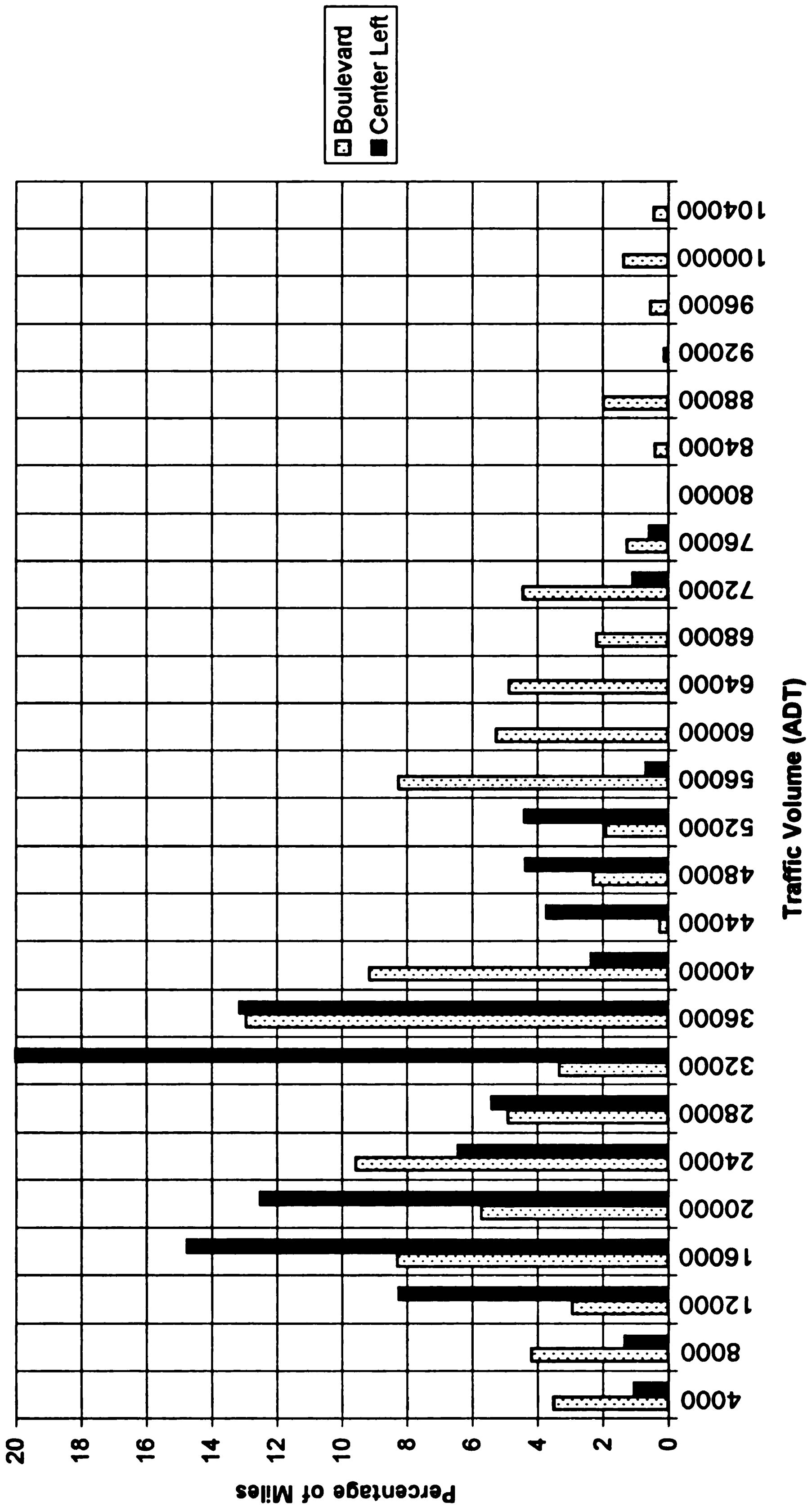


Figure 4.2.3 : Traffic Volume Percentage for All Section Lengths

Boulevard highway segments had a higher percentage in the 4,000 vehicles per day to 8,000 vehicles per day range and from 56,000 vehicles per day and higher. CCLTL highway segments with 12,000 to 52,000 vehicles per day had higher percentage than boulevard highway segments with similar levels of traffic with few of the volume category exceptions. It would appear that the lower volume roadways are associated with rural situations where boulevards are more prevalent and that CCLTLs are associated with urban situations. The exceptions are the very high volumes which can be accounted for by boulevard roadways such as 8 Mile Road in the Detroit Metropolitan area. This is illustrated in Figure 4.2.6 which indicates a higher percentage of boulevards in the 55 mph category. The CCLTL percentage is higher for the lower speeds except for the 40 mph category.

The traffic volume for the boulevard cross-section with the largest percentage of miles was an ADT of 36,000 vehicles per day, accounting for 31 miles or 12 percent of the total miles of that roadway type. The traffic volume for the CCLTL cross-section that accounted for the largest percentage of miles was an ADT of 16,000 vehicles per day, accounting for 25 miles or 15 percent of the total mileage for that roadway type. The highest actual volume for the boulevard cross-section was 104,000 vehicles per day. The highest volume for the CCLTL cross-section was 76,000 vehicles per day. In general it appears that the boulevard cross-section has more roadway mileage with the higher volumes.

The portion of traffic on a roadway that can be attributed to commercial traffic may be a factor in the accident occurrences on that highway. The distribution of the surveyed roadway mileage as a function of percent commercial for boulevard and CCLTL segments is illustrated in Figure 4.2.4.

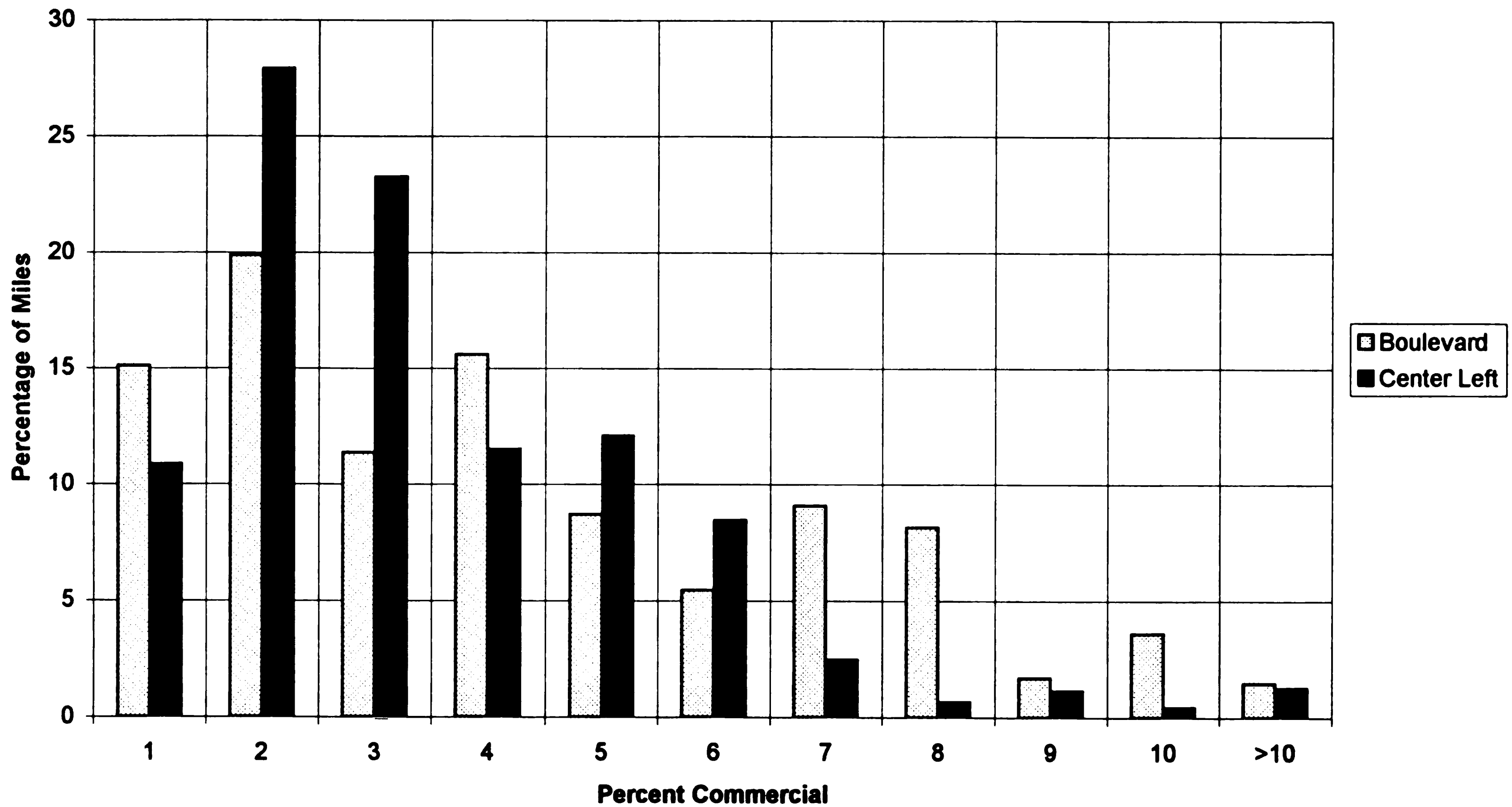


Figure 4.2.4 : Percent Commercial vs Percent of Miles, All Section Lengths

The commercial percentages of volume are provided for 11 categories. Except for the 1 and 4 percent categories, the CCLTL segments dominated the roadway with lower percentages of commercial traffic. This is the opposite of what may have been expected as the CCLTLs are found in the lower speed, urban areas which would be expected to have a higher commercial vehicle presence. The higher commercial vehicle traffic categories are dominated by the boulevard segments. This also was unexpected but could be accounted for by the boulevard roadways in southeastern Michigan.

The highest commercial percentage for the boulevard cross-section, 2 percent, accounted for 48 miles or 20 percent of the roadway mileage. The highest commercial percentage for the center left-turn cross-section, 2 percent accounted for 46 miles or 28 percent of the total mileage. The mileage for both the boulevard and CCLTL roadways appeared to be concentrated in areas with low percentages of commercial vehicle traffic.

It is believed that population could be a surrogate measure of development. In Figure 4.2.5 the distribution of roadway miles as a function of the county population is illustrated for boulevard and CCLTL highway segments.

Values in the bar chart are provided for 22 population categories ranging from 100,000 to 2,200,000, in increments of 100,000. Boulevard segments had a higher percentage of miles in less populated counties which would be expected as the boulevard segments were more prevalent in the higher speed areas (Figure 4.2.6). The CCLTL segments were more prevalent in the middle population areas. The boulevard segments were more prevalent in the higher population area.

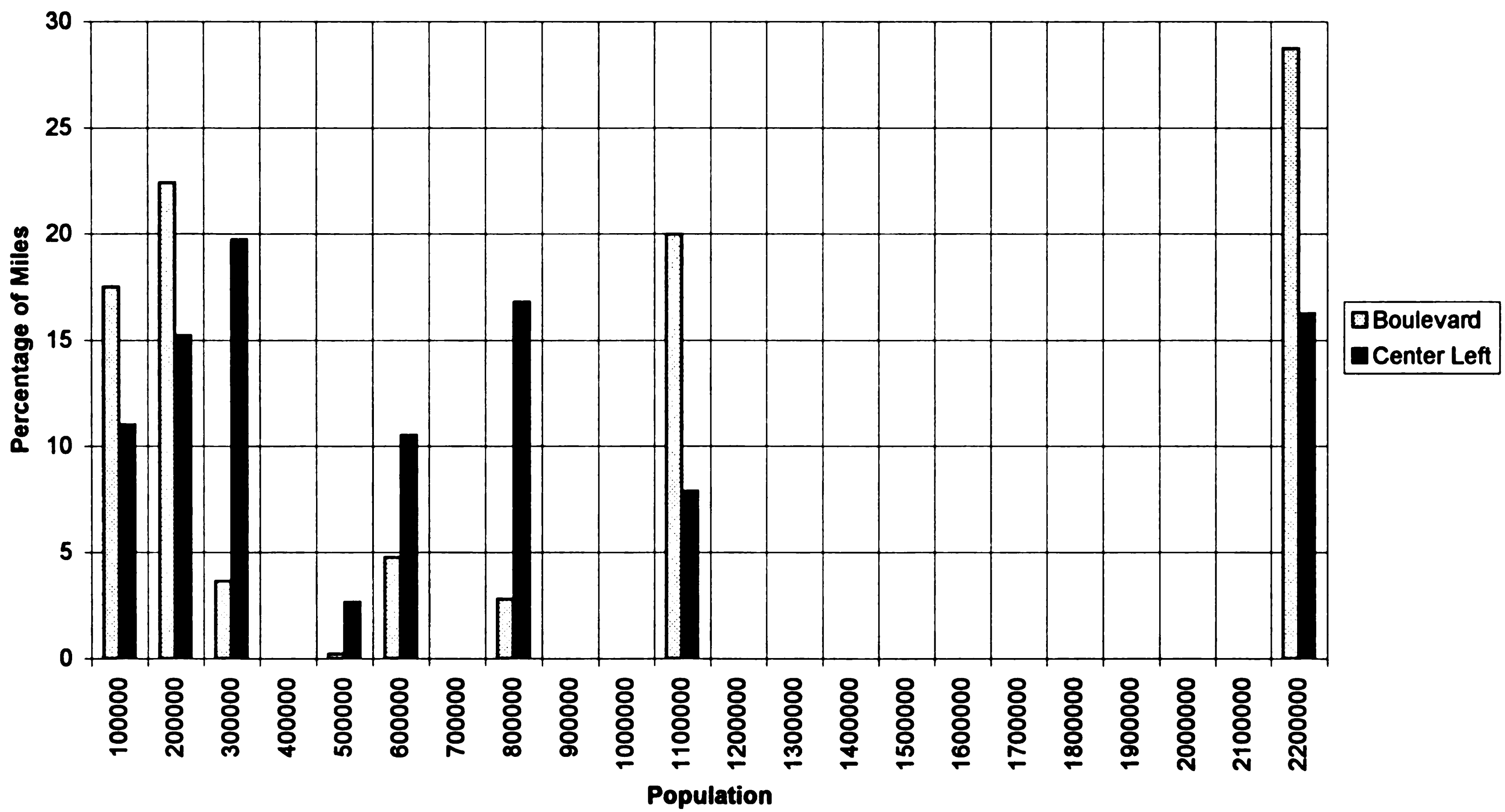


Figure 4.2.5 : Population Percentage for All Section Lengths

It is quite evident that the boulevard sections are located in both the least populated and most heavily populated areas while the CCLTLs are located mainly in the sparsely to moderately populated counties. Twenty-nine percent of the boulevard cross-section mileage (69 miles) is located in Wayne County. Twenty percent of the CCLTL cross-section mileage or 34 miles is located in Oakland County.

The posted speed limit can be an indication of the amount of development, and the rural or urban nature of a roadway. Figure 4.2.6 (Speed Limit Percentage for all Sections) illustrates the distribution of segment mileage as a function of posted speed limits for boulevard and CCLTL highways.

The seven posted speed categories (from 25 to 55 mph in 5 mph increments) are represented in the bar chart. The boulevard mileage appears to be linearly distributed. The greater percentage of CCLTL mileage is concentrated in the 35 to 50 mph category.

The greatest mileage of boulevard cross-section, 123 miles or 51 percent, has a 55 mph speed limit. The greatest mileage of CCLTL cross-section, 54 miles or 32 percent, have a 45 mph speed limit. The boulevard cross-sections are concentrated in the 55 mph speed limit areas and the CCLTL cross-sections are concentrated in the 35 and 45 mph speed limit areas.

It was found in the literature that intersection density can have an effect on the accident rate. Figure 4.2.7 illustrates the distribution of segment mileage as a function of intersection density for boulevard and CCLTL highway segments.

Nine categories of intersection density from five intersections per mile to greater than 40 intersections per mile in increments of five intersections per mile are presented in a bar

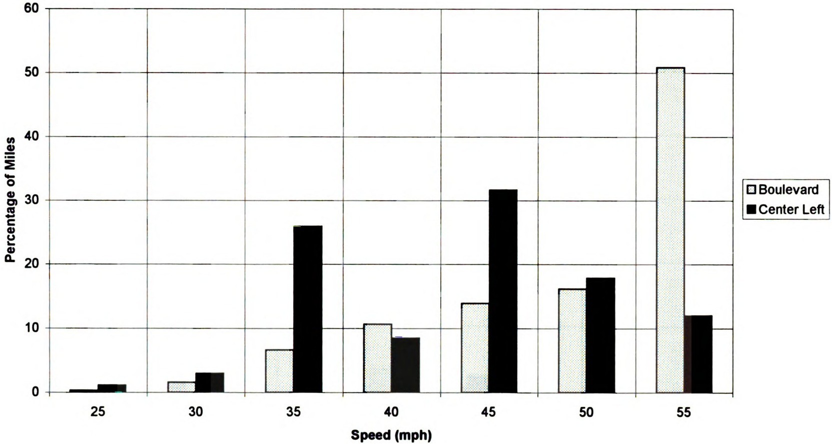


Figure 4.2.6 : Speed Percentage for All Sections

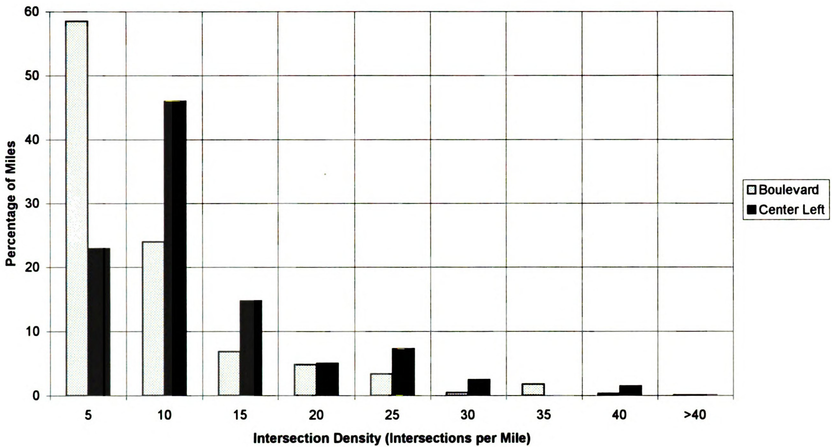


Figure 4.2.7 : Mile Percentage of Intersection Density, All Section Lengths

chart. The large number of intersections in some cases is due to the presence of short segments in the sample. These short segments were removed during the analysis phase. The largest portion of the boulevard segment-miles is concentrated in the five- to ten-intersection per mile categories. This is inconsistent with the population distribution which indicates that the boulevard segments are concentrated in more rural situations where a lower intersection density would exist and high population density areas where higher intersection density would be expected. The largest portion of CCLTL segments appears to be concentrated in the five- to ten-intersection per mile categories, indicating that these segments are found in a more urban setting than the boulevard segments.

The highest category of intersection density for a boulevard cross-section was 58 percent of the total or 142 miles, with an intersection spacing of five intersections per mile. The highest percentage of intersection density for CCLTL cross-section was 46 percent of the total or 79 miles for an intersection spacing of ten intersections per mile. The intersection spacing appears to be concentrated in an intersection density up to 15 intersections per mile.

It is possible that accidents are related to signal density. Figure 4.2.8 illustrates the distribution of signal density for boulevard and CCLTL highways. The signal density has been divided into categories ranging from one signal per mile to greater than ten signals per mile, in increments of one signal per mile. The largest percentage of boulevard mileage is concentrated in the category of one signal per mile which, with the intersection density, correlates with the concentration of boulevard mileage in rural areas. The majority of the boulevard mileage is concentrated in the two through four signal per mile category. The balance of the boulevard mileage is distributed in the five to greater than ten signal per mile

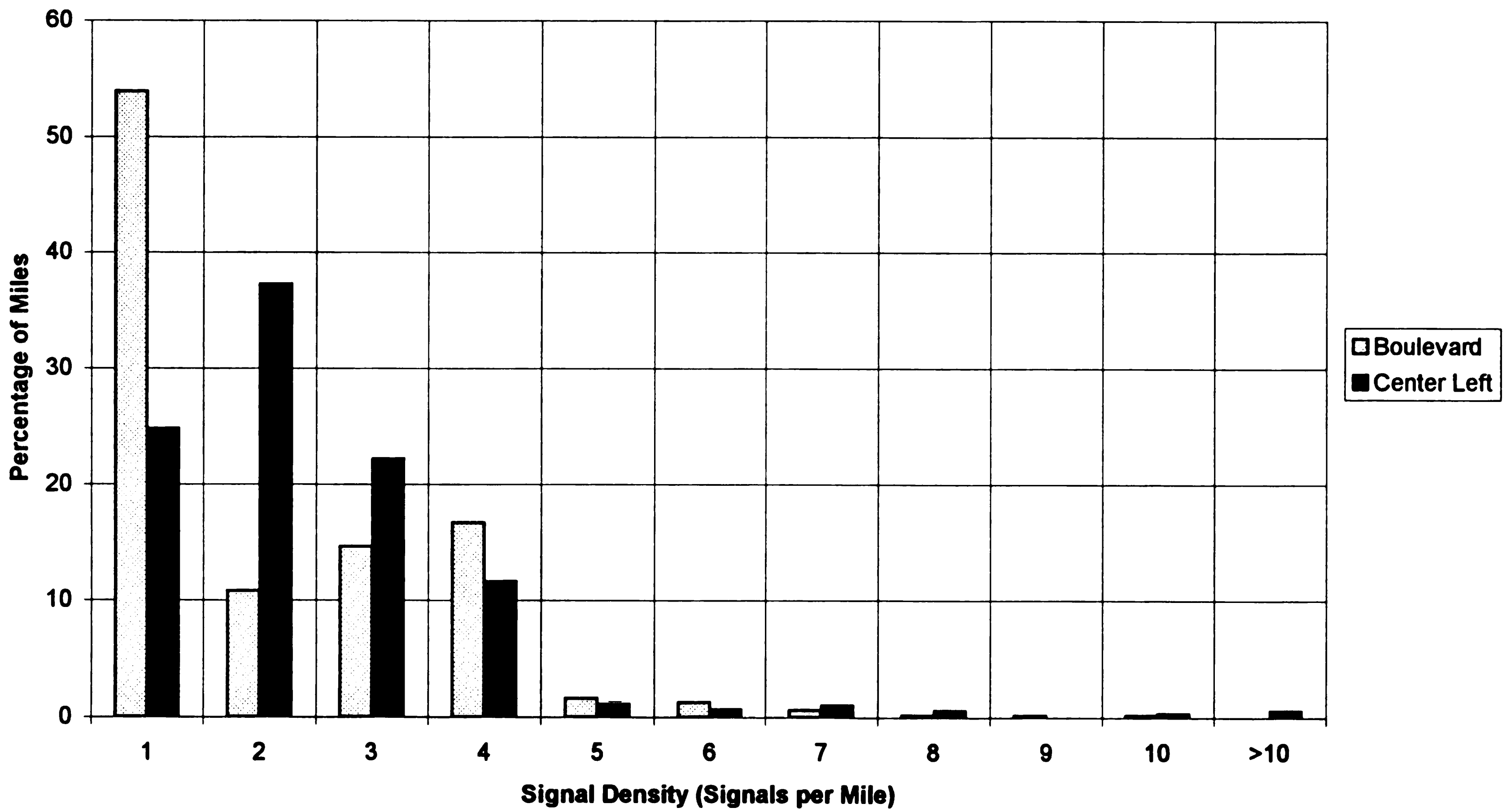


Figure 4.2.8 : Mile Percentage of Signal Density, All Section Lengths

category. The CCLTL mileage is concentrated in the one through four signal per mile category with no uniform distribution. The balance of the mileage is distributed in the five to greater than ten signal per mile categories. It appears that there is a higher concentration of the CCLTL mileage in the more urban areas, consistent with the higher signal concentrations and the distribution of mileage by speed limit.

The highest category of stop-go signalized intersection density for boulevard highways was 54 percent or 131 miles with a signal spacing of one signal per mile. The highest category of stop-go signal density on CCLTL highways was 37 percent or 64 miles for a signal spacing of two signals per mile. The stop-go signal spacing appears to be concentrated at a signal density of one signal per mile for boulevard cross-sections and two signals per mile for CCLTL cross-sections.

The amount of roadside development and the number of access points were shown to be related to the accident frequency in the literature search. Figure 4.2.9 illustrates the distribution of segment mileage as a function of driveway density for boulevard and CCLTL highways. Nine categories of driveway density ranging from five driveways per mile to greater than one hundred driveways per mile, in increments of five driveways per mile, are provided in the bar chart. The boulevard segments appear to be concentrated in the five driveways per mile to thirty driveways per mile category with the greatest concentration in the five driveways per mile category. The CCLTL mileage is concentrated in the 30 to 60 driveways per mile category. These coincide, once again, with the indication from the mileage/speed limit distribution which indicated the majority of boulevard mileage is in rural areas. This is indicated by a lower driveway density. The majority of CCLTL mileage is in more urbanized areas which is indicated by a higher driveway density.

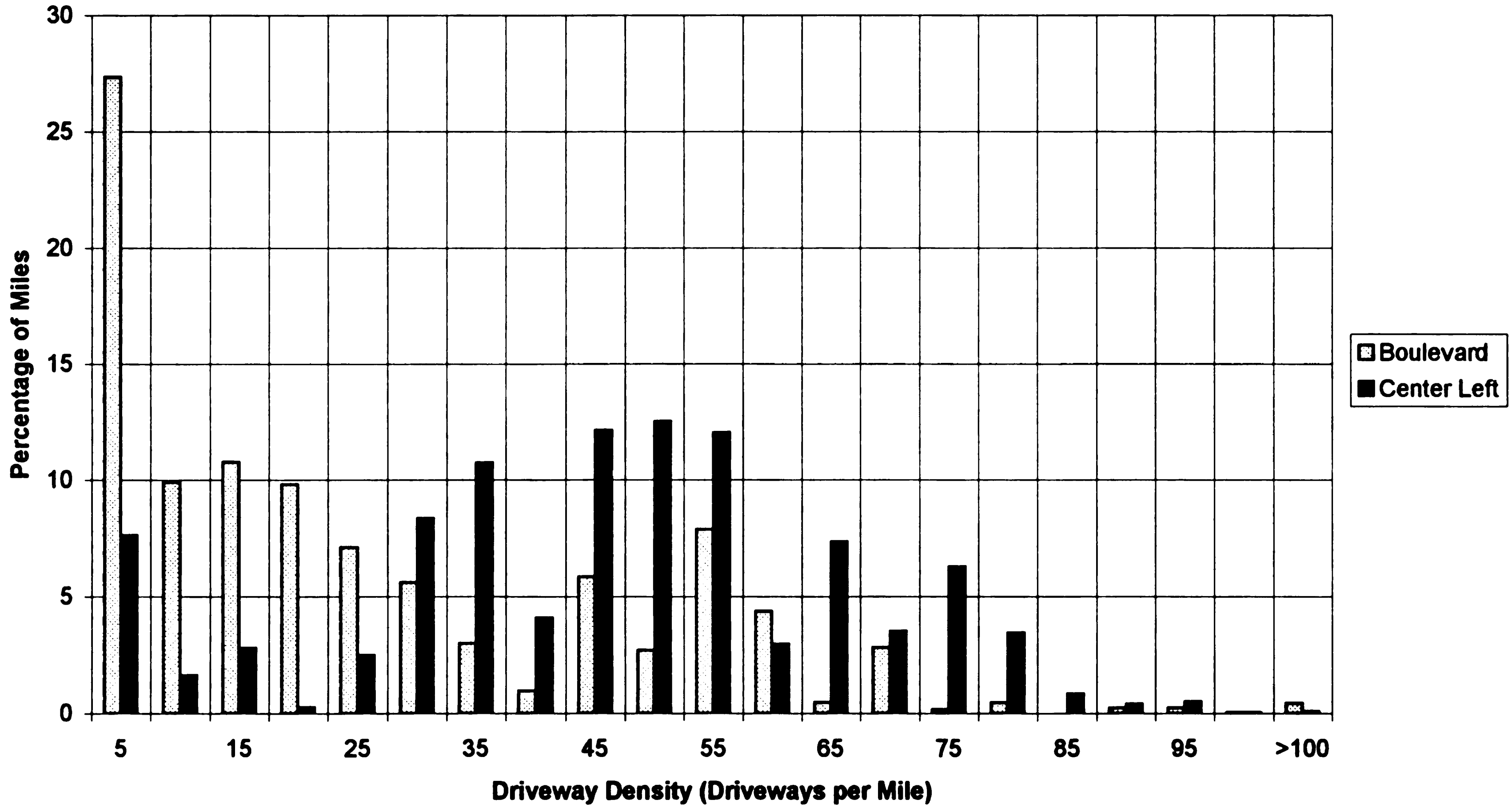


Figure 4.2.9 : Mile Percentage of Driveway Density, All Segment Lengths

The boulevard cross-section driveway concentration with the highest mileage percentage is five driveways per mile for 66 miles or 27 percent of the total mileage. The CCLTL driveway spacing has the highest concentration at 50 driveways per mile for 12 percent of the total mileage or 22 miles. It appears in general that the higher driveway concentration for the boulevard cross-section is in the 5 to 25 driveways per mile range and the CCLTL concentration is in the 30 to 80 driveways per mile range.

It was indicated in the literature search that the driveway access type could affect the accident rate. Figure 4.2.10 illustrates the distribution of segment mileage as a function of commercial driveway density for boulevard and CCLTL highway segments. The commercial driveway density is divided into 16 categories ranging from five driveways per mile to greater than seventy-five driveways per mile in increments of five driveways per mile. The largest portion of the boulevard mileage is concentrated in the five driveway per mile category. This would coincide with the boulevard speed distribution, which indicates that the boulevards are concentrated in the more rural areas. It could also be an indication that the number of commercial driveway access points on boulevard roadways are limited, with collector roads being utilized to supplement the access.The balance of the boulevard mileage is distributed fairly evenly between 10 commercial driveways per mile and 45 commercial driveways per mile, and between 50 commercial driveways per mile and over 75 commercial driveways per mile. The distribution of CCLTL mileage is concentrated between 5 commercial driveways per mile and 45 commercial driveways per mile, with the larger percentage between 35 and 45 commercial driveways per mile.

The boulevard cross-section, commercial driveway density with the highest percentage of mileage has five commercial driveways per mile, for 133 miles or 55 percent

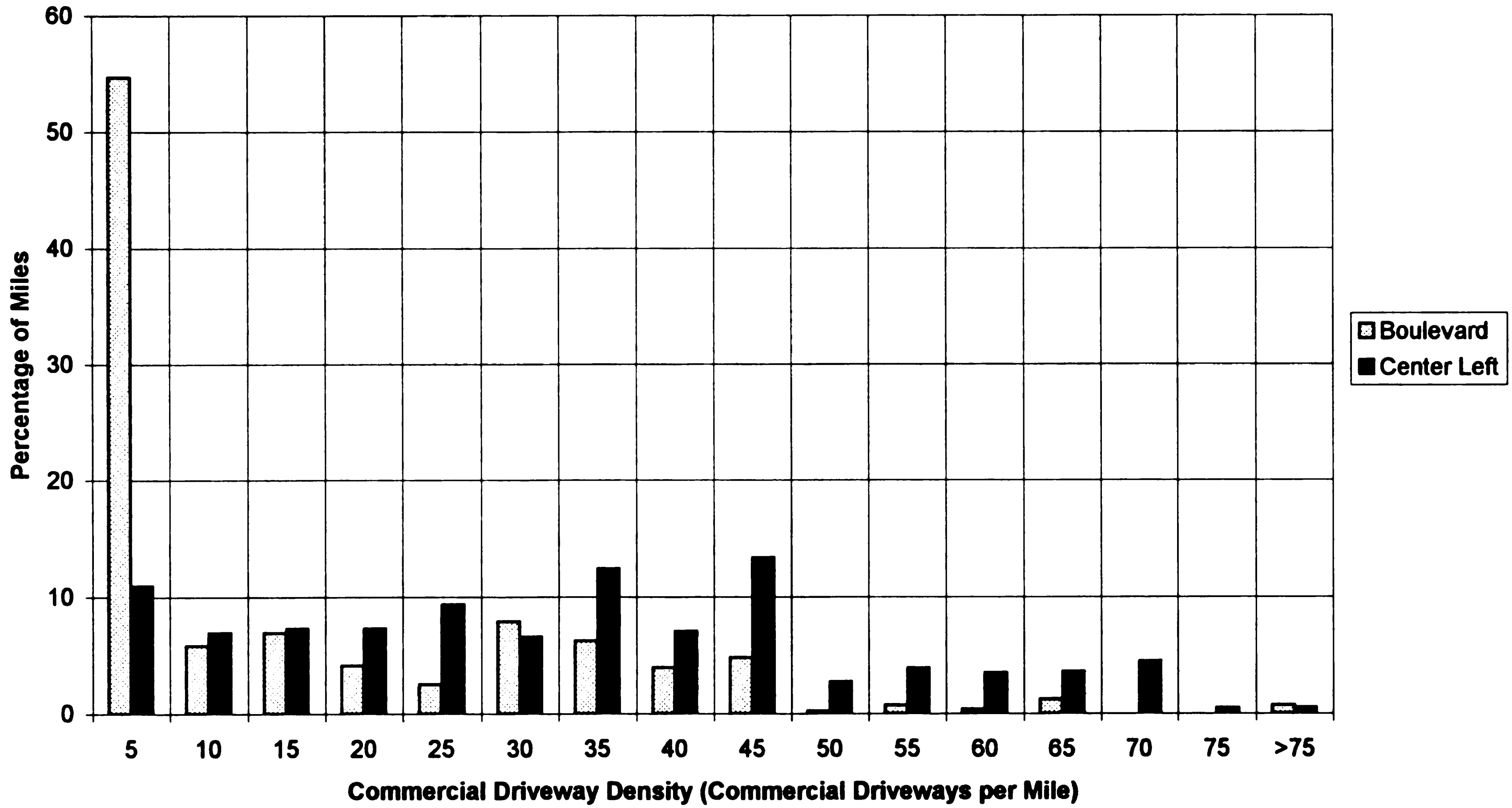


Figure 4.2.10 : Mile Percentage of Commercial Driveway Density, All Section Lengths

of the total mileage. The CCLTL section commercial driveway density with the highest percentage of mileage has 45 driveways per mile, for 23 miles or 13 percent of the total mileage. It appears that other than the concentration of the low density of commercial drives on boulevard cross-section roadways, there is no trend.

While information was not cited in the literature, it was decided to investigate the distribution of lane widths. Figure 4.2.11 illustrates the distribution of segment mileage as a function of lane width for boulevard and CCLTL highways. Four lane width categories ranging from nine feet to twelve feet in one foot increments, are provided in the bar chart. The largest percentage of mileage for both boulevard and CCLTL mileage is concentrated in the 12-foot lane category with CCLTL segments having a higher percentage of the mileage in this category. This coincides with the AASHTO guidelines which recommends that 12-foot lanes are desirable. The larger percentage of CCLTL mileage in this category could be attributed to the historically more recent nature of this construction type. This is also reflected in the next largest category which indicates that boulevards have a larger percentage of 11-foot lanes than the CCLTLs. The narrower widths could also be an indication of restricted right-of-way conditions.

Twelve-foot lanes are prevalent for both the boulevard and center left-turn lane cross-sections. The boulevard cross-section has 12-foot lanes on 153 miles or 63 percent of the total mileage. The CCLTL cross-section has 12-foot lanes on 134 or 77 percent of the total mileage.

There was an indication in investigations by other researchers that curbs could have an effect on accident rates. Figure 4.2.12 illustrates the distribution of segment mileage as a function of curbed and noncurbed roadway sections for boulevard and CCLTL highways.

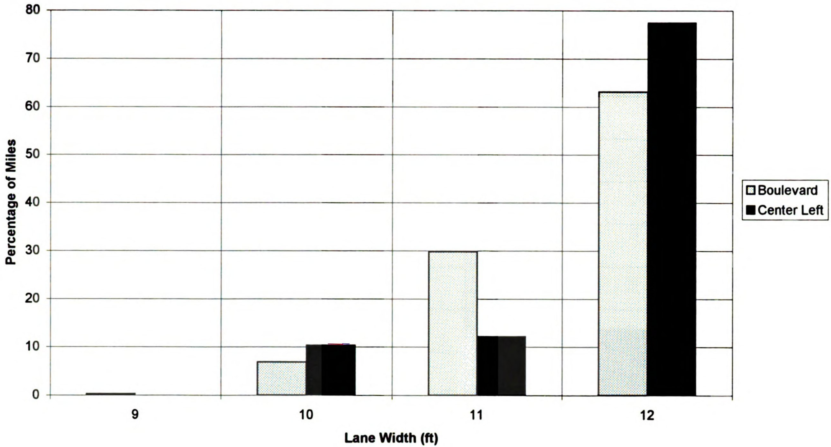


Figure 4.2.11 : Mile Percentage of Lane Width, All Section Lengths

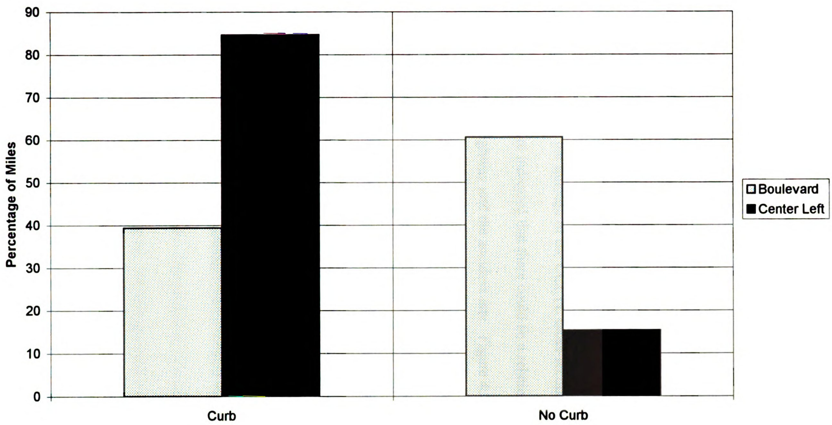


Figure 4.2.12 : Mile Percentage of Curb/No Curb, All Section Lengths

The curbed and noncurbed roadways are divided into these categories in Figure 4.2.12. The predominance of boulevard mileage is in the noncurbed roadway category as might be expected since the majority of the mileage is in rural areas. AASHTO guidelines recommend that no curb be placed adjacent to roadways where the posted speed limit is above 45 mph. The majority of the CCLTL mileage is in the curbed category, which is another indication of the primary location of these roadway types in an urban environment.

The majority of the mileage of the boulevard cross-section, 147 miles or 61 percent, is not curbed. The majority of the mileage of the CCLTL cross-section, 139 miles or 85 percent, is curbed. The literature indicated that there could be a relationship between the median width of a boulevard highway and the accident rate. Figure 4.2.13 illustrates the distribution of boulevard mileage as a function of median width for boulevard highway segments. There are values in the bar chart provided for three categories of median width: 0 to 30 feet, 30 to 60 feet, and greater than 60 feet. The highest percentage of mileage is in the 30 to 60 feet medians. The category of 30 to 60 feet, as found in the literature, is desirable for passenger vehicle operation. The 60-foot and greater category is desirable for truck operations.

The 30- to 60-foot median is the most common type of median with 135 miles or 56 percent of the roadway mileage in this category. The next most common median width is the greater than 60 feet with 98 miles or 40 percent. The least prevalent median width is less than 30 feet with only 4 percent in that category.

MDOT has been replacing bidirectional cross-overs with directional cross-overs. Figure 4.2.14 illustrates the distribution of cross-overs as a function of cross-over type for boulevard highway segments.

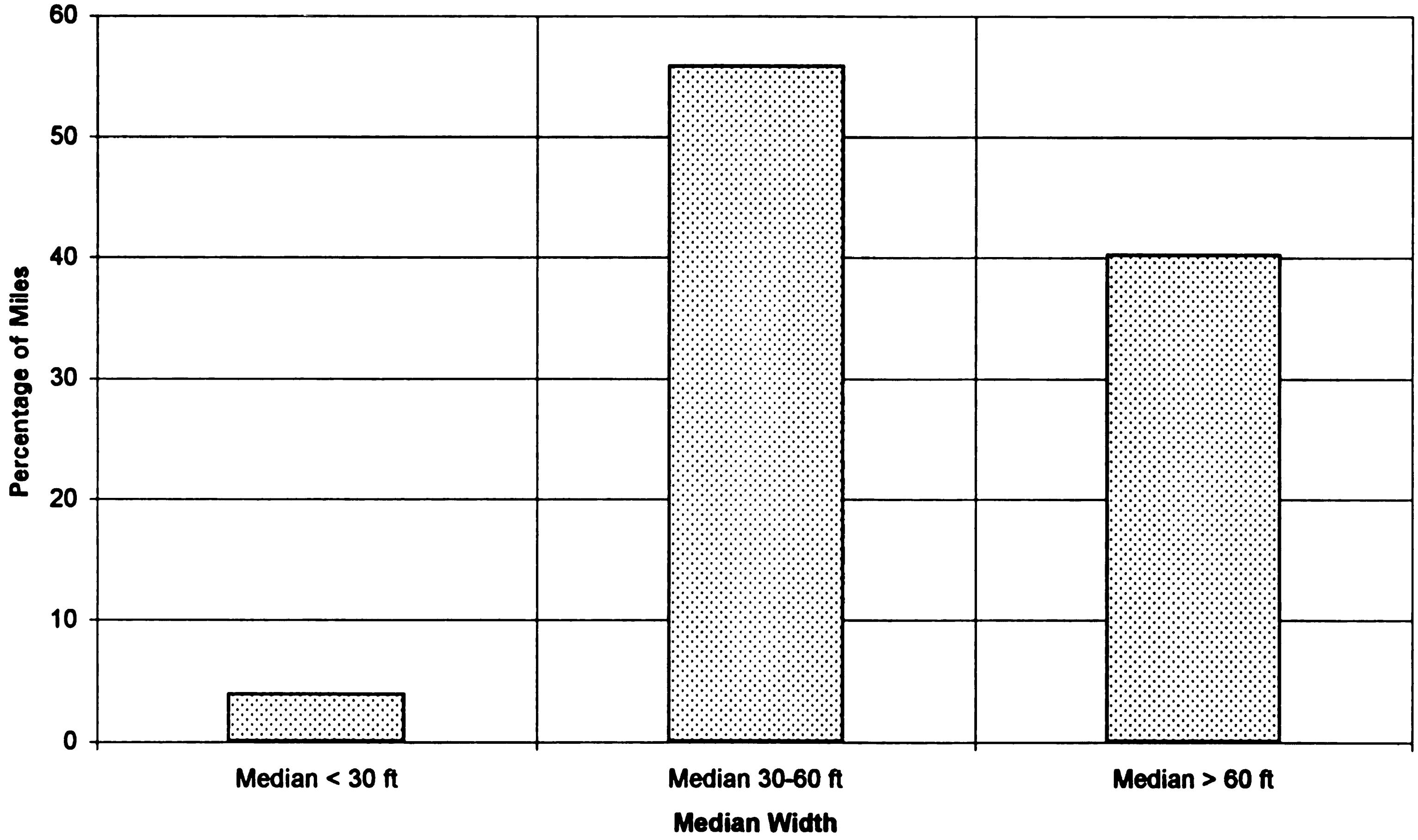


Figure 4.2.13 : Mile Percentage of Median Width, All BLVD Sections Lengths

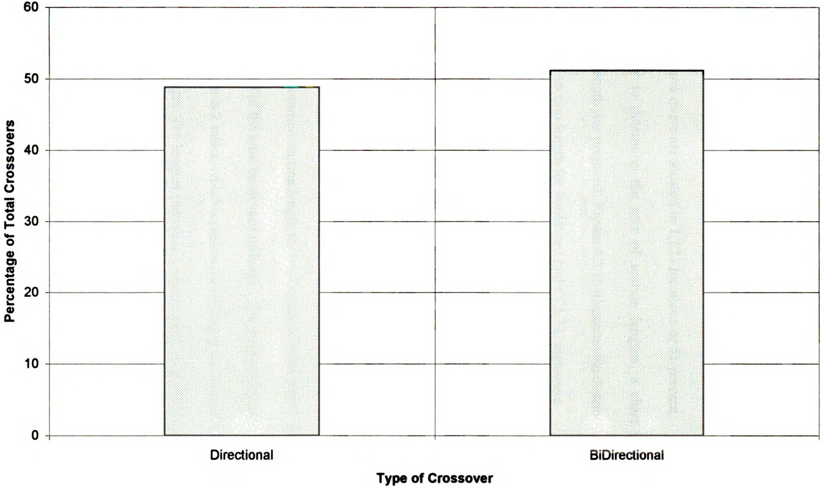


Figure 4.2.14 : Total Percentage of Crossover Type, All BLVD Section Lengths

The two cross-over types, directional and bidirectional, are graphically represented in Figure 4.2.14. The two types of cross-overs are fairly evenly distributed with approximately half of the cross-overs in each category.

Directional type cross-overs are located in 1,119 locations or 49 percent. Bidirectional cross-overs are located in 1,173 locations or 51 percent.

In order to determine the mix of section lengths, a chart indicating section distribution by length was prepared. Figure 4.2.15 illustrates the distribution of section miles as a function of section length for boulevard and CCLTL highways.

The highway segments are divided into 13 categories of section length in increments ranging from one to thirteen miles, in increments of one mile. The majority of both boulevard and CCLTL sections are one to four mile lengths, with the balance of the miles distributed between four-mile and nine-mile length categories. A larger percentage of the CCLTL sections than the boulevard sections are in the shorter categories of one and two mile lengths.

The most common section length for boulevards is three miles, which represents 54 miles or 22 percent of the total boulevard mileage. The most common center left-turn lane cross-section length is 2 miles, which represents 43 miles or 25 percent of the total mileage for that roadway type. The longest section is a boulevard cross-section roadway which is 13 miles long. The longest center left-turn lane cross-section roadway is eight miles long. The disproportionate length of these roadways compared to the preponderance of roadways with short sections has caused problems with the confidence intervals computed for accident rate vs. roadway type. It was therefore decided to reduce the segments longer than 0.25 mile to multiple segments of 0.25 mile for the remainder of the investigation.

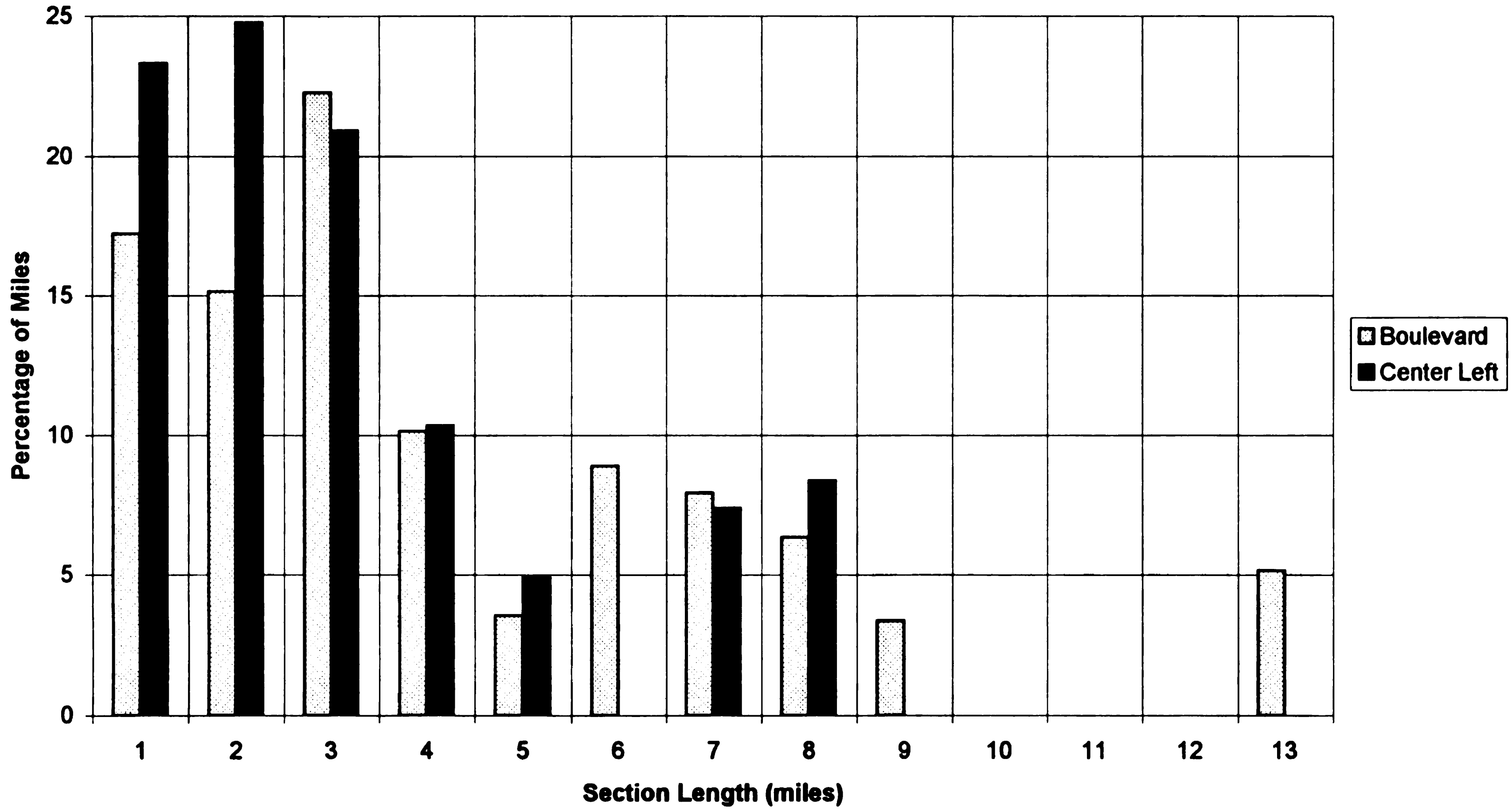


Figure 4.2.15 : Mile Percentage of Section Length, All Section Lengths

SUMMARY OF DATA INSPECTION

An inspection of the data indicates that it is not normally distributed for any of the data sets reviewed. Some of the data sets appear to have a Poisson distribution.

The rear-end, angle-straight, angle-turn, head-on-left turn, and driveway related accidents are the most prevalent types of accidents detected. Accident severity does not appear to be a factor when comparing boulevard with CCLTL roadways.

The traffic volume, intersection density, and population for boulevard and CCLTL roadways have similar distributions. The boulevards are prevalent in lower and higher values for these three categories and the CCLTL roadway are more prevalent in the middle ranges. The distributions of the speed limits followed the same pattern except boulevard and CCLTL are similarly distributed for low speed limits. Signal and driveway density distributions exhibit the same patterns except boulevards and CCLTLs are similarly distributed for high signal densities.

Commercial driveway density is distributed similarly for boulevards and CCLTLs for the lower and middle ranges but the CCLTLs are more prevalent in the higher driveway density ranges. There is a higher percentage of CCLTL roadways with curbed segments. These distributions are indicative of where these roadway types are located. The boulevard roadways are traditionally utilized in high density and rural areas. The CCLTLs are found in the medium to higher density areas.

The balance of the distribution comparisons do not indicate any similarity between boulevards and CCLTL roadways.

4.3 DISCRIMINATE ANALYSIS

Discriminate analysis is a procedure that is utilized to identify the variables that are most important for distinguishing among groups and can be used to develop a procedure to predict group membership for new cases. This analysis was used to determine which independent variables may explain the variance in accident rates for boulevard and CCLTL roadways for all accidents, rear-end accidents, and drive-related accidents. Certain criteria should be met when using this procedure; i.e., each group should be from a multivariant normal population, and the population covariance matrixes should all be equal. While all of the conditions are not necessarily met for this procedure, it was determined to be the most appropriate technique to identify the variables worthy of further analysis to determine their role in explaining the variance in the accident rates.

The discriminate analysis was progressively applied through a branching procedure. The data set was progressively divided into two data sets which produced the most significant difference in accident rates. The dichotomous split of the remaining data set continued until a sample size of 30 value or greater was no longer available or until no significant difference (with an $\alpha = 0.05$) was found between the two cells. The Student's *t*-test was utilized to determine the split between the values of the dependent variable that provided the most significant difference between the mean accident rates.

The variables selected to help explain the variance in the accident rates selected were:

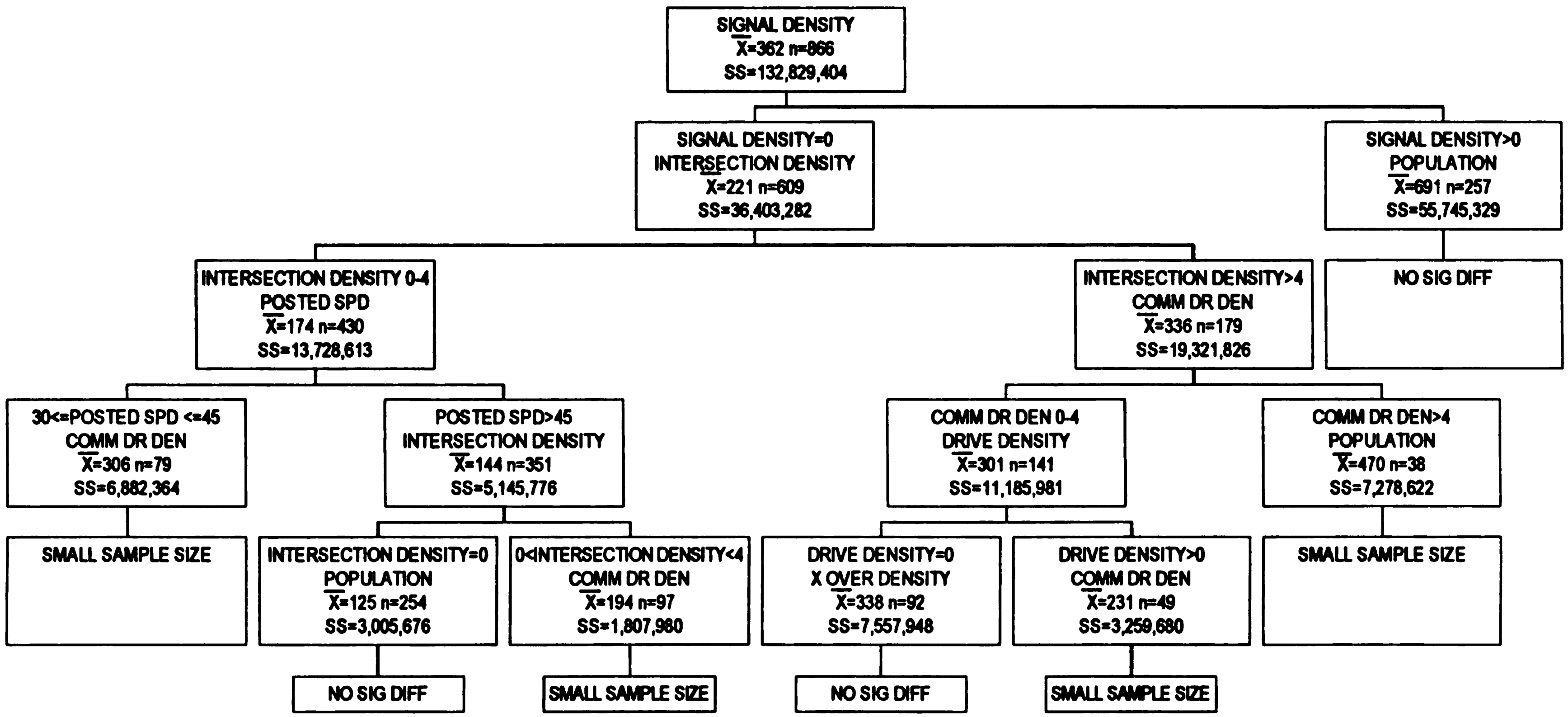
1. Average Daily Traffic
2. Commercial Drive Density
3. Curb/Shoulder
4. Driveway Density

5. Intersection Density
6. Lane Width
7. Number of Lanes
8. Percent Commercial
9. Population
10. Signal Density
11. Posted Speed
12. Median Width (Boulevard Roadway only)

4.3.1 BOULEVARD ROADWAY ALL ACCIDENTS

The discriminate analysis procedure was applied through a branching procedure to the overall boulevard roadway accident rate. The results of the discriminate analysis are displayed graphically in Figure 4.3.1. Signal density was identified as the dependent variable that explained the greatest difference in overall accident rates. The accident rates for the segment groupings were tested utilizing the *t*-test to determine which signal category would produce the most significant difference in accident rates between the groupings. This resulted in subdividing the segments into those that had no signals and those that did have signals. The mean accident rate for those segments without signals is 221 accidents per million vehicle miles (A/MVM) compared to an accident rate of 691 A/MVM for signalized segments. These rates are significantly different at the 0.95 significance level and resulted in a variance reduction of 31 percent.

The segments without signals were analyzed for the variable that would explain the most significant difference in accident rate in these segments. It was found that intersection



TSS 132,829,404
SS 85,537,599
$R^2 = 0.36$

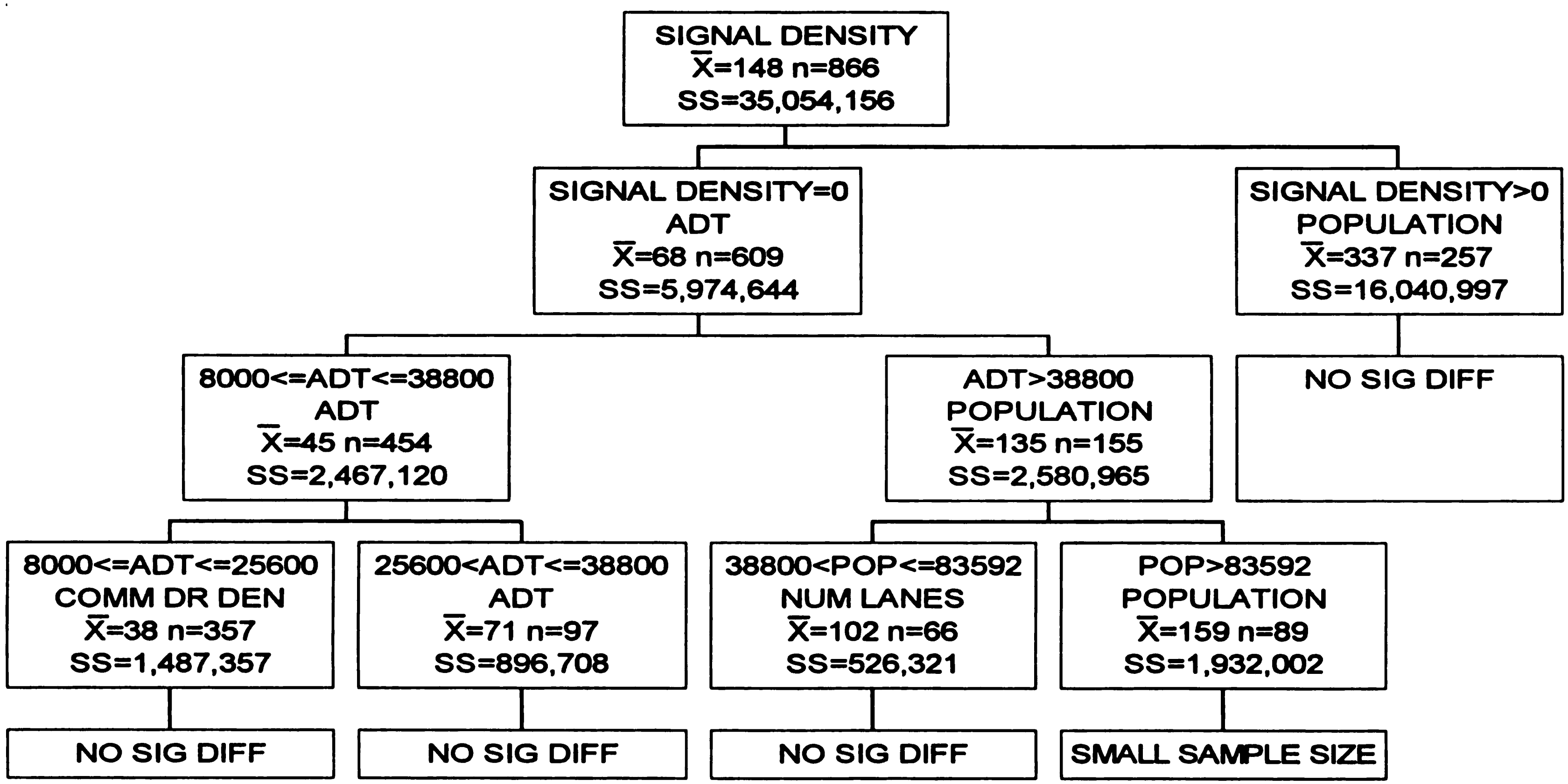
Figure 4.3.1 Discriminate Analysis Results for All Boulevard Roadway Accidents density best explains the difference between those segments with 0 to 4 intersections per mile, having an accident rate of 174 A/MVM, and those segments with an intersection density greater than 4 intersections per mile, having an accident rate of 336 A/MVM. This grouping explained an additional 9 percent of the sample variance.

The segments with signal density greater than zero were analyzed and population was identified as the variable which explains the most significant difference in accident rates. Further population analysis did not indicate a significant difference in the sample groupings for the various populations. Thus, the cells were not split further.

The discriminate analysis procedure was continued until the sample size was smaller than 30 values or there was no significant difference. This branching procedure resulted in an $R^2 = 0.36$. The signal density, with an R^2 of 0.31, explains 86 percent of the difference with all of the other variables shown in the chart explaining 14 percent of the remaining explainable difference. It would therefore appear that significant differences in boulevard accident rates are primarily signal related.

4.3.2 BOULEVARD ROADWAY REAR-END ACCIDENTS

The discriminate analysis procedure was also applied through a branching procedure to the boulevard roadway rear-end accident rate. The results of the discriminate analysis are displayed in Figure 4.3.2. The variable that explained the greatest difference in overall accident rate was signal density. The accident rates for the segment groupings were tested utilizing the *t*-test to determine which signal category splits would produce the most significantly different accident rates between groupings. This resulted in subdividing the segments into those that had no signals and those that did have signals. The mean accident



TSS 35,054,156
SS 20,883,385
$R^2 = 0.40$

Figure 4.3.2 Discriminate Analysis Results for Rear-End Boulevard Roadway Accidents rate for those segments without signals is 68 rear-end A/MVM compared to a mean accident rate of 337 rear-end A/MVM for signalized segments. These rates are significantly different at the 0.95 significance level and resulted in a variance reduction of 37 percent.

The segments without signals were analyzed for the variable that would explain the most significant difference in accident rate in those segments. It was found that ADT best explains the difference with an ADT less than or equal to 38,800 having a mean accident rate of 45 A/MVM and those segments with an ADT greater than 38,800 ADT having a mean accident rate of 135 A/MVM. This grouping explained an additional 16 percent of the sample variance.

The segments with signal density greater than zero were analyzed and population was identified as the variable which explains the most significant difference in the mean accident rates. Further population analysis indicated that there is no significant difference in the sample groupings for the various populations. Thus, the cells were not split further.

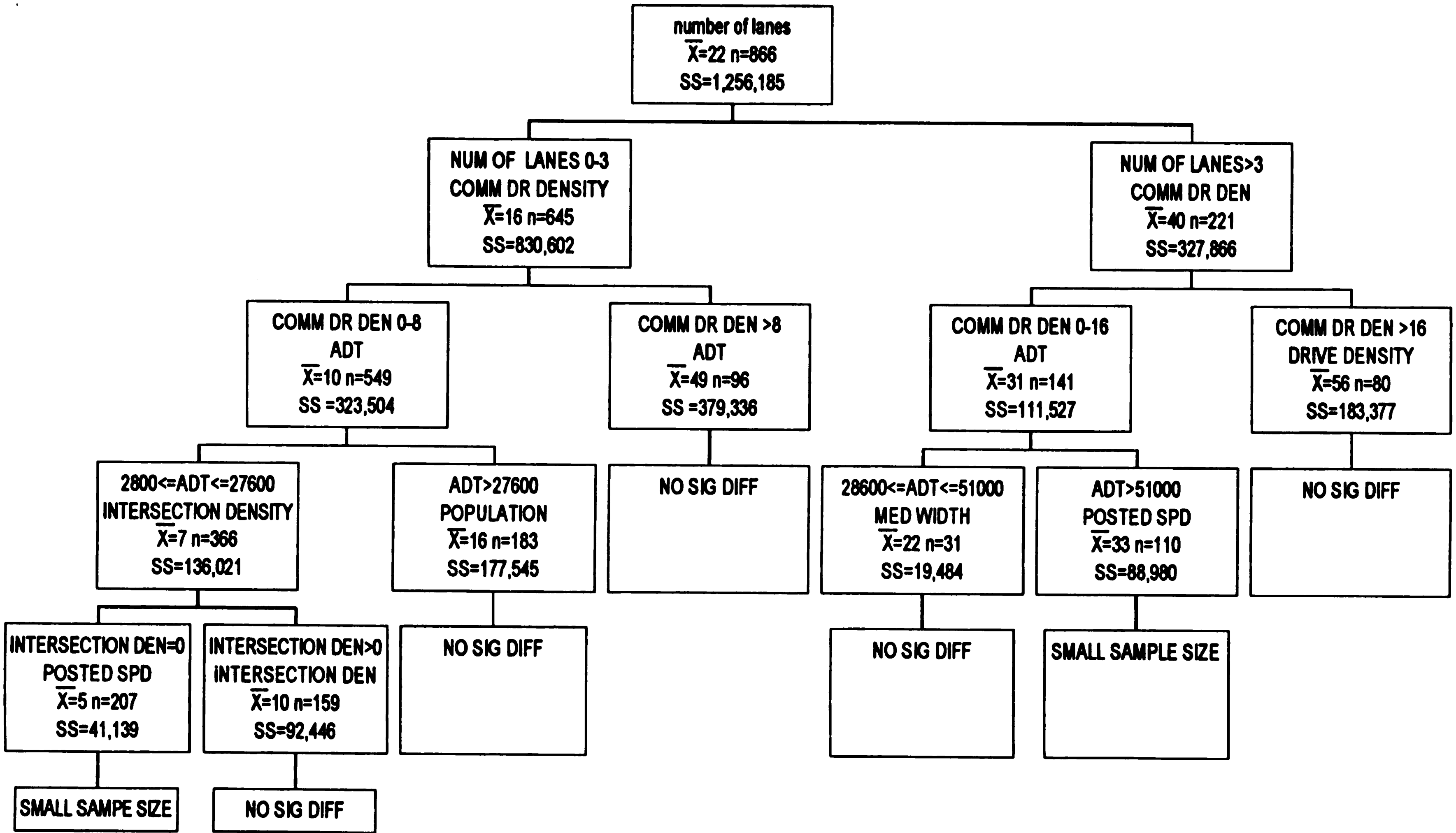
The discriminate analysis procedure was continued until the sample size was smaller than 30 values or there was no significant difference, resulting in an overall $R^2 = 0.40$. The signal density with an R^2 of 0.37 explains 92 percent of the difference with all of the other variables shown in the chart explaining 8 percent of the remaining explainable difference. It would, therefore, appear that the most significant differences in boulevard rear-end accident rates are primarily signal-related.

4.3.3 BOULEVARD ROADWAY DRIVE-RELATED ACCIDENTS

The discriminate analysis procedure was also applied through a branching procedure to the boulevard roadway drive-related accident rates. The results of the discriminate analysis are displayed graphically in Figure 4.3.3. The variable identified that explained the greatest difference in drive-related accident rates was the number of lanes. The accident rates for the segment groupings were tested utilizing the *t*-test to determine which number of lane category groupings would produce the most significant differences. This resulted in subdividing the segments into those that had up to six lanes (three lanes in each direction) and those that had greater than six lanes. The mean accident rate for those segments with up to six lanes is 16 A/MVM compared to a mean accident rate of 40 A/MVM for segments with greater than six lanes. These rates are significantly different at the 0.95 significance level and resulted, however, in a variance reduction of only 8 percent.

The segments with up to six lanes were analyzed for the variable that would explain the most significant difference in accident rate in these segments. It was found that commercial driveway density best explains the differences. Those segments with a commercial driveway density from 0 to 8 commercial driveways per mile have a mean accident rate of 10 A/MVM and those segments with commercial driveway density greater than eight commercial driveways per mile have a mean accident rate of 49 A/MVM. This grouping provided the greatest difference in mean accident rates and explained an additional 15 percent of the sample variance.

The segments with number of lanes greater than three were analyzed and commercial driveway density was again identified as the variable which explains the most significant difference in accident rate. It was found that segments with commercial driveway density from 0 to 16 commercial driveways per mile having a mean accident rate of 31 A/MVM and those segments with commercial driveway density greater than 16 commercial driveways per mile having a mean accident rate of 56 A/MVM. This grouping provided the greatest



TSS 1,256,185
SS 982,307
R^2 = 0.22

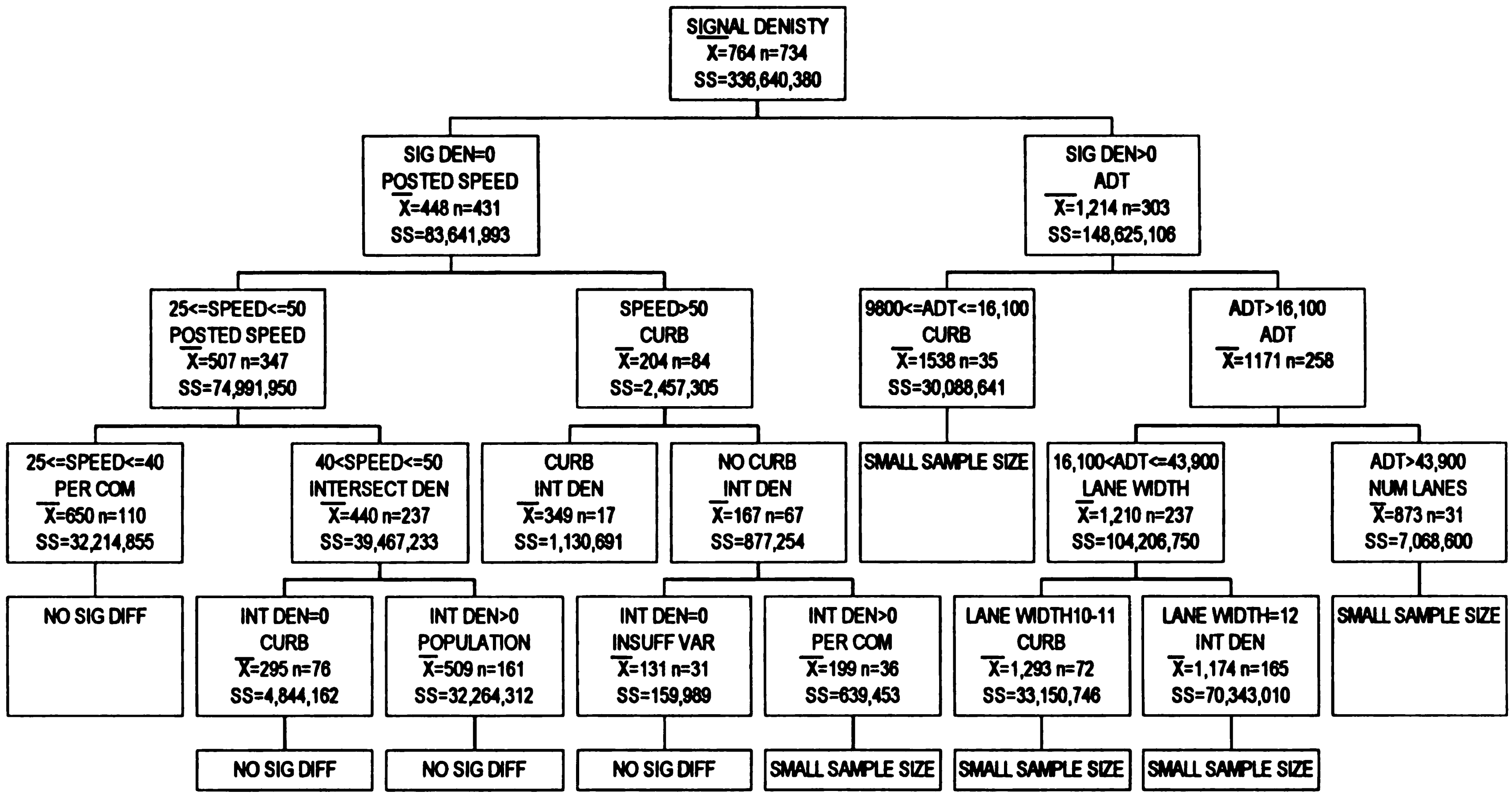
Figure 4.3.3 Discriminate Analysis Results for Drive-Related Boulevard Roadway Accidents difference in mean accident rate and explained an additional 10 percent of the sample variance.

The discriminate analysis procedure was continued until the sample size was smaller than 30 values or there was no significant difference. This resulted in an $R^2 = 0.22$. The number of lanes, with an $R^2 = 0.08$, explained only 36 percent of the difference. It appears that there is no significant factor that is responsible for differences in boulevard drive-related accident rates.

4.3.4 CCLTL ROADWAY ALL ACCIDENTS

The discriminate analysis procedure was also applied through a branching procedure to the overall CCLTL roadway accident rate. The results of the discriminate analysis are displayed graphicaly in Figure 4.3.4. The variable identified that explained the greatest difference in overall accident rates is signal density. The accident rates for the segment groupings were tested utilizing the *t*-test to determine which signal category would produce the most significant accident rate differences between groupings. This resulted in subdividing the segments into those that had no signals and those that did have signals. The mean accident rate for those segments without signals is 448 A/MVM compared to a mean accident rate of 1,214 A/MVM for signalized segments. These rates are significantly different at the 0.95 significance level and resulted in a variance reduction of 31 percent.

The segments without signals were analyzed for the variable that would explain the most significant difference in accident rates in these segments. It was found that posted speed limit best explains the difference, with those segments with posted speeds of 25 to 50 mph having a mean accident rate of 507 A/MVM and those segments with posted speeds



TSS 336,640,380
SS 211,904,459
$R^2 = 0.37$

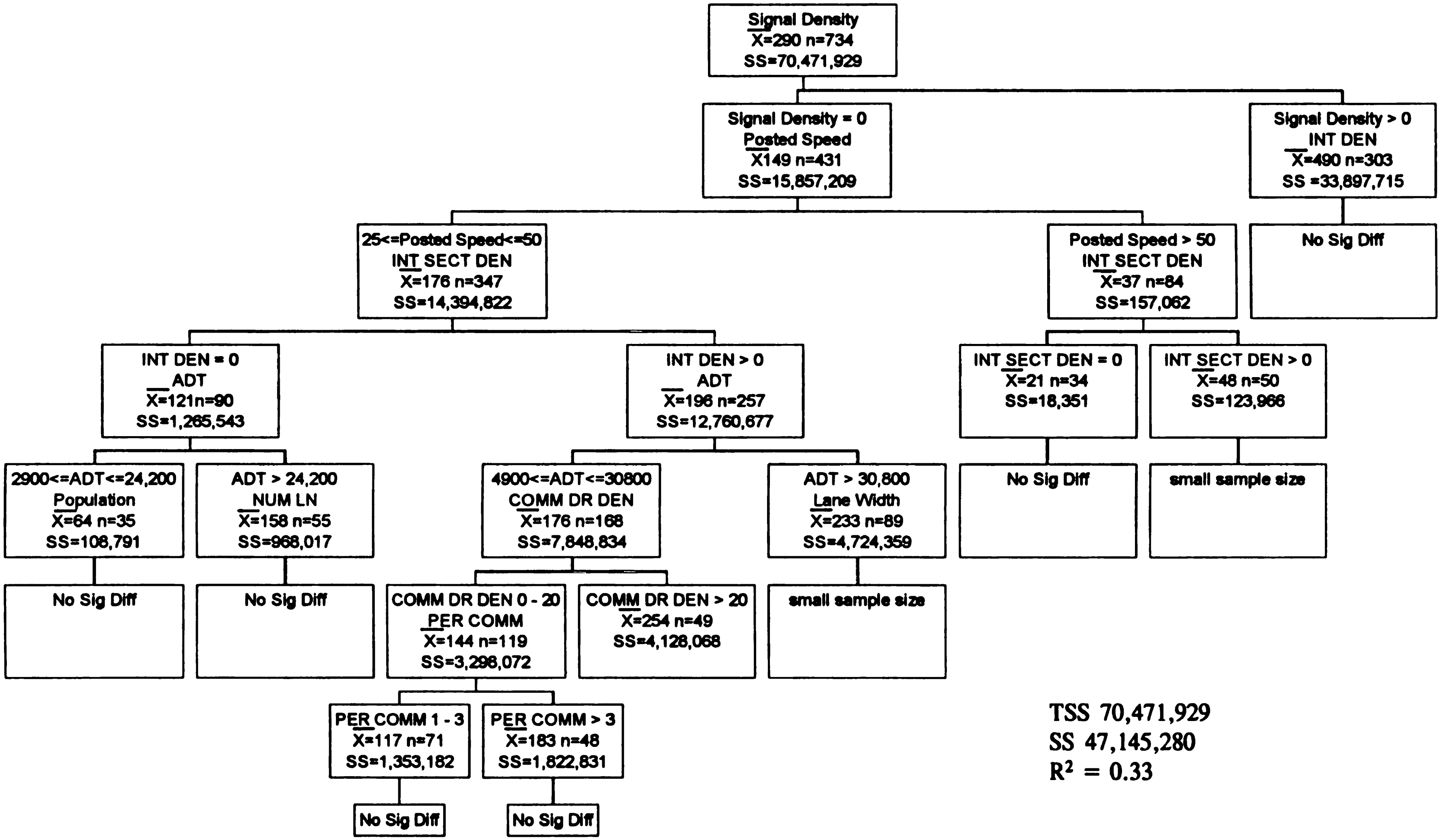
Figure 4.3.4 Discriminate Analysis Results for All Continuous Center Left-Turn Roadway Accidents greater that 50 mph having a mean accident rate of 204 A/MVM. This grouping provided the most significant difference in accident rates and explained an additional 7 percent of the sample variance.

The segments without signals were analyzed for the variable that would explain the most significant difference in accident rates in these segments. It was found that ADT best explains the difference with those segments with ADT from 9,800 to 16,100 having a mean accident rate of 1,538 A/MVM and those segments with greater than 16,100 having a mean accident rate of 1,171 A/MVM. This grouping providing the most significant difference in accident rates and explained an additional 7 percent of the sample variance.

The discriminate analysis procedure was continued until the sample size was smaller than 30 values or there was no significant difference. This resulted in an $R^2 = 0.37$. The signal density with an R^2 of 0.31, explains 84 percent of the explainable difference, with all of the other variables shown in the chart explaining 16 percent of the remaining explainable difference. It would, therefore, appear that the most significant differences in boulevard accident rates are also primarily signal-related.

4.3.5 CCLTL ROADWAY REAR-END ACCIDENTS

The discriminate analysis procedure was also applied through a branching procedure to the CCLTL roadway rear-end accident rate. Please refer to Figure 4.3.5. The variable identified that explained the most significant differences in rear-end accident rates was signal density. The accident rates for the segment groupings were tested utilizing the *t*-test to determine which signal category would produce the most significant difference between groupings. This resulted in subdividing the segments into those that had no signals and those



TSS 70,471,929
SS 47,145,280
$R^2 = 0.33$

Figure 4.3.5 Continuous Center Left-Turn Lane Roadway Rear-End Accidents that did have signals. The mean accident rate for those segments without signals is 149 A/MVM compared to a mean accident rate of 490 A/MVM for signalized segments. These rates are significantly different at the 0.95 significance level and resulted in a variance reduction of 29 percent.

The segments without signals were analyzed for the variable that would explain the most significant difference in accident rates in these segments. It was found that posted speed limits best explains the difference with those segments with posted speeds from 25 to 50 mph having a mean accident rate of 176 A/MVM and those segments with posted speeds greater than 50 mph having a mean accident rate of 37 A/MVM. This grouping provided the most significant difference and explained an additional 8 percent of the sample variance.

The segments with signal density greater than zero were analyzed and intersection density was identified as the variable which explains the most significant differences in accident rates. Further analysis of intersection density did not indicate that there is a significant difference in the sample groupings for the various intersection densities. Thus, the cells were not split further.

The discriminate analysis procedure was continued until the sample size was too small or there was no significant difference. This resulted in an $R^2 = 0.33$. The signal density, with an R^2 of 0.29, explains 88 percent of the difference with all of the other variables shown in the chart explaining 12 percent of the remaining explainable difference. It would, therefore, appear that the most significant differences in CCLTL rear-end accident rates are primarily signal-related.

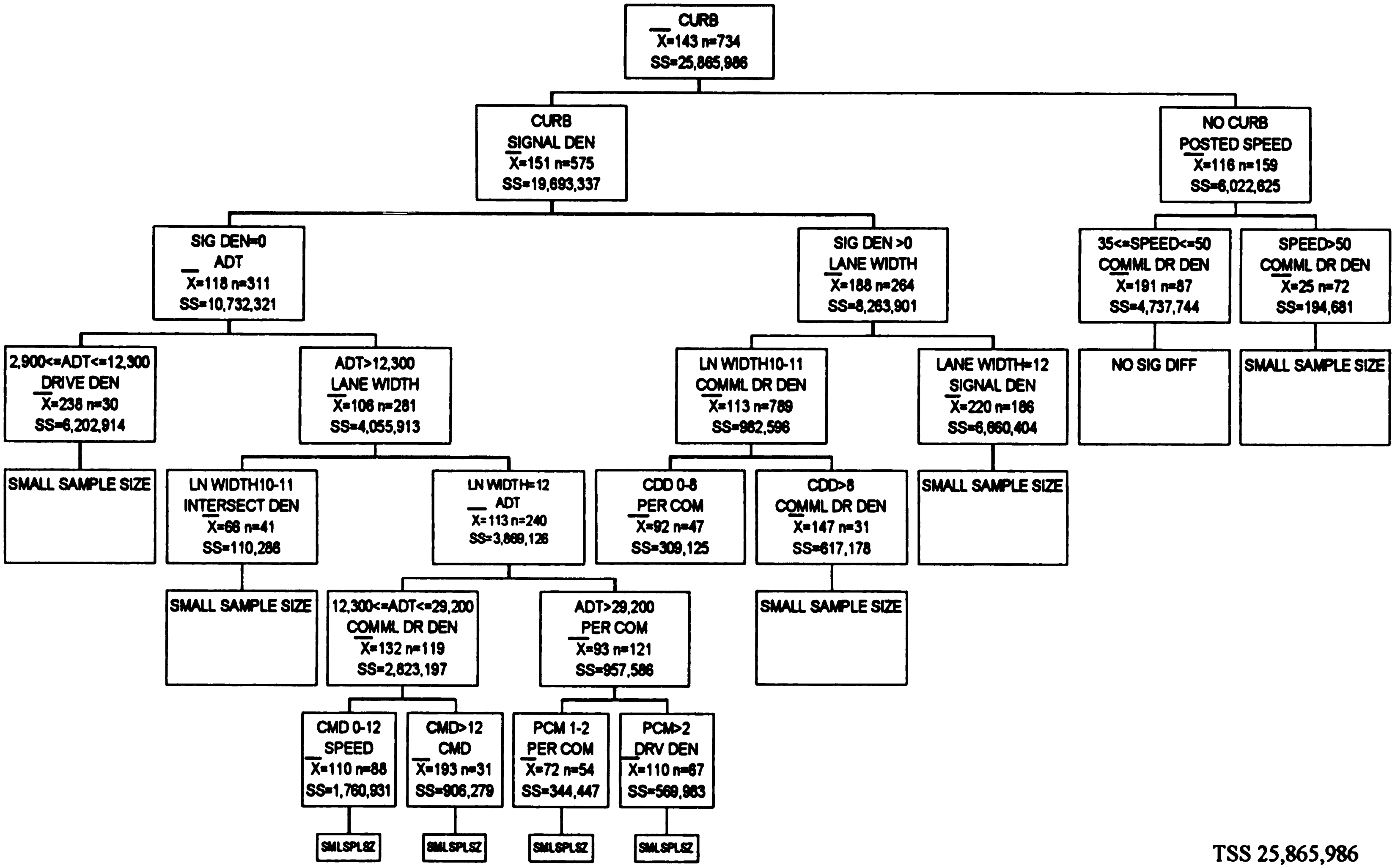
4.3.6 CCLTL ROADWAY DRIVE-RELATED ACCIDENTS

The discriminate analysis procedure was applied through a branching procedure to the CCLTL roadway drive-related accident rate. The results of the discriminate analysis are displayed graphically in Figure 4.3.6. The most important variable identified that explained the differences in drive-related accident rates was the presence or absence of curbs. The accident rates for those segments with curbs have a mean of 151 A/MVM compared to a mean accident rate of 116 A/MVM for uncurbed segments. These rates are significantly different at the 0.95 significance level and resulted in a variance reduction of only 0.6 percent.

The segments with curbs were analyzed for the variable that would best explain the differences in accident rates in these segments. It was found that signal density best explains the difference with those segments with signal densities equal to 0 signals per mile having a mean accident rate of 118 A/MVM and those segments with signal density greater than 0 signals per mile having a mean accident rate of 188 A/MVM. This grouping providing the most significant difference in accident rates and explained an additional 4 percent of the sample variance.

The segments without curbs were analyzed for the variable that would explain the most significant difference in accident rates in these segments. It was found that posted speed best explains the difference with those segments with posted speed from 35 to 50 mph having a mean accident rate of 191 A/MVM and those segments with a posted speed greater than 50 mph having a mean accident rate of 25 A/MVM. This grouping provided the greatest differneces and explained an additional 2 percent of the sample variance.

The discriminate analysis procedure was continued until the sample size was smaller than 30 values or there was no significant difference. This resulted in an $R^2 = 0.13$. The



TSS 25,865,986
SS 22,413,972
$R^2 = 0.13$

Figure 4.3.6 Discriminate Analysis Results for Drive Related Continuous Center Left-Turn Roadway Accidents curb/no curb with an R^2 of 0.01 explains 5 percent of the difference with all of the other variables shown in the chart explaining 95 percent of the remaining explainable difference. It appears that there is a weak relationship between the dependent variables and the CCLTL drive-related mean accident rate.

4.3.7 DISCRIMINATE ANALYSIS SUMMARY

The discriminate analysis process was utilized to investigate the factors that account for the differences in accident rates for all, rear-end and drive-related accidents for both boulevard and CCLT roadways. The main discriminating factor for all and rear-end accidents is the presence of signals for both boulevard and CCLTL roadways. Signalization explains from a low of 84 percent of the explainable difference for all types of accidents for CCLTL to a high of 92 percent of the explainable difference for rear-end accidents of boulevard roadways.

4.4 ACCIDENT ANALYSIS

The accident statistics were examined for the boulevard and center left-turn cross-sections for various conditions and the means between similar groups were compared utilizing the Student's *t*-test with an $\alpha = 0.05$. The results of the statistical analyses are summarized in Tables 4.4.1.1 to 4.4.4.1. These results are also graphically illustrated through the use of bar charts in Figures C.1 through C.27 which are located in Appendix C. The statistical analysis for significance of difference between the means is summarized in Tables D.1 through D.5 which are located in Appendix D. The results are summarized as follows:

4.4.1 BOULEVARDS AND CONTINUOUS CENTER LEFT-TURN LANES ACCIDENT ANALYSIS (Table 4.4.1, Appendix C, Figures C.1-C.3, Appendix D, Table D.1 - D.5)

4.4.1.1 TESTING OF FIRST HYPOTHESIS

The first hypotheses was stated as follows:

"It may, therefore, be postulated that the accident rate for a roadway with a boulevard is different than an accident rate for a roadway with a CCLTL."

To test this hypotheses, the accident rates for CCLTL and boulevard highways were compared.

4.4.1.2 SELECTION OF RANGE OF INVESTIGATION

Table 4.4.1.1 (Boulevard and CCLTL Accident Rates Per 100 Million Vehicle Miles) tabulates the accident statistics for seven accident categories for boulevard and CCLTL highway segments. These statistics are tabulated for all segments, segments without stop-and-go signals, and segments with stop-and-go signals. Appendix C illustrates graphically the mean accident rates for the seven categories of accident types. The statistical significance of the difference between the mean accident rates are summarized in Tables 1 and 2 in Appendix D.

ACCIDENTS PER 100 MILLION VEHICLE MILES

	ALL		REAR END		ANGLE STRAIGHT		ANGLE TURN		HEAD ON LEFT TURN		DRIVEWAY		OTHER TYPES	
	BLVD	CLTL	BLVD	CLTL	BLVD	CLTL	BLVD	CLTL	BLVD	CLTL	BLVD	CLTL	BLVD	CLTL
ALL SEGMENTS														
Mean	362	764	148	290	47	62	21	50	16	63	21	144	109	156
Standard Error	13	25	7	11	3	3	1	2	2	4	1	7	3	5
Standard Deviation	392	678	201	310	82	94	31	61	61	104	38	188	95	141
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	2718	4940	1468	2515	628	718	241	674	1359	966	395	2192	845	1240
Sum	313717	561063	127874	212899	40443	45804	17870	36470	14077	46411	19007	105341	94446	114139
Count	866	734	866	734	866	734	866	734	866	734	866	734	866	734
UNSIGNALIZED SEGMENTS														
Mean	221	448	68	149	25	25	11	34	10	19	13	106	94	115
Standard Error	10	21	4	9	2	2	1	3	3	2	1	8	3	5
Standard Deviation	245	441	99	192	60	51	21	57	65	40	27	175	84	112
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	2718	3661	756	1454	515	434	183	674	1359	338	264	2192	614	1108
Sum	134871	193181	41382	64301	15428	10885	6549	14539	6222	8136	8012	45605	57278	49716
Count	609	431	609	431	609	431	609	431	609	431	609	431	609	431
SIGNALIZED SEGMENTS														
Mean	696	1214	337	490	97	115	44	72	31	126	43	197	145	213
Standard Error	29	40	16	19	6	7	2	4	3	8	3	11	7	9
Standard Deviation	467	702	250	335	101	115	37	61	48	131	50	192	110	158
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	2599	4940	1468	2515	628	718	241	450	277	966	395	994	845	1240
Sum	178846	367883	86492	148598	25015	34919	11321	21930	7855	38275	10995	59737	37167	64423
Count	257	303	257	303	257	303	257	303	257	303	257	303	257	303

TABLE 4.4.1.1 BOULEVARD AND CENTER LEFT TURN LANE ACCIDENT RATES

4.4.1.3 INVESTIGATION OF ALL SEGMENTS (Appendix C, Figure C.1, Appendix D, Table D.1)

CCLTL highways had a higher overall mean accident rate for all accident categories than boulevard highways. The difference between the means expressed as a percentage of the larger mean accident rate and the significance of the difference as determined by the Student's *t*-test was as follows:

Accident Type	Percent Difference	*t*-test
All	53	Significant
Rear-End	49	Significant
Angle-Straight	24	Significant
Angle-Turn	58	Significant
Head-On Left	75	Significant
Driveway-Related	85	Significant
Other	30	Significant

The intersection-related accident types of rear-end, angle-straight, angle-turn, and head-on left-turn are reduced by directing turning movements through cross-overs on boulevard-type highways. The driveway-related mean accident rate is significantly lower for boulevard highways when compared to CCLTL highways. There are more CCLTL highway segments with higher driveway densities which helps to account for the difference.

There is no reason to believe that the mean accident rate for boulevard highways is the same as for CCLTL highways. Boulevard highways have a lower mean accident rate for all the accident types investigated.

4.4.1.4 INVESTIGATION OF UNSIGNALIZED SEGMENTS (Appendix C, Chart C.2, Appendix D, Table D.2)

The CCLTL highways had a higher mean accident rate than boulevard highways for all seven categories of accident types for unsignalized segments. The difference between the mean accident rate expressed as a percentage of the larger mean accident rate and the significance of the difference as determined by the Student's *t*-test was as follows:

Accident Type	Percent Difference	*t*-test
All	51	Significant
Rear-End	54	Significant
Angle-Turn	68	Significant
Head-On Left	47	Significant
Driveway-Related	87	Significant
Other	18	Significant

The only category that was not significant was the angle-straight accident type which is an intersection-related accident where through and crossing traffic movement conflict. Apparently, this type of accident is unaffected by the roadway type, as only the left-turning movements are removed from through intersections on a boulevard highway. The crossing traffic conflict remains the same for both roadway types.

Rear-end, angle-turn, and head-on left-turn are intersection-related. The removal of the left-turns from the major boulevard intersections can be presumed to account for the difference in the mean accident rate along with the continuous friction that exists at the interface of the CCLTL and through traffic. The left turns from the CCLTLs provide a continuous opportunity for turning movement-related accidents to occur.

The driveway-related mean accident rate is inordinately higher for the CCLTL highway segments and could be partially attributed to the higher density of driveways on CCLTL highways, but also may be attributed to the movement from the CCLTL into driveways across opposing lanes of traffic.

4.4.1.5 INVESTIGATION OF SIGNALIZED SEGMENTS (Appendix C, Table C.3, Appendix D, Table D.3)

The CCLTL highways had a higher mean accident rate than boulevard highways for all seven categories of accident types for signalized highway segments. The difference between the means expressed as percentages of the larger mean accident rates and the significance of the differences as determined by the Student's *t*-test are as follows:

Accident Type	Percent Difference	*t*-test
All	43	Significant
Rear-End	31	Significant
Angle-Straight	16	Significant
Angle-Turn	39	Significant
Head-On Left	75	Significant
Driveway-Related	78	Significant
Other	32	Significant

All accident categories exhibited a significant difference between the mean accident rates. The intersection-related accidents of rear-end and angle-turn exhibited a smaller relative difference than the unsignalized highway segments, except for head-on left-turn accidents, which exhibited a higher relative difference. The angle-straight mean accident rate exhibited a significant difference for signalized highway segments where it did not for unsignalized highway segments. The difference between the mean accident rates for driveway-related accidents for signalized segments was less than for unsignalized highway segments which could be attributed to lower speeds in the signalized highway segments.

4.4.1.6 INVESTIGATION OF BOULEVARD ACCIDENT RATES: UNSIGNALIZED VS. SIGNALIZED SEGMENTS (Appendix D, Table D.4)

The signalized boulevard highways exhibited a higher mean accident rate for all seven accident categories when compared to the unsignalized boulevard highways. The differences between the means, expressed as percentages of the larger mean accident rates and the significance of the differences as determined by the Student's *t*-test, are as follows:

Accident Type	Percent Difference	*t*-test
All	68	Significant
Rear-End	80	Significant
Angle-Straight	74	Significant
Angle-Turn	75	Significant
Head-On Left	68	Significant
Driveway-Related	70	Significant
Other	35	Significant

The difference in the mean accident rate for signalized vs. unsignalized boulevard highway segments is significant as measured by the Student's *t*-test in all accident categories. As there are more signals in urbanized areas, it may be that the increase in driveway-related accidents is due to an increase in driveway density in urbanized areas. The intersection-related accidents increased for the signalized segments as would be expected.

4.4.1.7 INVESTIGATION OF CCLTL ACCIDENT RATES UNSIGNALIZED VS. SIGNALIZED SEGMENTS (Appendix D, Table D.5)

The signalized CCLTL highway segments exhibited a higher mean accident rate for all seven accident categories when compared to the unsignalized CCLTL highway segments. The differences between the mean accident rates, expressed as percentages of the larger mean accident rates and the significance of the differences as determined by the Student's *t*-test are as follows:

Accident Type	Percent Difference	*t*-test
All	63	Significant
Rear-End	70	Significant
Angle-Straight	78	Significant
Angle-Turn	53	Significant
Head-On Left	85	Significant
Driveway-Related	46	Significant
Other	46	Significant

The difference in the mean accident rates for signalized vs. unsignalized CCLTL highway segments is significant, as measured by the Student's *t*-test, in all accident categories. The increase of the mean accident rate for driveway-related accidents would be expected as stop-and-go signals are located in more urbanized areas where driveway density is higher. The opportunity for accidents is thus increased with the increased driveway density. The intersection-related accident types of rear-end, angle-turn, and head-on left-turn had higher mean accident rates in signalized segments. This would be expected as the opportunity for rear-end accidents and turning movement accidents increases in signalized segments.

4.4.1.8 SUMMARY

It is evident from numeric and graphical representations that the accident rates for CCLTLs are higher than those of boulevard roadways in all categories and that there is a significant difference between the mean accident rates in all categories except one. Also, it is evident that there is a significant difference between the mean accident rate for signalized and unsignalized segments for both boulevard and CCLTL segments with signalized segment accident rates being much higher.

4.4.2 BOULEVARD ACCIDENT ANALYSIS FOR VARYING MEDIAN WIDTHS

(Table 4.4.2.1, Figure 4.4.2.2, Appendix C, Tables C.4-C.10, Appendix D, Figure D.1)

4.4.2.1.TESTING OF SECOND HYPOTHESES

The second hypotheses was stated in part as follows:

"The accident rate for roadways with a boulevard cross-section is influenced by geometric features and roadway environment; i.e., median width, posted speed, and average daily traffic." In this section the median width portion of this hypothesis will be tested.

The results of the statistical analysis for accident rates by median width are shown in Table 4.4.2.1. The method of analysis that was used was the tukey-b multiple comparison test. The tukey-b multiple comparison test adjusts for the number of comparisons that are being made. This test protects from finding that the differences between two means may be significant as determined by the Student's *t*-test while in reality, the means are not significantly different. The tukey-b multiple comparison test was utilized for all of the comparisons that involved more than two means. The results of the tukey-b multiple

ACCIDENTS PER 100 MILLION VEHICLE MILES

	ALL TYPES			REAR END			ANGLE STRAIGHT			ANGLE TURN			HEAD-ON LEFT TURN			DRIVEWAY			OTHER TYPES		
	M<=30	30<M<60	M>=60	M<=30	30<M<60	M>=60	M<=30	30<M<60	M>=60	M<=30	30<M<60	M>=60	M<=30	30<M<60	M>=60	M<=30	30<M<60	M>=60	M<=30	30<M<60	M>=60
ALL SEGMENTS																					
Mean	375	323	407	119	129	178	47	45	48	16	17	26	41	15	11	23	18	27	129	98	117
Standard Error	47	19	20	19	10	11	10	4	4	3	1	2	16	2	1	6	2	2	13	5	5
Standard Deviation	468	381	378	182	198	208	100	82	76	31	29	32	157	37	22	54	32	39	126	94	84
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	2718	2599	2381	1000	1246	1468	628	515	562	157	183	241	1359	321	208	395	251	250	722	845	513
Sum	36413	136645	140660	11582	54754	61538	4565	19207	16671	1575	7200	9095	3971	6419	3687	2226	7565	9216	12493	41501	40453
Count	97	423	346	97	423	346	97	423	346	97	423	346	97	423	346	97	423	346	97	423	346
UNSIGNALIZED SEGMENTS																					
Mean	262	197	244	60	57	88	31	27	21	10	9	13	33	8	5	15	12	15	112	85	101
Standard Error	40	12	16	8	5	9	9	4	3	2	1	2	18	2	1	4	1	2	12	4	6
Standard Deviation	356	215	231	71	85	124	77	65	42	22	21	22	166	28	15	38	24	27	109	77	81
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	2718	1568	1642	383	756	713	395	515	257	132	183	139	1359	321	137	264	140	175	614	551	513
Sum	21186	63712	49974	4830	18544	18009	2532	8591	4305	818	2969	2761	2660	2462	1100	1254	3752	3007	9092	27395	20792
Count	81	323	205	81	323	205	81	323	205	81	323	205	81	323	205	81	323	205	81	323	205
SIGNALIZED SEGMENTS																					
Mean	952	729	643	422	362	309	127	106	88	47	42	45	82	40	18	61	38	44	213	141	139
Standard Error	137	49	36	66	27	20	39	10	8	11	4	3	24	5	2	24	4	4	42	13	7
Standard Deviation	547	499	423	263	267	234	154	100	94	46	36	36	95	51	29	95	44	47	168	128	84
Minimum	268	0	0	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	0	0
Maximum	1858	2599	2381	1000	1246	1468	628	507	562	157	165	241	277	231	208	395	251	250	722	845	467
Sum	15227	72933	90686	6752	36210	43530	2033	10616	12366	757	4231	6334	1311	3957	2587	973	3813	6209	3401	14106	19661
Count	16	100	141	16	100	141	16	100	141	16	100	141	16	100	141	16	100	141	16	100	141

TABLE 4.4.2.1 BOULEVARD ACCIDENT RATES BY MEDIAN WIDTH

comparison test are shown in Figure 4.4.2.2. A sample of the tukey-b multiple comparison test is shown in Figure D.1.

4.4.2.2 SELECTION OF RANGE OF INVESTIGATION

The literature indicated that there are three categories of median widths for operational purposes: median widths less than or equal to 30 feet that do not readily accommodate passenger vehicle U-turns (Category 1); median widths greater than 30 feet but less than 60 feet, that accommodate passenger vehicle U-turns, but do not readily accommodate larger truck U-turns (Category 2); median widths greater than or equal to 60 feet that accommodate all larger legal vehicle U-turn movements (Category 3). These three categories were, therefore, selected for analysis.

4.4.2.3 INVESTIGATION OF ALL SEGMENTS, UNSIGNALIZED SEGMENTS, AND SIGNALIZED SEGMENTS

The difference discussed in this and subsequent sections within this chapter refer to significant differences in the statistical sense ($\alpha = 0.05$) of the mean accident rate of two groupings of data being compared. The references to roadways refer to "boulevard" roadways.

Roadways with Category 1 medians exhibit higher mean accident rates when compared to roadways with Category 2 medians for both head-on-left-turn and other types of accidents. This is true for both unsignalized and signalized roadways. In addition, these roadways exhibit a higher mean accident rate for the overall accident category for unsignalized roadways.

	ALL SEGMENTS			UNSIGNALIZED SEGMENTS			SIGNALIZED SEGMENTS		
Group 1	M<=30	M<=30	30<M<60	M<=30	M<=30	30<M<60	M<+30	<<+30	30<M<60
Group 2	30<M<60	M>=60	M>=60	30<M<60	M>=60	M>=60	30<M<60	M>=60	M>=60
ALL			S+	+S		S+		+S	
REAR-END		S+	S+		S+	S+			
ANGLE-STRAIGHT									
ANGLE-TURN		S+	S+						
HEAD-ON LEFT-TURN	+S	+S		+S	+S		+S	+S	+S
DRIVEWAY			S+						
OTHER TYPES	+S		S+	+S	+S		+S	+S	

Figure 4.4.2.2 One-way Anova Results for Varying Median Widths (expressed in feet) for Boulevard Roadways

"S" Denotes a significant difference at the 0.95 level between groups 1 and 2.
+S indicates there was a significant difference and the narrower median had the higher mean accident rate.
S+ indicates there was a significant difference and the wider median had the higher mean accident rate.

Conversely, roadways with Category 1 medians exhibit a lower mean accident rate when compared to roadways with Category 3 medians for rear-end and angle-turn accidents. However, there is a higher mean accident rate for head-on left-turn type accidents on roadways with Category 1 medians. For unsignalized roadways, roadways with Category 1 medians exhibit a higher mean accident rate for head-on left-turn and other type of accidents than roadways with Category 3 medians. However, they have a higher mean accident rate for rear-end accidents. For signalized roadways, roadways with Category 1 medians exhibit a higher mean accident rate than roadways with Category 3 medians for the overall head-on left-turn and other types of accidents.

When roadways with Category 2 medians are compared to roadways with Category 3 medians, these roadways exhibit a significant and lower mean accident rate for all accident types except head-on left-turn. When these two categories of roadways are compared for unsignalized roadways, the mean accident rate for the overall and rear-end accidents are lower for roadways with Category 2 medians. For the signalized roadways only the mean accident rate for the head-on left-turns exhibit a significant difference with the Category 3 roadways exhibiting the lower mean accident rate.

4.4.2.4 SUMMARY

Roadways with median widths greater than 30 feet and less than 60 feet appear to consistently exhibit a significantly lower mean accident rate for most accident types when compared to roadways with median widths less than or equal to 30 feet or greater than or equal to 60 feet.

Unsignalized roadways in Category 2 exhibit a lower mean accident rate than the other two categories for all accident types where the mean accident rates are significantly different.

The only apparent trend for signalized roadways with regard to median widths and accident rates is that, in those cases where there is a significant difference in mean accident rates for a specific accident type, the Category 1 roadways exhibited the higher accident rate.

4.4.3 BOULEVARD ACCIDENT ANALYSIS FOR VARYING POSTED SPEEDS

(Table 4.4.3.1, Figure 4.4.3.2, Appendix C, Tables C.11-C.17)

4.4.3.1 TESTING OF SECOND HYPOTHESES

In this section the portion of the second hypotheses stated in Sections 2.10 and 4.4.2.1 that referred to the relationship of accident rates to posted speed limits will be tested. The results of the statistical analysis for accident rates by posted speed limits are shown in Table 4.4.3.1. The method of analysis that was used was the tukey-b multiple comparison test, as discussed in Section 4.4.2.1. The results of the tukey-b multiple comparison test are shown in Figure 4.4.3.2.

4.4.3.2 SELECTION OF RANGE OF INVESTIGATION

The posted speed limit categories for accident analysis were chosen by the areas they represent, with speed limits less than or equal to 35 representing the urban areas, speed limits greater than 35 mph and less than 55 mph representing suburban areas, and speed limits greater than or equal to 55 mph representing rural conditions.

ACCIDENTS PER 100 MILLION VEHICLE MILES

	ALL TYPES			REAR END			ANGLE STRAIGHT			ANGLE TURN			HEAD-ON LEFT TUR			DRIVEWAY			OTHER TYPES		
	S<=35	35<S<55	S>55	S<=35	35<S<55	S>55	S<=35	35<S<55	S>55	S<=35	35<S<55	S>55	S<=35	35<S<55	S>55	S<=35	35<S<55	S>55	S<=35	35<S<55	S>55
ALL																					
Mean	614	461	243	254	221	69	97	55	33	33	31	10	24	16	15	27	35	10	178	103	105
Standard Error	65	21	15	29	12	6	14	4	4	4	2	1	6	2	4	4	2	2	23	4	4
Standard Deviation	497	413	309	226	228	131	111	79	76	28	33	25	43	32	79	29	42	32	176	80	88
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	2599	2381	2717	1180	1468	852	628	562	507	120	241	183	228	277	1359	136	251	395	844	513	614
Sum	36206	172373	105139	15012	82835	30027	5707	20638	14098	1936	11478	4456	1432	5950	6695	1591	12924	4492	10527	38548	45371
Count	59	374	433	59	374	433	59	374	433	59	374	433	59	374	433	59	374	433	59	374	433
NO SIGNALS																					
Mean	431	258	193	183	109	42	55	25	24	24	16	7	15	7	12	22	24	7	133	77	100
Standard Error	72	17	12	34	8	4	15	4	3	6	1	1	7	1	4	6	2	1	28	5	4
Standard Deviation	329	231	238	156	115	72	67	51	64	28	20	21	30	13	80	26	33	22	128	69	86
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	1329	1641	2718	497	712	756	250	515	446	120	139	183	125	118	1359	76	176	264	551	513	614
Sum	9046	50261	75564	3843	21229	16311	1145	4738	9545	495	3152	2900	318	1376	4528	452	4622	2938	2793	15143	39343
Count	21	195	393	21	195	393	21	195	393	21	195	393	21	195	393	21	195	393	21	195	393
SIGNALIZED																					
Mean	715	682	739	294	344	343	120	89	114	38	47	39	29	26	54	30	46	39	204	131	151
Standard Error	87	34	72	40	19	37	20	7	19	4	3	7	8	3	10	5	4	12	31	6	15
Standard Deviation	546	453	456	249	255	232	124	89	122	27	37	42	48	42	63	30	47	73	194	82	95
Minimum	0	0	62	0	0	108	0	0	8	0	0	27	0	0	20	0	0	0	0	13	8
Maximum	2599	2380	2151	1180	1468	852	628	562	507	106	241	152	228	277	231	136	251	395	845	467	442
Sum	27159	122113	29575	11170	61606	13716	4561	15900	4553	1441	8325	1556	1114	4574	2167	1139	8302	1554	7734	23405	6028
Count	38	179	40	38	179	40	38	179	40	38	179	40	38	179	40	38	179	40	38	179	40

TABLE 4.4.3.1 BOULEVARD ACCIDENT RATES BY POSTED SPEED LIMIT

	ALL SEGMENTS			UNSIGNALIZED SEGMENTS			SIGNALIZED SEGMENTS		
Group 1	S<=35	S<=35	35<S<55	S<=35	S<=35	35<S<55	S<=35	S<=35	35<S<55
Group 2	35<S<55	S>=55	S>=55	35<S<55	S>=55	S>=55	35<S<55	S>=55	S>=55
ALL	+S	+S	+S	+S	+S	+S			
REAR-END		+S	+S	+S	+S	+S			
ANGLE-STRAIGHT	+S	+S	+S	+S	+S				
ANGLE-TURN		+S	+S		+S	+S			
HEAD-ON LEFT-TURN								+S	+S
DRIVEWAY		+S	+S		+S	+S			
OTHER TYPES	+S	+S		+S		S+	+S	+S	

Figure 4.4.3.2 One-way Anova Results for Varying Posted Speeds (expressed in mph) for Boulevard Roadways

"S" Denotes a significant difference at the 0.95 Level.
+S indicates there was a significant difference and the narrower median had the higher mean accident rate.
S+ indicates there was a significant difference and the wider median had the higher mean accident rate.

4.4.3.3 INVESTIGATION OF ALL UNSIGNALIZED AND SIGNALIZED SEGMENTS

Urban roadways have a higher mean accident rate for the overall, angle-straight, and "other" accident category types than both the suburban and rural roadways. In addition, urban roadways have a higher mean accident rate for angle-turn and driveway-related accident types than rural roadways. These differences in mean accident rates are also true for unsignalized roadways. In addition, rear-end accidents are significantly higher on suburban roadways than rural roadways. When signalized, the urban roadways have a higher mean accident rates for "other" accident types than suburban roadways. They also have higher mean accident rates for head-on left-turn and "other" accident types than rural roadways.

Rural roadways have a lower mean accident rate for all accident categories except head-on left-turn and other accident types when compared to suburban roadways. The same is true for unsignalized roadways except for angle-straight and other accident types. When comparing roadways with the same two posted speed categories for signalized roadways, the only significantly different mean accident rate was for head-on left-turn accidents with the suburban roadways having the lower mean accident rate.

4.4.3.4 SUMMARY

The clear trend is that roadways with lower posted speeds exhibit a higher accident rate. This is true for unsignalized roadways also. Signalized roadways have only a few accident types which exhibit significantly different accident rates at different posted speeds, but these accident types also have the same trend of higher accident rates for lower posted speed roadways.

These trends of higher accident rates for lower speed may not necessarily be cause and effect, but may be the result of lower speed roadways being located in areas of higher development with resultant increases in points of conflict and congestion providing for increased opportunities for accidents.

4.4.4 BOULEVARD ACCIDENT ANALYSIS FOR VARYING AVERAGE DAILY TRAFFIC (Table 4.4.4.1, Figure 4.4.4.2, Appendix C, Tables C.18-C.24)

4.4.4.1 TESTING OF THE SECOND HYPOTHESES

The second hypotheses will be tested in this section with regard to the relationship of boulevard roadway accident rates to average daily traffic. The hypothesis was stated in Section 2.10. The results of the statistical anaylsis for accidents by average daily traffic are shown in Table 4.4.4.1. The method of analysis that was used was the tukey-b multiple comparison test as discussed in Section 4.4.2.1. The results of the tukey-b multiple comparison test are shown in Figure 4.4.4.2.

4.4.4.2 SELECTION OF RANGE OF INVESTIGATION

The frequency distributions were divided into three volume categories: 0 to 30,000 vehicles per day (category 1), 30,000 to 60,000 vehicles per day (category 2), and greater than 60,000 vehicles per day (category 3). The accident records were, therefore, aggregated into these three categories.

ACCIDENTS PER 100 MILLION VEHICLE MILES

	ALL TYPES			REAR END			ANGLE STRAIGHT			ANGLE TURN			HEAD-ON LEFT TURN			DRIVEWAY			OTHER TYPES		
	ADT<=30000	30000<ADT<=60000	ADT>60000	ADT<=30000	30000<ADT<=60000	ADT>60000	ADT<=30000	30000<ADT<=60000	ADT>60000	ADT<=30000	30000<ADT<=60000	ADT>60000	ADT<=30000	30000<ADT<=60000	ADT>60000	ADT<=30000	30000<ADT<=60000	ADT>60000	ADT<=30000	30000<ADT<=60000	ADT>60000
ALL																					
Mean	267	466	455	74	217	244	41	55	48	12	30	28	17	16	13	10	35	31	112	112	91
Standard Error	16	26	29	7	14	16	4	4	5	1	2	2	4	2	2	1	3	3	5	6	6
Standard Deviation	341	451	326	138	244	181	91	77	55	27	35	21	81	30	20	26	48	34	97	103	65
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	2718	2599	1844	1000	1468	962	628	562	237	183	241	134	1359	244	184	221	395	251	722	845	346
Sum	118629	136398	58691	32967	63485	31423	18118	16176	6148	5333	8870	3667	7753	4593	1731	4566	10397	4044	49893	32875	11678
Count	444	293	129	444	293	129	444	293	129	444	293	129	444	293	129	444	293	129	444	293	129
UNSIGNALIZED																					
Mean	198	263	272	41	109	140	27	23	22	8	16	18	11	9	7	8	24	22	103	82	63
Standard Error	12	21	26	3	10	15	4	3	4	1	2	2	4	2	1	1	3	3	4	6	7
Standard Deviation	243	255	203	71	124	115	70	40	29	22	22	14	79	19	9	20	38	24	89	77	50
Minimum	0	0	25	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Maximum	2718	1642	905	756	713	813	515	257	125	185	139	55	1359	125	51	132	264	92	614	551	229
Sum	78352	40452	16067	16383	16710	8289	10499	3611	1318	3102	2408	1038	4451	1365	406	3030	3711	1271	40886	12646	3746
Count	396	154	59	396	154	59	396	154	59	396	154	59	396	154	59	396	154	59	396	154	59
SIGNALIZED																					
Mean	839	690	609	345	337	330	159	90	69	46	46	38	69	23	19	32	48	40	188	146	113
Standard Error	69	43	40	33	24	22	21	8	7	6	3	3	10	3	3	7	5	5	18	10	8
Standard Deviation	477	510	331	231	285	181	143	91	32	43	40	22	73	38	25	51	55	39	124	118	68
Minimum	62	0	154	0	0	99	0	0	0	0	0	3	0	0	0	0	0	0	8	0	5
Maximum	2151	2599	1844	1000	1468	962	628	562	237	165	241	134	277	244	184	221	395	251	722	845	346
Sum	40277	95946	42623	16583	46775	23134	7619	12566	4831	2231	6462	2629	3302	3228	1325	1536	6686	2773	9006	20230	7932
Count	48	139	70	48	139	70	48	139	70	48	139	70	48	139	70	48	139	70	48	139	70

TABLE 4.4.4.1 BOULEVARD ACCIDENT RATES BY AVERAGE DAILY TRAFFIC

	ALL SEGMENTS			UNSIGNALIZED SEGMENTS			SIGNALIZED SEGMENTS		
Group 1	ADT<=30000	ADT<=30000	30000<ADT<60000	ADT<=30000	ADT<=3000	30000<ADT< 60000	ADT<=30000	ADT<=30000	30000<ADT< 60000
Group 2	30000<ADT< 60000	ADT>60000	ADT>=60000	30000<ADT< 60000	ADT>=60000	ADT>=60000	30000<ADT< 60000	ADT>=60000	ADT>=60000
ALL	S+	S+		S+	S+			+S	
REAR-END	S+	S+		S+	S+	S+			
ANGLE-STRAIGHT	S+						+S	+S	
ANGLE-TURN	S+	S+		S+	S+				
HEAD-ON LEFT-TURN							+S	+S	
DRIVEWAY	S+	S+		S+	S+				
OTHER TYPES		+S	+S	+S	+S		+S	+S	

Figure 4.4.4.2 One-way Anova Results for Varying Average Daily Traffic (expressed in vehicles per day) for Boulevard Roadways

"S" Denotes a significant difference at the 0.95 Level.
+S indicates there was a significant difference and the narrower median had the higher mean accident rate.
S+ indicates there was a significant difference and the wider median had the higher mean accident rate.

4.4.4.3 INVESTIGATION OF ALL SEGMENTS, UNSIGNALIZED SEGMENTS AND SIGNALIZED SEGMENTS

The Category 1 roadways exhibit a lower mean accident rate for the overall, rear-end, angle-straight, angle-turn, and driveway accident categories than Category 2 roadways. The same is true for unsignalized roadways with the exception that a significant difference in the mean accident rate was not observed for angle-straight accident types and Category 2 roadways exhibited a lower mean accident rate for "other" accident types. When these two roadway categories are compared for signalized roadways, the reverse is true with Category 1 roadways exhibiting a higher mean accident rate for angle-straight, head-on left-turn, and "other" accident types.

When Category 1 roadways are compared to Category 3 roadways, they exhibit a lower mean accident rate for all accident categories except "other" accident types, which was higher, and angle-straight and head-on left-turn accidents, which did not exhibit a significant difference in the mean accident rate. When these two roadway categories are compared for unsignalized roadways, the results are identical. For signalized roadways, the Category 1 roadways exhibit a higher mean accident rate for the categories of overall, angle-straight, head-on left-turn, and "other" accident types.

Category 2 roadways exhibit a higher mean accident rate than Category 3 roadways for the only category that was found to be significant, "other" accident types. For these same ADT categories of roadways only rear-end accidents exhibit a significant difference in the mean accident rate for unsignalized roadways. There is no significant difference between the mean accident rates for any accident category when signalized roadways are compared.

4.4.4.4 SUMMARY

There appears to be a clear trend that roadways with a higher ADT exhibit a higher mean accident rate for almost all accident types found to have a significant difference. This conclusion holds true for the unsignalized roadways. The roadways with signalization exhibit the opposite results with the lower ADT roadways having the higher mean accident rates. This may be attributed to the element of surprise when a signal is encountered in a rural area which is where most lower ADT roadways are located. However, the posted speed analysis does not support this observations.

4.4.5 BOULEVARD ACCIDENT ANALYSIS FOR DIRECTIONAL VS. BIDIRECTIONAL CROSS-OVERS (Table 4.4.5.1 Appendix C, Tables C.25-C.27)

4.4.5.1 TESTING OF THE THIRD HYPOTHESIS

The third hypothesis may be stated as follows:

"There is a difference in the accident rate for a boulevard with directional cross-overs and a boulevard with bidirectional cross-overs." In this section the accident rates for boulevard roadways with directional cross-overs will be compared to those with bidirectional cross-overs.

4.4.5.2 INVESTIGATION PARAMETERS

The boulevard segments were divided into segments containing bidirectional cross-overs and segments containing directional cross-overs and further subdivided into segments with and without stop-and-go signals. This was done to provide a comparison between the accident histories of the two cross-over types and then to compare the accident histories of the two cross-over types when located in segments with and without signals.

The boulevard directional and bidirectional accident rates are shown in Table 4.4.5.1 and displayed graphically in Appendix C on charts C.25 to C.27. The *t*-test results are displayed in Table 4.4.5.1.

4.4.5.3 INVESTIGATION OF ALL SEGMENTS

There is a great disparity between the number of unsignalized vs. signalized boulevard segments. This tends to bias the results towards the larger sample which is unsignalized segments for bidirectional cross-overs and signalized segments for directional cross-overs. Therefore, the values are presented in Table 4.4.5.1.

4.4.5.4 INVESTIGATION OF UNSIGNALIZED SEGMENTS

The boulevard segments with directional cross-overs have significantly lower mean accident rates for angle-straight and "other" accident types.

The boulevard segments with bidirectional cross-overs have significantly lower mean accident rates for rear-end, angle-turn, and driveway accidents.

4.4.5.5 INVESTIGATION OF SIGNALIZED SEGMENTS

The boulevard segments with directional cross-overs have the lowest mean accident rate for the accident categories which were considered significant. This included all accidents, head-on left-turn, and other types. Head-on left-turn accidents are improbable to occur in a directional cross-over.

	ALL SEGMENTS				UNSIGNALIZED SEGMENTS				SIGNALIZED SEGMENTS			
	Mean A/MVM				Mean A/MVM				Mean A/MVM			
	Directional	Bidirectional	t-Value	2 Tail Sig	Directional	Bidirectional	t-Value	2 Tail Sig	Directional	Bidirectional	t-Value	2 Tail Sig
ALL	468	280	5.96	0	224	206	0.7	0.48	669	880	-2.43	0.02
REAR-END	231	77	9.94	0	97	42	6.93	0	341	359	-0.38	0.71
ANGLE-STRAIGHT	4	14	-6.63	0	2	6	-3.33	0	19	23	-0.81	0.42
ANGLE-TURN	33	13	8.17	0	17	9	3.71	0	45	46	-0.07	0.95
HEAD-ON LEFT-TURN	13	20	-1.35	0.18	6	14	-1.06	0.28	19	70	-7.03	0
DRIVEWAY	31	11	7.92	0	19	8	4.8	0	41	37	0.5	0.62
OTHER TYPES	104	113	-1.28	0.2	66	102	-4.53	0	135	207	-3.62	0
SAMPLE SIZE	n=310	n=327			n=140	n=291			n=170	n=36		

Table 4.4.5.1 *t*-test Results for Directional vs. Bidirectional Cross-Overs at the 0.95 Level.

4.4.5.6 SUMMARY

The results appear to indicate that the directional cross-overs are safer than bidirectional for signalized intersections.

The higher accident rate for directional cross-overs for rear-end accidents in unsignalized segments is not as may have been expected, as directional cross-overs have storage lanes which allow vehicles to move out of the main stream of traffic into a sheltered area. The other accident categories which were significantly different had lower accident rates for both categories of cross-overs.

4.5 CHAPTER SUMMARY

The information that was collected during the data collection phase was examined through the use of frequency distributions. The frequency distributions provided an indication of which subsets of data were dominant, the minimum, maximum, sample size, outliers, and coding errors that could be encountered.

Discriminate analysis was performed for boulevard and CCLTL roadway segments for all, rear-end, and driveway-related accident types. The presence of stop/go traffic signals emerged as the dominate factor in accounting for significant differences in accident rates with the signal/no signal scenario being the most common group division. This provided an indication of the categories that would be used for the analysis of boulevard and CCLTL highways.

Accident analysis was performed for boulevard and CCLTL highways for seven accident categories for the groupings of all, unsignalized, and signalized segments.

The investigation indicated a significant difference between the boulevard and CCLTL roadway mean accident rates, with boulevard roadway segments having the lower mean accident rate by as much as 50 percent in most cases.

Boulevard roadways were then further investigated to determine whether the accident rate is affected by the following:

A. Median width.

Roadways with median widths greater than 30 feet and less than 60 feet appear to consistently exhibit a significantly lower mean accident rate for most accident types when compared to roadways with median widths less than or equal to 30 feet and greater than or equal to 60 feet. The same was generally true for unsignalized roadways.

For boulevard highway segments containing intersections with traffic signals, the above trend was not evident. For all accident types, the roadways with median widths less than or equal to 30 feet had the highest mean accident rate which was significantly different from the other two median types.

B. Posted speed limit.

There appears to be a trend of roadways with lower posted speeds exhibiting higher accident rates, which also appears to be true for unsignalized roadways. These trends of higher accident rates for lower speeds may not be necessarily cause and effect, but may be the result of lower speed roadways being located in areas of higher development, with resultant increases in points of conflict and congestion.

C. ADT.

There appears to be an indication that roadways with a higher ADT exhibit a higher mean accident rate for almost all accident types determined to have a significant difference between the means, which is also true for the unsignalized roadways. The roadways with signalization exhibit the opposite results with the lower ADT roadways having the higher mean accident rates. This could be attributed to the element of surprise when a signal is encountered in a rural area which is where most lower ADT roadways are located, but the posted speed analysis does not support the theory of a higher mean accident rate for signalized roadways in higher speed areas.

D. Cross-over type.

The results indicate that the directional cross-overs have a significantly lower mean accident rate for a signalized operation than bidirectional cross-overs.

The higher rear-end accident rate for directional when compared to bidirectional cross-overs for unsignalized roadways is not as expected as directional cross-overs have storage lanes which allow vehicles to move out of the main stream of traffic into a sheltered area. The other accident categories which were significantly different had relatively lower accident rates for both categories of cross-overs.

CHAPTER 5

CONCLUSION

5.1 SUMMARY

As the interstate highways system approaches completion, the nation's attention is drawn to the improvement of our free-access arterials. The choices that may be made are multilane undivided, CCLTL or boulevard roadway treatments. In this work, the accident rates for a five-year period for boulevard and CCLTL roadways have been investigated. An attempt was made to gain insight as to the relative safety of the two roadway types. The results indicate that boulevard roadways have a significantly lower mean accident rate than CCLTL. The boulevard roadways were further investigated to determine the effect of cross-over type, median width, posted speed, and average daily traffic on the mean accident rates. It is recognized that other factors, in addition to accident history, will be utilized to make the decision as to which roadway type should be selected for these arterials, but it is intended that this work will provide some additional guidance in the selection process.

5.2 BOULEVARD VS. CCLTL

The results of the research provide an indication that boulevard roadways have a significantly lower mean accident rate than roadways with a CCLTL. The boulevard mean accident rate is approximately fifty percent that of the CCLTL in most cases.

The advantages and disadvantages of both roadway types examined from the study and over 30 years of personal experience can be summarized as follows:

	Boulevard	CCLTL
Intersections	limited +	many
Signals	limited +	many
Traffic separation	median +	none
Access to drives	limited	unlimited +
Right of way	wide	narrow +
Construction cost	high	moderate +
Accident rate	moderate +	high

It appears that the roadway of choice is a boulevard roadway.

5.3 UNSIGNALIZED VS. SIGNALIZED

It was found that for both boulevard and CCLTL roadways that roadways with stop/go signals have a significantly higher mean accident rate than roadways that do not have signals. Discriminate analysis indicates that this factor is the most important in explaining differences in the mean accident rates within roadway categories.

5.4 BOULEVARD MEDIAN WIDTHS

It appears, as found in this research, that the most effective median width is in the 30 to 60 foot range. Roadways with this median width have a significantly lower mean accident rate than that of roadways with median widths less than or equal to 30 feet or greater than or equal to 60 feet. The 30- to 60-foot median width has a significantly lower mean accident rate for signalized roadways when compared to the less than or equal to 30-foot median, which could be the result of not being able to accommodate vehicle storage in the narrower median.

The median of choice would, therefore, appear to be the 30- to 60-foot median based soley on accident rates. However, other factors such as intersection sight distance and vehicle turning radius for commercial vehicles needs to be considered.

5.5 BOULEVARD MEDIAN CROSS-OVERS

The directional boulevard cross-overs had a significantly lower mean accident rate than the bidirectional cross-overs for signalized roadways.

APPENDICES

APPENDIX A

DATA COLLECTION

C.S.	COUNTY	ROAD	B.M	E.M	LENGTH
3023	Allegan	M-89 (Otsego)	9.9	12.2	2.3
3032	Allegan	US-31	1.5	4.5	3
4031	Alpena	US-23	12.6	14	1.4
4032	Alpena	US-23	1.5	2.2	0.7
9032	Bay	M-13	1.9	4.2	2.3
9033	Bay	M-13	2	3.5	1.5
9042	Bay	M-25 / I-5 BL	3.2	5.9	2.7
9071	Bay	M-15	0	9.6	9.6
11013	Berrian	I-94 BL	0.5	2.4	1.9
11053	Berrian	M-63 / I94 BR	0	3.1	3.1
11101	Berrian	US-12	0	3.78	3.78
11031	Berrien	M-139	1.4	4.2	2.8
11051	Berrien	US-31	0	4.5	4.5
11052	Berrien	US-31	18.1	22.8	4.7
13032	Calhoun	M-66	0	1.5	1.5
13042	Calhoun	I94 BL	0	1.6	1.6
13044	Calhoun	I-94 BL	0	0.5	0.5
13121	Calhoun	I-94 BL	3	8.3	5.3
13131	Calhoun	M-96	1.2	2.4	1.2
14061	Cass	M-60	1.56	3.3	1.74
17032	Chippewa	I-75 BS	0.2	3	2.8
19031	Clinton	US-27	0	16.1	16.1
19032	Clinton	US-27	0	8.2	8.2
21021	Delta	US-2 US-41	11.4	12.4	1
21022	Delta	US-2 / US-41 / M-35	0	8.4	8.4
21025	Delta	US-2 / US-41	0	6.2	6.2
22011	Dickenson	M-95	0.7	1.7	1
22021	Dickenson	US-2/ 141/ M-95	3.6	6.8	3.2
22022	Dickenson	US-2	2.4	4.3	1.9
23012	Eaton	US-27 / TEMP I-69	0	15.6	15.6
23042	Eaton	M-43 / Saginaw	0	6.96	6.96
23092	Eaton	M-99 / Logon	3.2	10.6	7.4
23092	Eaton	M-99, Logon	0	2.2	2.2
24011	Emmet	US-31	9.4	10	0.6
25061	Genesee	M-121	0	2.2	2.2
25072	Genesee	M-54 (OLD)	0.8	8.6	7.8
25081	Genesee	M-21	0	5.5	5.5
25081	Genesee	M-21	5.7	12.4	6.7
25092	Genesee	M-15	0	4.2	4.2
25071	Genesse	M-54	3.2	6.2	3
27021	Gogebic	US-2	2.5	12.5	10
28012	Grand Traverse	US-31 / M-37	3.6	5.7	2.1
28013	Grand Traverse	US-31 / M-72 / M-37	1.9	8.7	6.8
19041	Gratiot	I-69 BL (continues 76021)	0	1.14	1.14
29011	Gratiot	US-27	0	11	11
30032	Hillsdale	M-99	4.5	4.8	0.3
30061	Hillsdale	M-99	8.7	8.8	0.1

Table A.1: Investigation Sites

C.S.	COUNTY	ROAD	B.M	E.M	LENGTH
30062	Hillsdale	US-12	0	0.2	0.2
32032	Huron	M-53 / M-142	0.5	1.8	1.3
33011	Ingham	M-99 / Logon	0	5.993	5.993
33021	Ingham	M-36	0.3	0.8	0.5
33032	Ingham	I-96 BL	0	4.1	4.1
33034	Ingham	US-27 BR	0.9	2	1.1
33043	Ingham	I-69BL	0	4.967	4.967
33061	Ingham	M-43 / I-69 BL	0	0.8	0.8
33082	Ingham	M-43	0	5.13	5.13
37011	Isabella	US-27BR	2	3.5	1.5
37022	Isabella	M-20	0	2	2
35032	Isco	US-23	15.9	16.6	0.7
38071	Jackson	M-50 / US-127 BR	0	1.7	1.7
38082	Jackson	I-94 BL	1.9	2.4	0.5
38083	Jackson	I-94 BL	1.4	3.9	2.5
39011	Kalamazoo		0	5	5
39041	Kalamazoo	I-94 BL	0	3	3
39081	Kalamazoo	M-43	0.9	7.1	6.2
39082	Kalamazoo	M-43 / M-89	3	4.2	1.2
39121	Kalamazoo		0	2.9	2.9
41012	Kent	M-44 Conn	0	4.2	4.2
41013	Kent	M-44	0	2.8	2.8
41014	Kent	US-131 BR	0.5	2.5	2
41033	Kent	M-37	0	8.5	8.5
41043	Kent	M-21	0	7	7
41051	Kent	M-37	0	4.5	4.5
41061	Kent	M-11	7.3	8.3	1
41062	Kent	M-11	0	4.2	4.2
41063	Kent	M-11	0	6.7	6.7
41081	Kent	M-45	0.3	6.1	5.8
44011	Lapeer	m-24	9.5	11.8	2.3
46062	Lenawee	US-223	2.6	3.3	0.7
46072	Lenawee	M-52 (Adrian)	1	4	3
47061	Livingston	I-96 BL	2.4	2.7	0.3
47062	Livingston	I-96 (GRAND RIVER)	0	2.3	2.3
47082	Livingston	M-59	12.5	13	0.5
49023	Mackinac	US-2	23.3	26.9	3.6
50011	Macomb	M-53	0	12.7	12.7
50022	Macomb	M-59	0.6	8.8	8.2
50031	Macomb	M-97	7.2	14	6.8
50031	Macomb	M-97	0	7.2	7.2
50051	Macomb	M-3	0	6.8	6.8
50051	Macomb	M-3	12.5	14.4	1.9
50052	Macomb	M-3 / M-59	0	3.2	3.2
50072	Macomb	M-29 / 23 MILE	0	4.1	4.1
52041	Marquette	US-41, M-28	1.9	6	4.1
52042	Marquette	M-28 / US-41	4	15.7	11.7

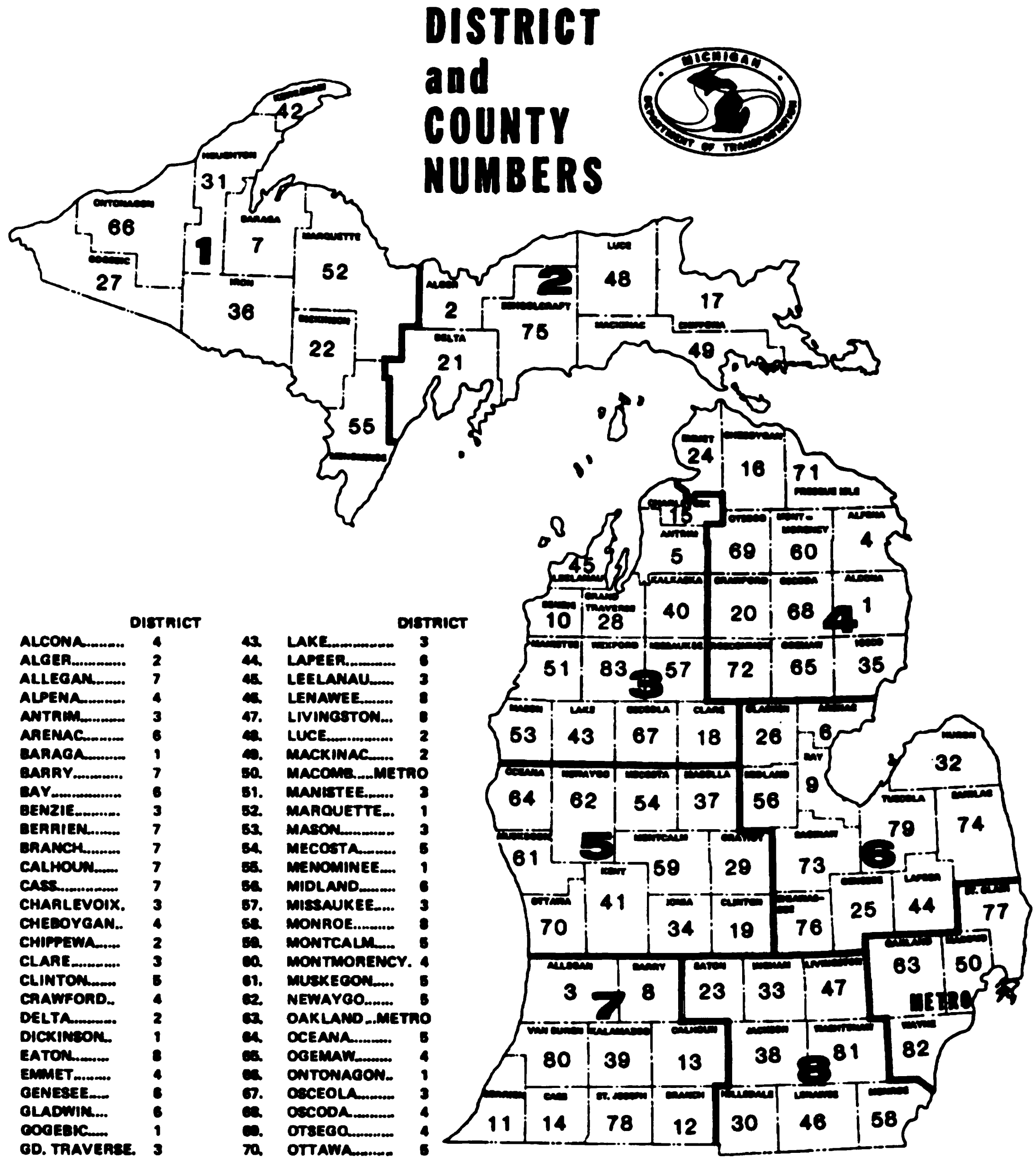
Table A.1: Continued

C.S.	COUNTY	ROAD	B.M	E.M	LENGTH
53021	Mason	US-10	0	2.3	2.3
53032	Mason	US-31, US-10	0	2	2
54011	Mecosta	US-131 (OLD)	14.7	15.8	1.1
54021	Mecosta	M-20	2	4.2	2.2
56021	Midland	M-20	11.8	17.6	5.8
58052	Monroe	US-24	8.3	10.7	2.4
58071	Monroe	M-125	12	17.3	5.3
58091	Monroe	I-75 / US-25 CONN	0	2.8	2.8
61023	Muskegon	M-46	0	7.2	7.2
61076	Muskegon	M-120	0	1.4	1.4
61151	Muskegon	US-31 BR	0	6.1	6.1
61153	Muskegon	US-31 BR / M-46	0	3.4	3.4
63021	Oakland	OLD I96 BL	0	3.8	3.8
63022	Oakland	M-102	17.5	19.2	1.7
63031	Oakland	US-24 (Telegraph)	0	11.3	11.3
63041	Oakland	M-59	0	9	9
63042	Oakland	M-59	5.8	6.3	0.5
63051	Oakland	M-1 (Woodward)	0	13	13
63052	Oakland	US-10	3	6.9	3.9
63052	Oakland	US-24	1.4	2.1	0.7
63053	Oakland	US-24	0	6.2	6.2
63082	Oakland	M-10	0	4	4
63091	Oakland	I-75 BL	0.2	3.6	3.4
63112	Oakland	M-24	0	15	15
63132	Oakland	M-150	0	3.9	3.9
63151	Oakland	I-75 BL / US-24 BR	1	2.5	1.5
63151	Oakland	M-24	0	4.5	4.5
69011	Otsego	I-75 BL	0	2.9	2.9
69023	Otsego	M-32, 1-75 BL	0	1	1
70012	Ottawa	US-31B / I-96	0	1.6	1.6
70013	Ottawa	US-31	0	13.2	13.2
70014	Ottawa	US-31	0	7.6	7.6
70021	Ottawa	US-31	0	2	2
70023	Ottawa	I-196 BL	0	5.5	5.5
70062	Ottawa	M-11	0	1.8	1.8
70081	Ottawa	M-104	0.3	0.7	0.4
73033	Saginaw	M-84	0	3.2	3.2
73062	Saginaw	M-46	0	9	9
73063	Saginaw	M-46	0	4.5	4.5
73073	Saginaw	M-58	2.7	5	2.3
73073	Saginaw	M-58	4.9	13.5	8.6
73091	Saginaw	M-13	0	1.5	1.5
76021	Shiawassee	OLD M-78	0	8	8
77031	St Clair	I-94 BL	0	0.7	0.7
77032	St Clair	I-94 BL / I-69 BL	0	5.2	5.2
77052	St Clair	M-29	15.9	16.6	0.7
77091	St Clair	I-94 BL / I-69 BL	0	2.8	2.8

Table A.1: Continued

C.S.	COUNTY	ROAD	B.M	E.M	LENGTH
77132	St Clair	M-25	0	1.5	1.5
78014	St Joseph	US-131	0	2.2	2.2
78051	St Joseph	M-66 (Sturgis)	1.3	2.7	1.4
78013	St.Joseph	US-131BR	0	8.7	8.7
78041	St.Joseph	M-60	5.5	6.2	0.7
80011	VanBuren	M-140 (OLD I96)	0	2.7	2.7
80032	VanBuren	I-196 BL	0.3	1.5	1.2
80033	VanBuren	I-196 BL	0	1.1	1.1
82211	Wanye	M-85 (Fort St)	0	15.1	15.1
81032	Washtenaw	US-12 / M-17 (Ypsi)	1.1	5.4	4.3
81072	Washtenaw	I-94 BL / US-23 BR	0	4.2	4.2
81073	Washtenaw	US-23 BR	0	0.34	0.34
81081	Washtenaw	M-17	0	3	3
81101	Washtenaw	I-94 BL	0.1	2.4	2.3
81121	Washtenaw		0	1.1	1.1
81031	Washtenaw	US-12	11.6	12.5	0.9
82051	Wayne	US-24	0	1.3	1.3
82052	Wayne	US-24 (Telegraph)	0	11.1	11.1
82053	Wayne	US-24	0	9.9	9.9
82061	Wayne	US-12	0	14.5	14.5
82062	Wayne	US-12	0	11.9	11.9
82071	Wayne	I-75 CONN	0.6	1.5	0.9
82072	Wayne	M-3 Gratiot	0	9.4	9.4
82081	Wayne	M-153	2.9	20	17.1
82101	Wayne	OLD M-14	3.3	14.1	10.8
82111	Wayne	I-375 BS Jefferson Ave	2.5	4	1.5
82121	Wayne	M-5	0	8.4	8.4
82131	Wayne	M-1 Woodward Ave	0	8.7	8.7
82141	Wayne	8-mile (M-102)	0	6	6
82142	Wayne	8-mile (M-102)	0	4	4
82143	Wayne	8-mile (M-102)	0	8	8
82144	Wayne	8-mile (M-102)	0	2.7	2.7
82151	Wayne	M-53	0	4.9	4.9
82192	Wayne	M-39 (Southfield)	0	2.5	2.5
83032	Wexford	US-131	0	2.5	2.5

Table A.1: Continued



		DISTRICT
1.	ALCONA	4
2.	ALGER	2
3.	ALLEGAN	7
4.	ALPENA	4
5.	ANTRIM	3
6.	ARENAC	6
7.	BARAGA	1
8.	BARRY	7
9.	BAY	6
10.	BENZIE	3
11.	BERRIEN	7
12.	BRANCH	7
13.	CALHOUN	7
14.	CASS	7
15.	CHARLEVOIX	3
16.	CHEBOYGAN	4
17.	CHIPPEWA	2
18.	CLARE	3
19.	CLINTON	5
20.	CRAWFORD	4
21.	DELTA	2
22.	DICKINSON	1
23.	EATON	8
24.	EMMET	4
25.	GENESEE	6
26.	GLADWIN	6
27.	GOGEBIC	1
28.	GD. TRAVERSE	3
29.	GRATIOT	5
30.	HILLSDALE	8
31.	HOUGHTON	1
32.	HURON	6
33.	INGHAM	8
34.	IONIA	5
35.	IOSCO	4
36.	IRON	1
37.	ISABELLA	5
38.	JACKSON	8
39.	KALAMAZOO	7
40.	KALKASKA	3
41.	KENT	5
42.	KEWEENAW	1

		DISTRICT
43.	LAKE	3
44.	LAPEER	6
45.	LEELANAU	3
46.	LENAWEE	8
47.	LIVINGSTON	8
48.	LUCE	2
49.	MACKINAC	2
50.	MACOMB	METRO
51.	MANISTEE	3
52.	MARQUETTE	1
53.	MASON	3
54.	MECOSTA	5
55.	MENOMINEE	1
56.	MIDLAND	6
57.	MISSAUKEE	3
58.	MONROE	8
59.	MONTCALM	5
60.	MONTMORENCY	4
61.	MUSKEGON	5
62.	NEWAYGO	5
63.	OAKLAND	METRO
64.	OCEANA	5
65.	OGEMAW	4
66.	ONTONAGON	1
67.	OSCEOLA	3
68.	OSCODA	4
69.	OTSEGO	4
70.	OTTAWA	5
71.	PRESQUE ISLE	4
72.	ROSCOMMON	4
73.	SAGINAW	6
74.	SANILAC	6
75.	SCHOOLCRAFT	2
76.	SHIAWASSEE	6
77.	ST.CLAIR	METRO
78.	ST.JOSEPH	7
79.	TUSCOLA	6
80.	VAN BUREN	7
81.	WASHTENAW	8
82.	WAYNE	METRO
83.	WEXFORD	3

Figure A.1: MDOT District Map

PHOTO LOG INVENTORY INSTRUCTIONS

1. Record control section, date, direction, variable being recorded one time, unless a change occurs, then record it only when the change occurs.

2. Record one event per pass:

   a. First pass record number of lanes.

   b. Second pass record intersection mile points and names as close to the center of the intersection as possible Interpolate distance. Intersections are public streets. The MALI designation for the street names shall be used, as it is important for future reconciliation of mile points.

   c. Third pass record cross-over mile points at the center of the cross-over and the type of cross-over. Where an intersection is aligned with a cross-over, both shall be identified in their respective pass.

   d. Fourth pass record drive mile points and their characteristics.

   e. Fifth pass record unusual features such as loons and bus turn-outs.

   f. Sixth pass record whether the roadway type is a boulevard, center left-turn or other type of facility.

GENERAL DISCUSSION

Use the comment area to note unusual circumstances, such as closed drives or merge areas that are treated as intersections. Note any problem areas for resolution. Record all events for both directions. Use only codes provided. Make a decision on the situation, code it accordingly and note any problems or observations in the comments area only.

Thank you.

Sam

Figure A.2: Photo Log Instructions

MEDIAN CROSS-OVER STUDY

PHOTO LOG CODES

CONTROL SECTION

Five digit numeric
xxxxx

DATE

Six digit numeric
xxxxxx

DIRECTION

One digit numeric
1 north bound
2 south bound
3 east bound
4 west bound

VARIABLE

One digit alpha
A number of lanes
B intersecting street
C cross-over
D drives
E other feature
F roadway type

MILE POINT

Five digit numeric
xxx.xx note: decimal indicated by digit placement
99999 no cross-overs* Code on Form "C" if after reviewing entire control section no cross-overs are found.

NUMBER OF LANES

One digit numeric
x

Figure A.3: Photo Log Codes

INTERSECTION TYPE*

One digit numeric
0 through intersection
1 "T" intersection

INTERSECTING STREET NAME

Eighteen digit alpha/numeric
xxxxxxxxxxxxxxxxxx

CROSS-OVER

One digit numeric
1 directional
2 bidirectional
9 no cross-overs* Code on Form "C" if after reviewing entire control section no cross-overs are found.

DRIVE LAND USE

Two digit numeric
1 residential
2 commercial, high turnover
Ex: 7-11, Burger King, Gas Station
3 commercial, strip mall
4 commercial, minor
Ex: cleaner, bar, bank, restaurant
5 commercial, intermediate
Ex: Kmart, Kroger, Large Car Dealer, Red Roof Inn
6 commercial, major
Ex: Meijers, Meridian Mall
7 institutional, minor
Ex: police, fire, small office center, PA
8 Institutional, major
Ex: stadium, school, hospital, high rise, church, large factory
9 Alley
10 2-way midblock Xover
99 Other/unknown

NUMBER OF LAND USES PER DRIVE

One digit numeric
1 single
2 multiple
9 unknown

Figure A.3: Continued

DRIVEWAY OPERATION

One digit numeric
1 2-way
2 divided, 2-way
< 50 ft. Separation
3 one way
4 unrestricted access
9 unknown

SPEED CHANGE

One digit numeric
1 accel/decel lane
2 no accel/decel lane
9 N/A, unknown

TERMINAL CONTROL

One digit numeric
0 none
1 stop sign
2 signal/flasher
3 stop & go
4 yield
9 N/A, unknown

RESTRICTIONS

One digit numeric
0 no restriction
1 left-turn only
2 right turn only
3 no turns
9 unknown

OTHER

One digit numeric
1 Xover loon
2 bus turnout
3 right turn lane
4 left turn lane

Figure A.3: Continued

ROADWAY TYPE

One digit numeric
1 boulevard
2 center left turn
3 other

Figure A.3: Continued

control section route no FORM “A” 03/24/94

	CNTL SEC	DATE	DIR	VAR	MILE PT	NO LANES	COMMENTS
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							

data collected by data verified by sheet no of

Figure A.4: Data Collection Sheet “A”

control section route no FORM "B" 03/24/94

	CNTL. SEC	DATE	DIR	VAR	MILE PT	TYPE	INTERSECTING STREET NAME
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							

data collected by data verified by sheet no of

Figure A.5: Data Collection Sheet "B"

control section | route no | FORM “C” 03/24/94

	CNTL SEC	DATE	DIR	VAR	MILE PT	XOVER	COMMENTS
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							

data collected by | data verified by | sheet no of

Figure A.6: Data Collection Sheet “C”

control section | route no | FORM "D" 03/24/94

	CNTL	DATE	DIR	VAR	MILE PT	LAND USE	LAND USE PER DR	OPERATING	SPEED CHNG	DR BEG MILE PT	DR END MILE PT	TERM CNTL	RESTRICN	COMMENTS
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														

data collected by | data verified by | sheet no of

Figure A.7: Data Collection Sheet "D"

control section route no FORM "E" 03/24/94

	CNTL SEC	DATE	DIR	VAR	BEGINNING MILE PT	ENDING MILE PT	OTHER	COMMENTS
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

data collected by **data verified by** **sheet no of**

Figure A.8: Data Collection Sheet "E"

control section route no FORM “F” 03/24/94

	CNTL SEC	DATE	DIR	VAR	BEGINNING MILE PT	ENDING MILE PT	ROADWAY TYPE	COMMENTS
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

data collected by **data verified by** **sheet no of**

Figure A.9: Data Collection Sheet “F”

PHOTOLOG USE BY CONSULTANT PERSONNEL

When the Traffic & Safety photolog facilities in the Transportation Building are made available for use by consultant personnel, the following work rules shall apply. Any consultant requested changes to these rules shall be approved by the MDOT Project Manager and the Photolog Supervisor prior to implementation.

Two types of viewing equipment may be available - laser disc and 35 mm film viewing machines. Current film is available for all districts except District 5 (Grand Rapids) and District 9 (Metro Detroit Area). The most current photolog for these two districts is only on disc.

Work Rules

Work hours for consultants personnel shall be 7:30 a.m. to 11:45 a.m. and 12:45 p.m. to 4:30 p.m. Monday through Friday. No work is allowed during the normal lunch hour (11:45 a.m. to 12:45 p.m.) In deference to state employees in the photolog/graphics area. No work will be allowed on Saturdays, Sundays, or holidays.

Disc and film viewing equipment shall remain where it is currently located. NO MOVING of equipment except for minor table angle adjustments shall be made without the assistance of photolog personnel. The 35 mm viewers are not as subject to motion disturbance as the laser disc system, but are much older and should be considered fragile.

Consultant personnel shall be responsible for finding and properly loading the appropriate disc of reel of 35 mm film. Photolog personnel will instruct consultant personnel in the proper loading or hanging procedures and will be available for assistance if something goes wrong with either system. In case of the laser disc, if it locks up and cannot be restarted via a "hard reboot," photolog personnel will try to resolve the problem. If the problem cannot be fixed in a short period of time, the consultant employee affected may be required to stop work until the equipment is repaired.

If the 35 mm film rips, stop the viewer immediately and notify photolog personnel. Do not take the film off the machine. Repairs will be made by photolog personnel. If there is any question regarding use of the equipment, **DO NOT ASSUME!!! PLEASE ASK!!!**

Figure A.10: Work Rules

MEDIAN CROSS-OVER STUDY
VIDEO LOG INVENTORY INSTRUCTIONS

1. Record control section, date, direction, variable being recorded one time, unless a change occurs, then record it only when the change occurs.

2. Record one event per pass.

   G) First pass record median width, lane width and speed limit.

General Discussion

Use the comment area to note unusual circumstances, such as closed drives or merged areas that are treated as intersections. Note any problem areas for resolution. Record all events for both directions. Use only codes provided. Make a decision on the situation, code it accordingly and note any problem or observations in the comment area only.

Figure A.11: Field Data Collection Instructions

MEDIAN CROSS-OVER STUDY VIDEO LOG CODES

CONTROL SECTION

Five digit numeric
xxxxx

DATE

Six digit numeric
xxxxxx

DIRECTION

One digit numeric
1 northbound
2 southbound
3 eastbound
4 westbound

VARIABLE

One character alpha
G median width
H lane width
J speed limit

MILE POINT

Five digit numeric
xxx.xx note: decimal indicated by digit placement

MEDIAN WIDTH

Five digit numeric
xxx.xx note: decimal indicated by digit placement

LANE WIDTH

Four digit numeric
xx.xx note: decimal indicated by digit placement

SPEED LIMIT

Two digit numeric
xx

Figure A.12: Field Data Collection Codes

control section route no FORM "G" 03/24/94

	CNTL SEC	DATE	DIR	VAR	BEGINNING MILE PT	ENDING MILE PT	SPEED LIMIT	MEDIAN WIDTH	LANE WIDTH
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									

data collected by **data verified by** **sheet no of**

Figure A.13: Data Collection Sheets "G"

APPENDIX B

DISCRIMINATE ANALYSIS

ROADWAY=1

- - - - - - - - D I S C R I M I N A N T   A N A L Y S I S - - - - - - - -

On groups defined by RALLR3   RALL REVISED DATA GROUPED BY 3

866 (Unweighted) cases were processed.
0 of these were excluded from the analysis.
866 (Unweighted) cases will be used in the analysis.

Number of cases by group

	Number of cases		
RALLR3	Unweighted	Weighted	Label
1	289	289.0	0 TO 130
2	288	288.0	130 TO 368
3	289	289.0	>368
Total	866	866.0	

Group means

RALLR3	ADTB	COMDRDEN	CURB	DRVDENS
1	26235.29412	1.52249	1.77509	7.72318
2	36713.19444	7.38889	1.56944	15.01389
3	43933.56401	14.56055	1.39100	21.05190
Total	35626.09700	7.82448	1.57852	14.59584

RALLR3	INTDENS	LNWD	NUMLN	PERCOMM
1	2.31142	11.65744	2.19377	5.00000
2	6.19444	11.60069	2.68056	4.42708
3	10.72664	11.54671	2.99308	3.47751
Total	6.41109	11.60162	2.62240	4.30139

Figure B.1: Discriminate Analysis Example

ROADWAY=1

RALLR3	POP	SIGDENS	SPD	MED
1	154477.43253	.20761	52.54325	53.00346
2	130571.86111	.76389	50.00000	53.70833
3	174878.46713	3.23875	46.15917	55.57093
Total	153335.50924	1.40416	49.56697	54.09469

Group standard deviations

RALLR3	ADTB	COMDRDEN	CURB	DRVDENS
1	17601.23102	5.07790	.41825	11.16198
2	22876.37659	14.78916	.49602	22.14113
3	23271.62707	22.02848	.48882	28.41167
Total	22583.48494	16.46848	.49408	22.42017

RALLR3	INTDENS	LNWD	NUMLN	PERCOMM
1	4.31083	.47539	.53732	3.02765
2	7.41904	.62770	.90414	3.00897
3	8.88417	.72077	.91284	2.52632
Total	7.91089	.61725	.86788	2.92850

RALLR3	POP	SIGDENS	SPD	MED
1	160242.78061	.94931	4.75282	28.77131
2	116574.51671	1.64427	6.12017	26.52114
3	175316.47267	2.75412	7.33302	24.25034
Total	153687.16687	2.33707	6.68988	26.56988

Figure B.1: Continued

ROADWAY=1

Pooled within-groups correlation matrix

	ADTB	COMDRDEN	CURB	DRVDENS	INTDENS	LNWD
ADTB	1.00000					
COMDRDEN	.14684	1.00000				
CURB	-.56956	-.27471	1.00000			
DRVDENS	.11588	.86395	-.27409	1.00000		
INTDENS	.24290	.15561	-.22098	.07544	1.00000	
LNWD	.01947	-.09211	.20623	-.04309	-.46449	1.00000
NUMLN	.70026	.25502	-.66765	.24277	.26882	-.17414
PERCOMM	-.48779	-.05578	.32788	.03613	-.26707	.06084
POP	.06020	.12669	-.07972	.08754	-.10415	.06359
SIGDENS	.33366	.14332	-.25808	.12876	.27008	-.01102
SPD	-.48876	-.29715	.59742	-.25463	-.31533	.19341
MED	.07872	.18209	-.04336	.15261	.04368	.03860

	NUMLN	PERCOMM	POP	SIGDENS	SPD	MED
NUMLN	1.00000					
PERCOMM	-.30893	1.00000				
POP	-.01057	-.25579	1.00000			
SIGDENS	.33812	-.14013	.13891	1.00000		
SPD	-.57100	.29892	-.11707	-.32115	1.00000	
MED	.08721	-.03526	.03406	.04825	-.17415	1.00000

Wilks' Lambda (U-statistic) and univariate F-ratio
with 2 and 863 degrees of freedom

Variable	Wilks' Lambda	F	Significance
ADTB	.89625	49.9516	.0000
COMDRDEN	.89495	50.6524	.0000
CURB	.89888	48.5409	.0000
DRVDENS	.94079	27.1590	.0000
INTDENS	.81060	100.8248	.0000
LNWD	.99462	2.3327	.0976
NUMLN	.85606	72.5524	.0000
PERCOMM	.95393	20.8395	.0000
POP	.98611	6.0769	.0024
SIGDENS	.68155	201.6157	.0000
SPD	.84578	78.6795	.0000
MED	.99833	.7198	.4871

Figure B.1: Continued

ROADWAY=1

- - - - - - - - D I S C R I M I N A N T   A N A L Y S I S - - - - - - - -

On groups defined by RALLR3   RALL REVISED DATA GROUPED BY 3

Analysis number   1

Direct method: all variables passing the tolerance test are entered.

Minimum tolerance level.................. .00100

Canonical Discriminant Functions

Maximum number of functions.............. 2
Minimum cumulative percent of variance... 100.00
Maximum significance of Wilks' Lambda.... 1.0000

Prior probability for each group is .33333

Classification function coefficients
(Fisher's linear discriminant functions)

RALLR3 =	1 0 TO 130	2 130 TO 368	3 >368
ADTB	-.0002802	-.0002767	-.0002911
COMDRDEN	.1230054	.1353073	.1731393
CURB	.2282162	.1427605	.0608063
DRVDENS	-.0725388	-.0703095	-.0889914
INTDENS	2.2167106	2.2871628	2.3320329
LNWD	42.4198558	42.8175570	43.0803928
NUMLN	21.7449300	22.2543821	22.1146557
PERCOMM	1.1911056	1.2132113	1.1703634
POP	.0000289	.0000280	.0000284
SIGDENS	-1.7871039	-1.7971094	-1.1815041
SPD	2.3229964	2.3241538	2.2818160
MED	.0664825	.0634075	.0606841
(Constant)	-338.9193751	-345.0062050	-346.3490705

Figure B.1: Continued

ROADWAY= 1

Canonical Discriminant Functions

Fcn	Eigenvalue	Pct of Variance	Cum Pct	Canonical Corr		After Fcn	Wilks' Lambda	Chi-square	df	Sig
					:	0	.578511	469.308	24	.0000
1*	.6332	91.55	91.55	.6226	:	1	.944801	48.690	11	.0000
2*	.0584	8.45	100.00	.2349	:					

* Marks the 2 canonical discriminant functions remaining in the analysis.

Standardized canonical discriminant function coefficients

	Func 1	Func 2
ADTB	-.14306	.27392
COMDRDEN	.41843	-.07793
CURB	-.03921	-.03175
DRVDENS	-.21005	.29512
INTDENS	.39954	.48962
LNWD	.19827	.23555
NUMLN	.11370	.61047
PERCOMM	-.04227	.15400
POP	-.01987	-.20839
SIGDENS	.66724	-.69915
SPD	-.14508	.15719
MED	-.07655	-.06814

Figure B.1: Continued

ROADWAY=1

Structure matrix:

Pooled within-groups correlations between discriminating variables
and canonical discriminant functions
(Variables ordered by size of correlation within function)

	Func 1	Func 2
SIGDENS	.85278*	-.34098
INTDENS	.59716*	.36721
SPD	-.53325*	-.19823
COMDRDEN	.42427*	.24184
CURB	-.40624*	-.37004
DRVDENS	.30272*	.29010
PERCOMM	-.27513*	-.07937
LNWD	-.08968*	-.07334
MED	.05131*	-.00427
NUMLN	.48333	.58838*
ADTB	.40384	.46262*
POP	.09694	-.37311*

* denotes largest absolute correlation between each variable and any discriminant function.

Canonical discriminant functions evaluated at group means (group centroids)

Group	Func 1	Func 2
1	-.81954	-.23295
2	-.25558	.33290
3	1.07424	-.09879

>Warning # 43
>MXMEMORY (the maximum amount of memory that can be allocated dynamically)
>has been reached. To increase this value, use the SET MXMEMORY command.

Figure B.1: Continued

ROADWAY=1

Classification results -

Actual Group	No. of Cases	Predicted Group Membership 1	2	3
Group 1 0 TO 130	289	227 78.5%	48 16.6%	14 4.8%
Group 2 130 TO 368	288	123 42.7%	111 38.5%	54 18.8%
Group 3 >368	289	40 13.8%	55 19.0%	194 67.1%

Percent of "grouped" cases correctly classified: 61.43%

Classification processing summary

866 (Unweighted) cases were processed.
0 cases were excluded for missing or out-of-range group codes.
0 cases had at least one missing discriminating variable.
866 (Unweighted) cases were used for printed output.

ROADWAY=1;SIGNAL DENSITY=0

Number of valid observations (listwise) = 609.00

Variable RALL TOTAL ACCIDENT RATE

Mean	221.463	S.E. Mean	9.915
Std Dev	244.691	Variance	59873.819
Range	2717.808	Minimum	.00
Maximum	2717.81	Sum	134871.132

Valid observations - 609 Missing observations - 0

Figure B.1: Continued

APPENDIX C

DATA ANALYSIS RESULTS

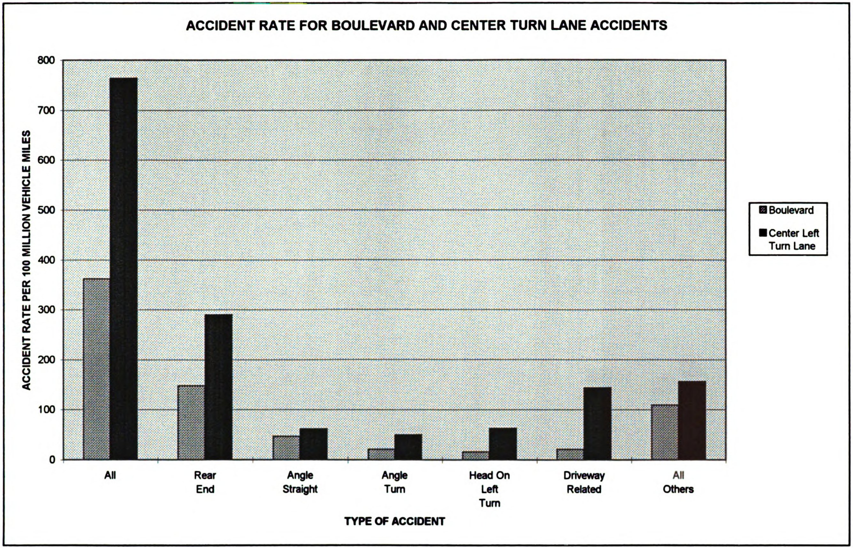


Figure C.1: Accident Rates for Boulevard and Center Left-Turn Lane Accidents

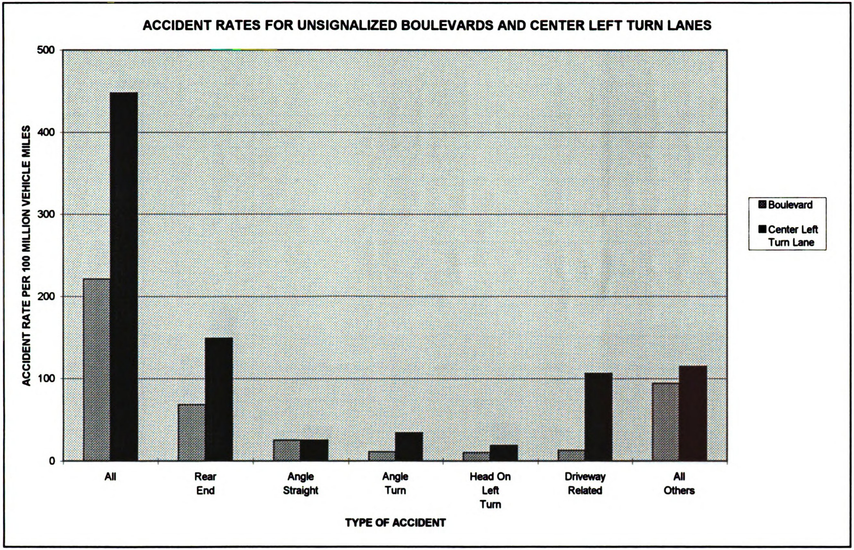


Figure C.2: Accident Rates for Unsignalized Boulevards and Center Left-Turn Lanes

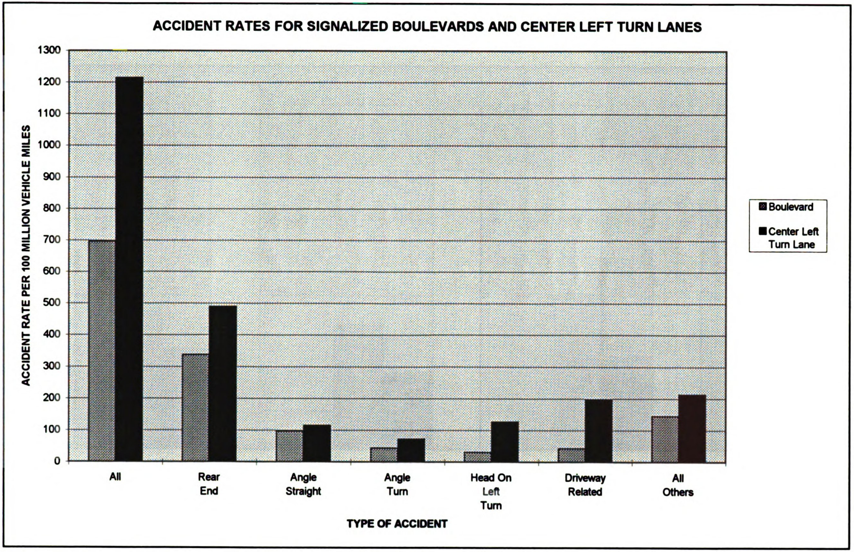


Figure C.3: Accident Rates for Signalized Boulevards and Center Left-Turn Lanes

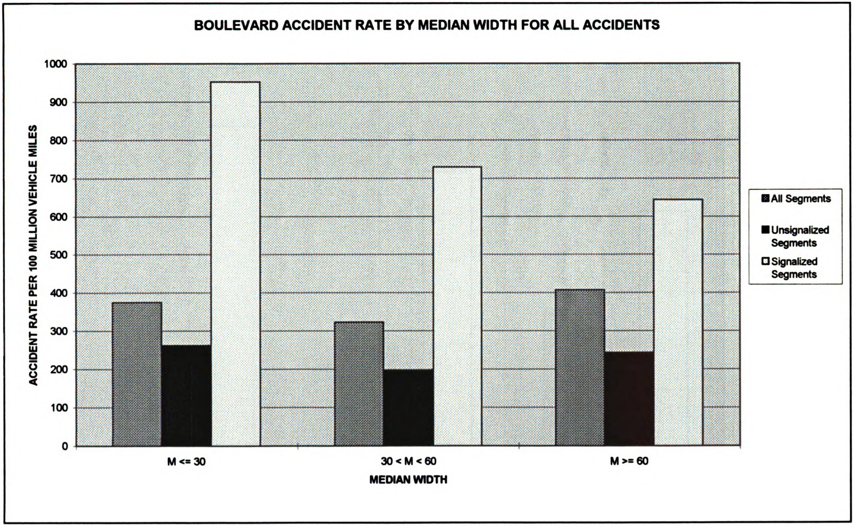


Figure C.4: Boulevard Accident Rate by Median Width for All Accidents

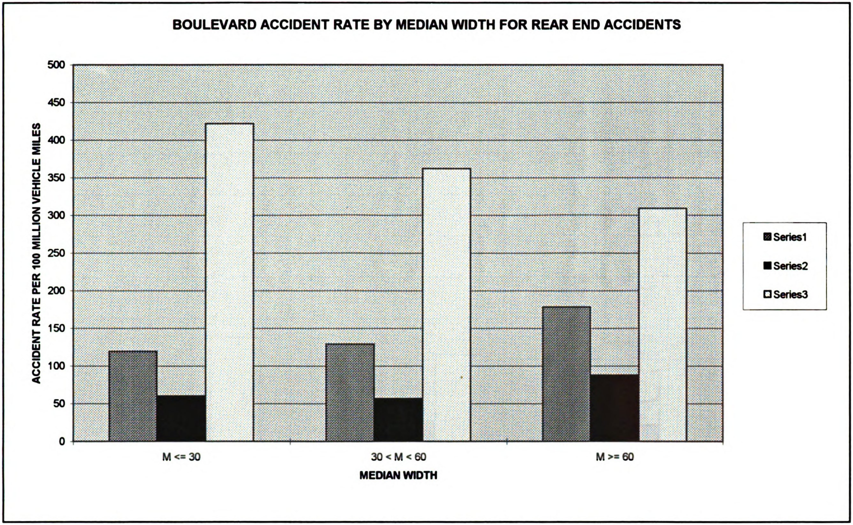


Figure C.5: Boulevard Accident Rate by Median Width for Rear-End Accidents

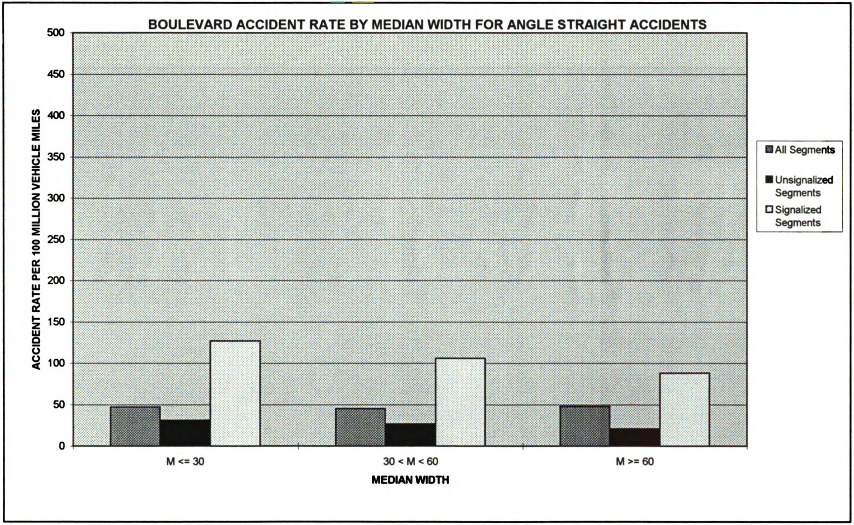


Figure C.6: Boulevard Accident Rate by Median Width for Angle-Straight Accidents

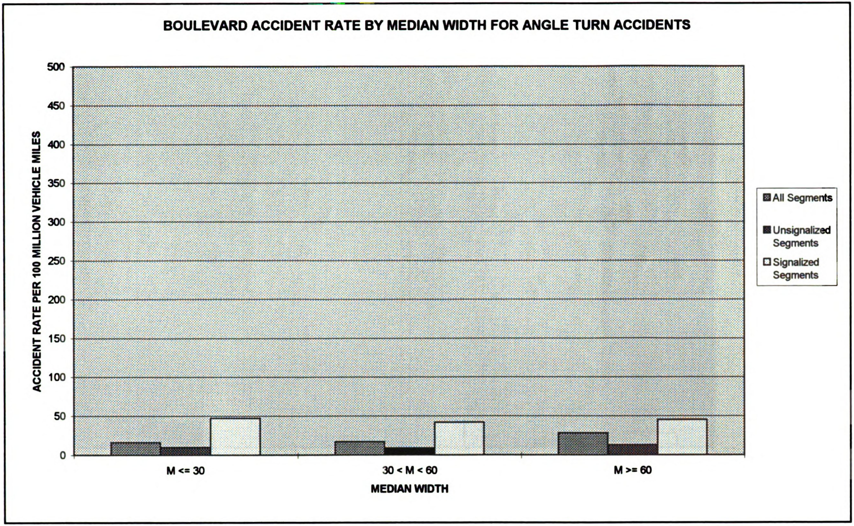


Figure C.7: Boulevard Accident Rate by Median Width for Angle-Turn Accidents

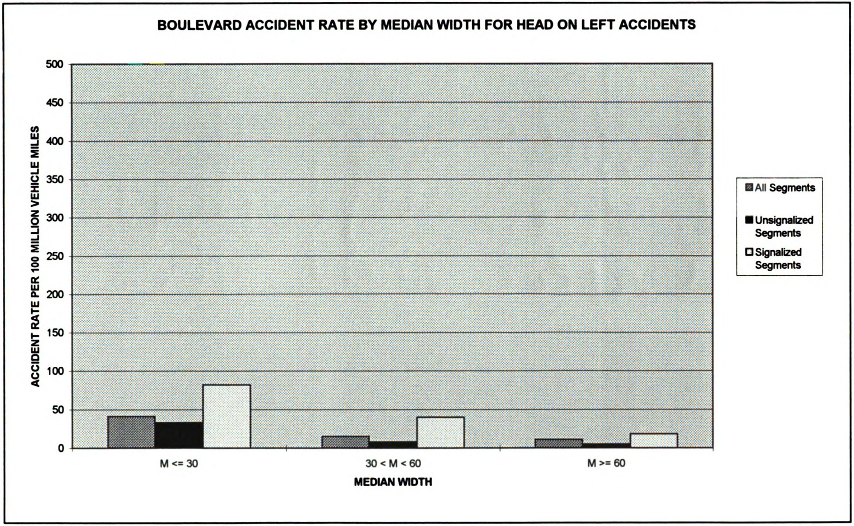


Figure C.8: Boulevard Accident Rate by Median Width for Head-On Left Accidents

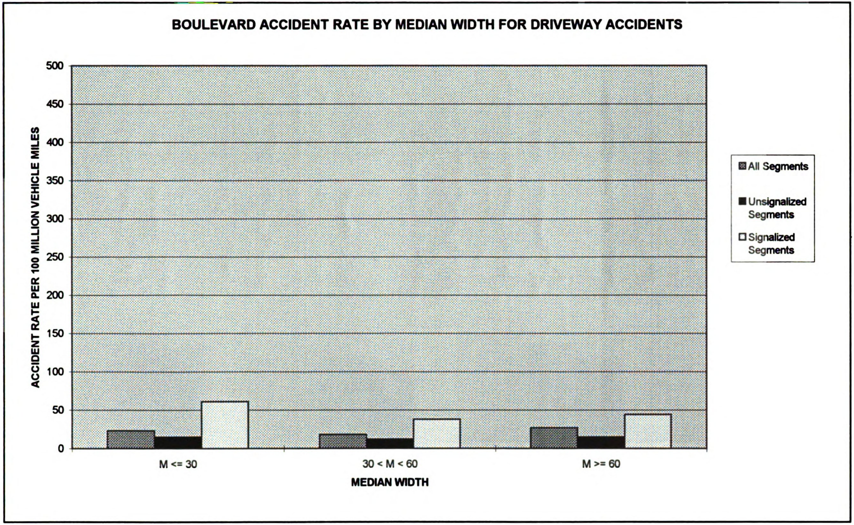


Figure C.9: Boulevard Accident Rate by Median Width for Driveway Accidents

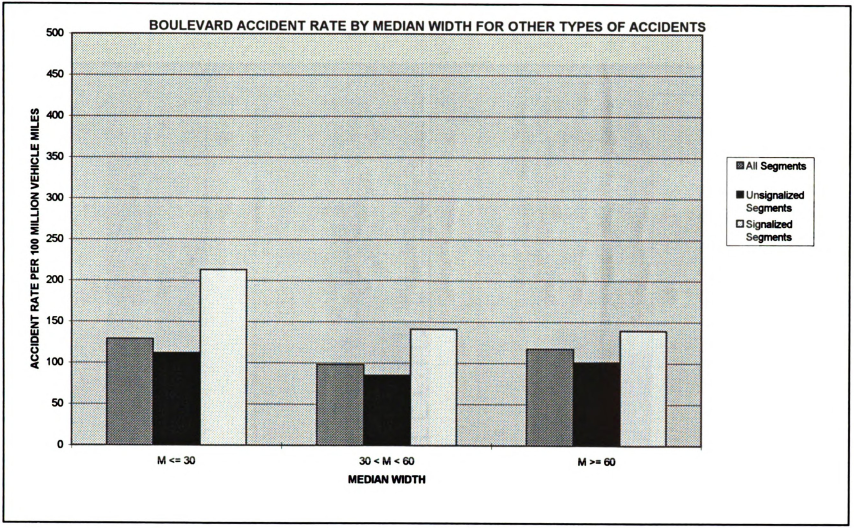


Figure C.10: Boulevard Accident Rate by Median Width for Other Types of Accidents

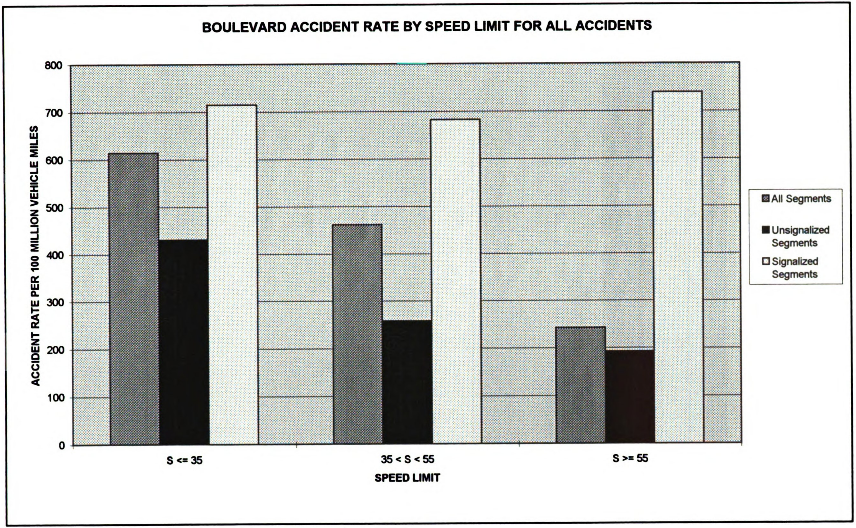


Figure C.11: Boulevard Accident Rate by Speed Limit for All Accidents

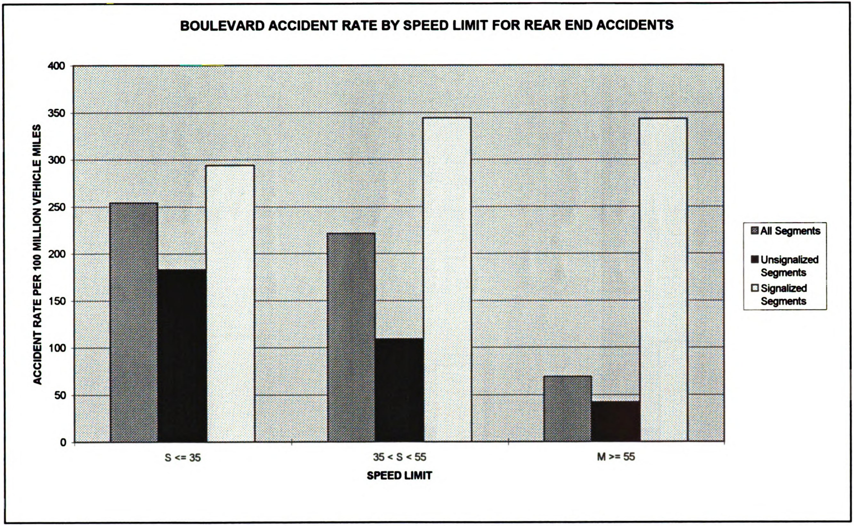


Figure C.12: Boulevard Accident Rate by Speed Limit for Rear-End Accidents

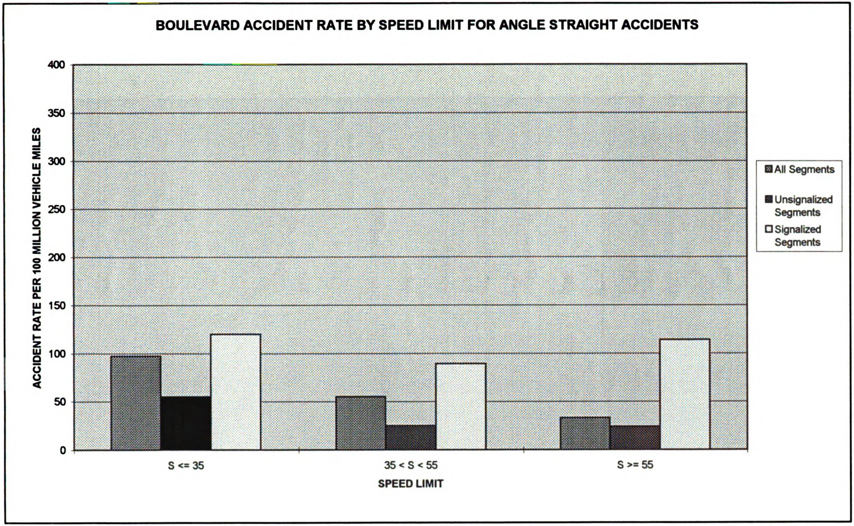


Figure C.13: Boulevard Accident Rate by Speed Limit for Angle-Straight Accidents

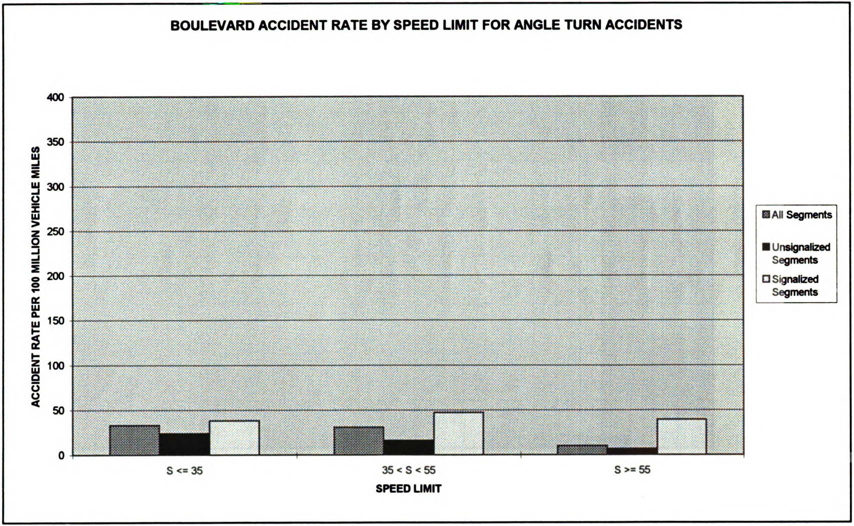


Figure C.14: Boulevard Accident Rate by Speed Limit for Angle-Turn Accidents

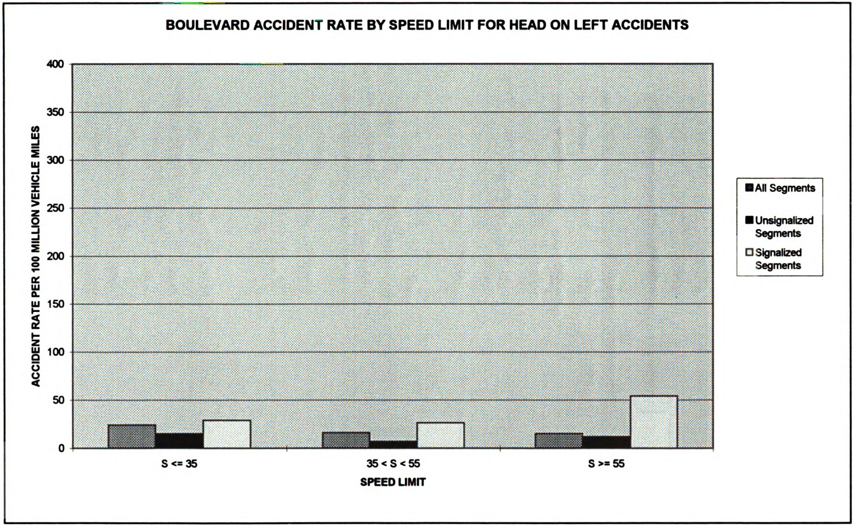


Figure C.15: Boulevard Accident Rate by Speed Limit for Head-On Left Accidents

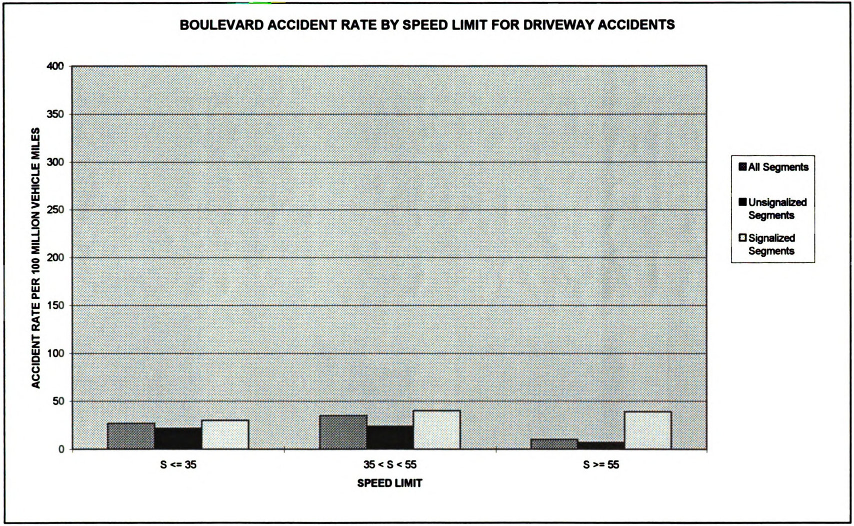


Figure C.16: Boulevard Accident Rate by Speed Limit for Driveway Accidents

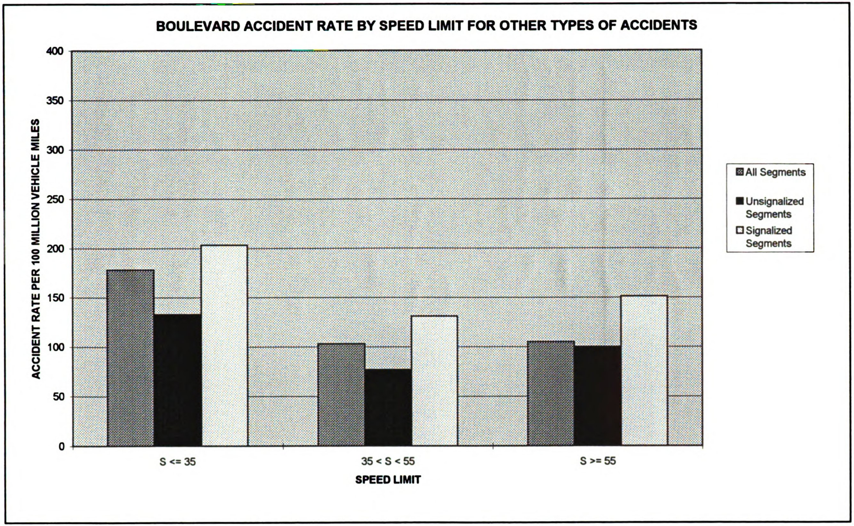


Figure C.17: Boulevard Accident Rate by Speed Limit for Other Types of Accidents

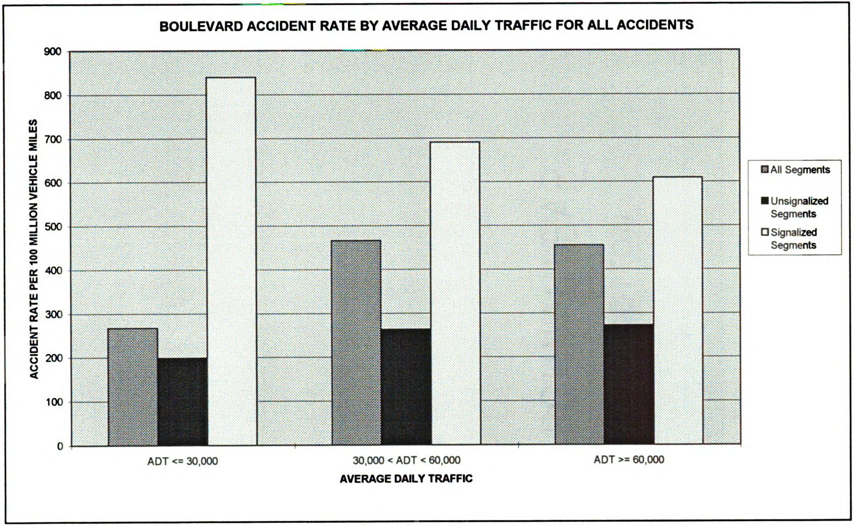


Figure C.18: Boulevard Accident Rate by Average Daily Traffic for All Accidents

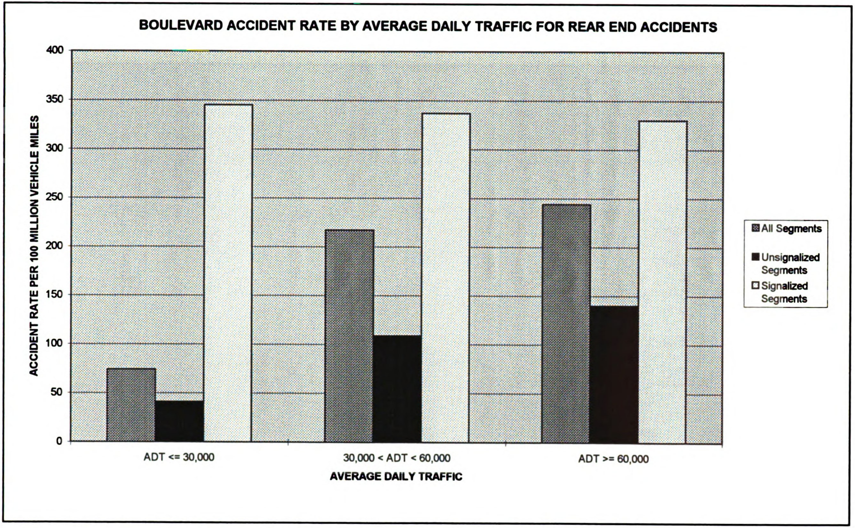


Figure C.19: Boulevard Accident Rate by Average Daily Traffic for Rear-End Accidents

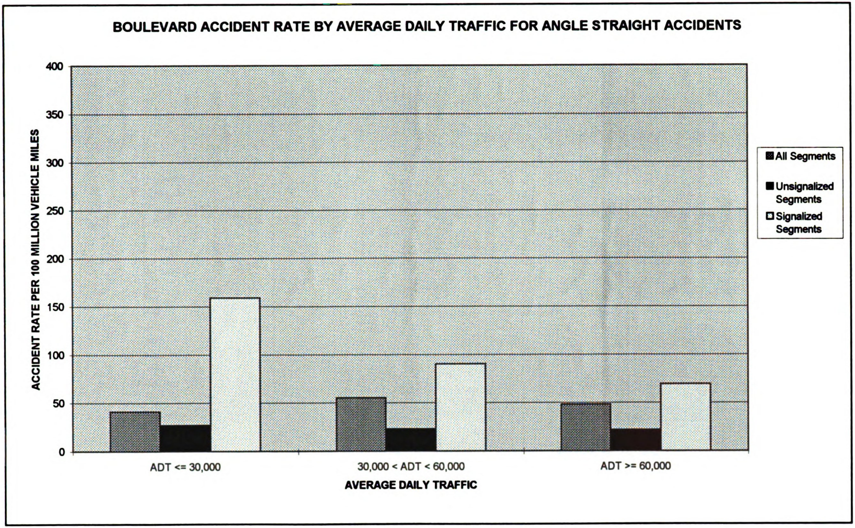


Figure C.20: Boulevard Accident Rate by Average Daily Traffic for Angle-Straight Accidents

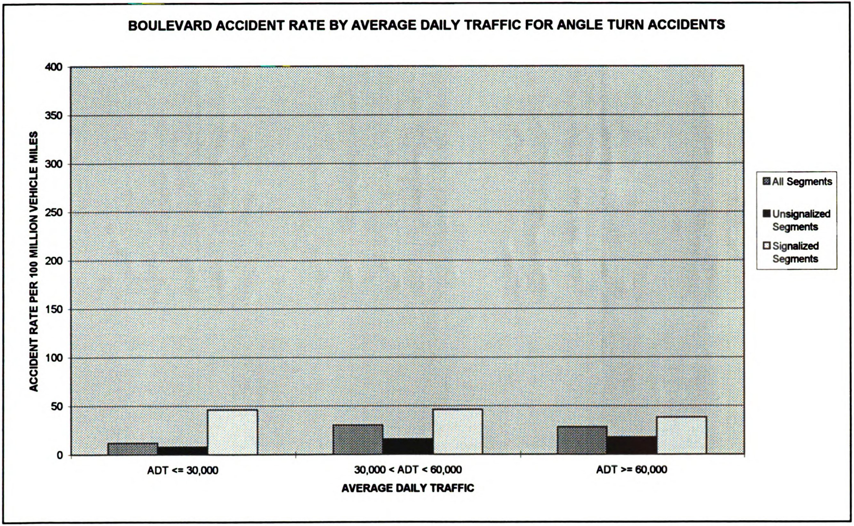


Figure C.21: Boulevard Accident Rate by Average Daily Traffic for Angle-Turn Accidents

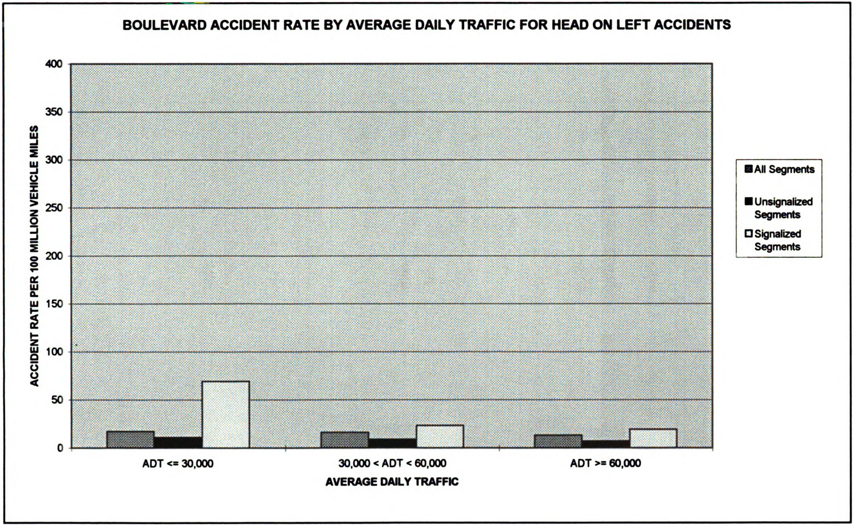


Figure C.22: Boulevard Accident Rate by Average Daily Traffic for Head-On Left Accidents

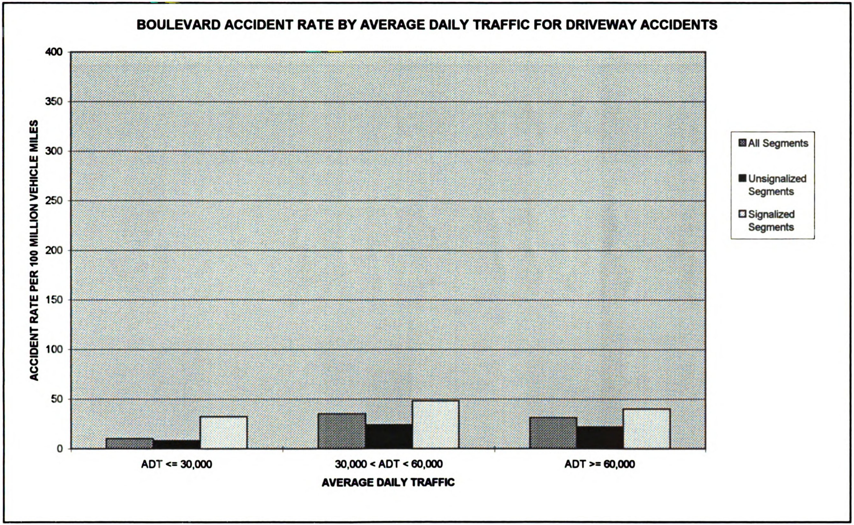


Figure C.23: Boulevard Accident Rate by Average Daily Traffic for Driveway Accidents

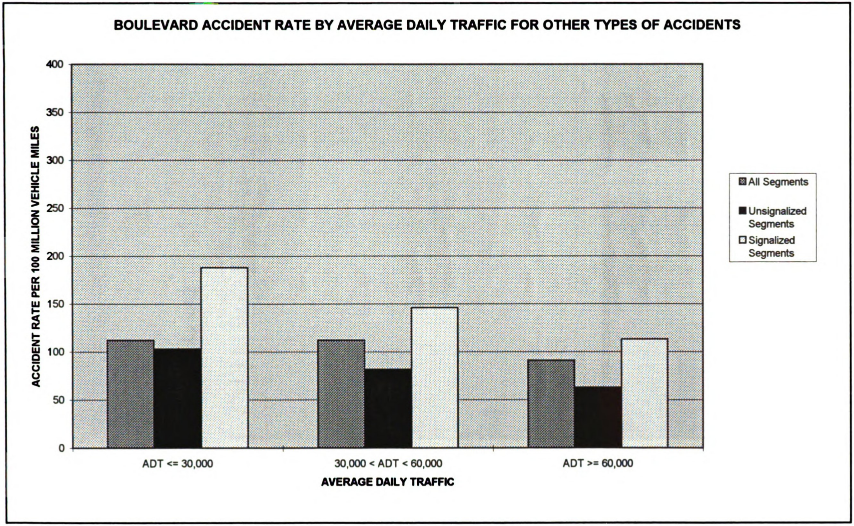


Figure C.24: Boulevard Accident Rate by Average Daily Traffic for Other Types of Accidents

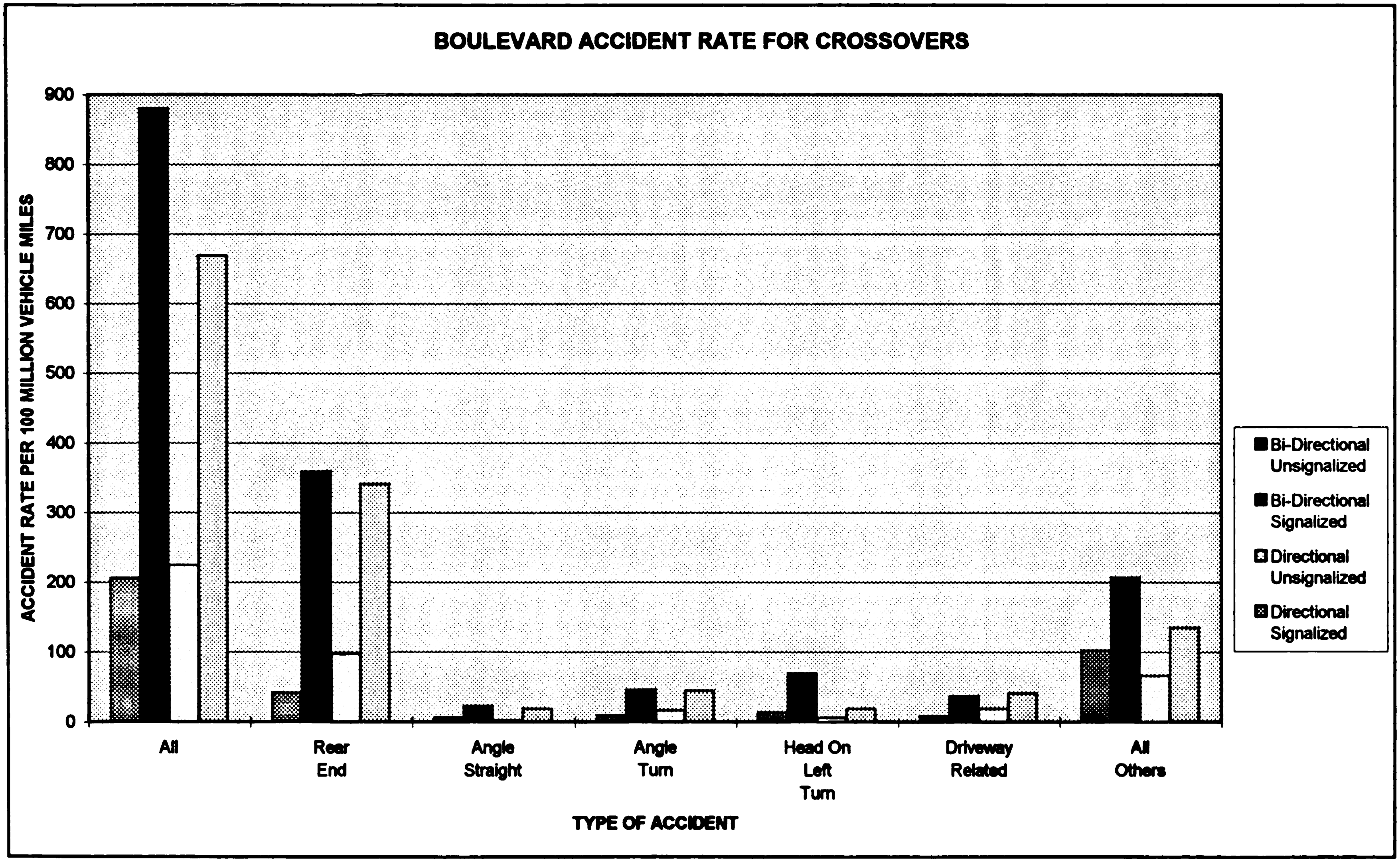


Figure C.25: Boulevard Accident Rate for Cross-Overs

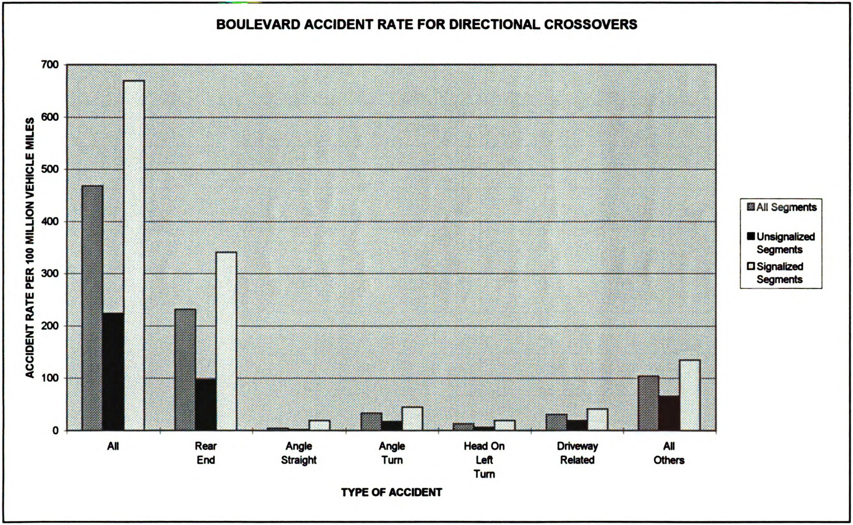


Figure C.26: Boulevard Accident Rate for Directional Cross-Overs

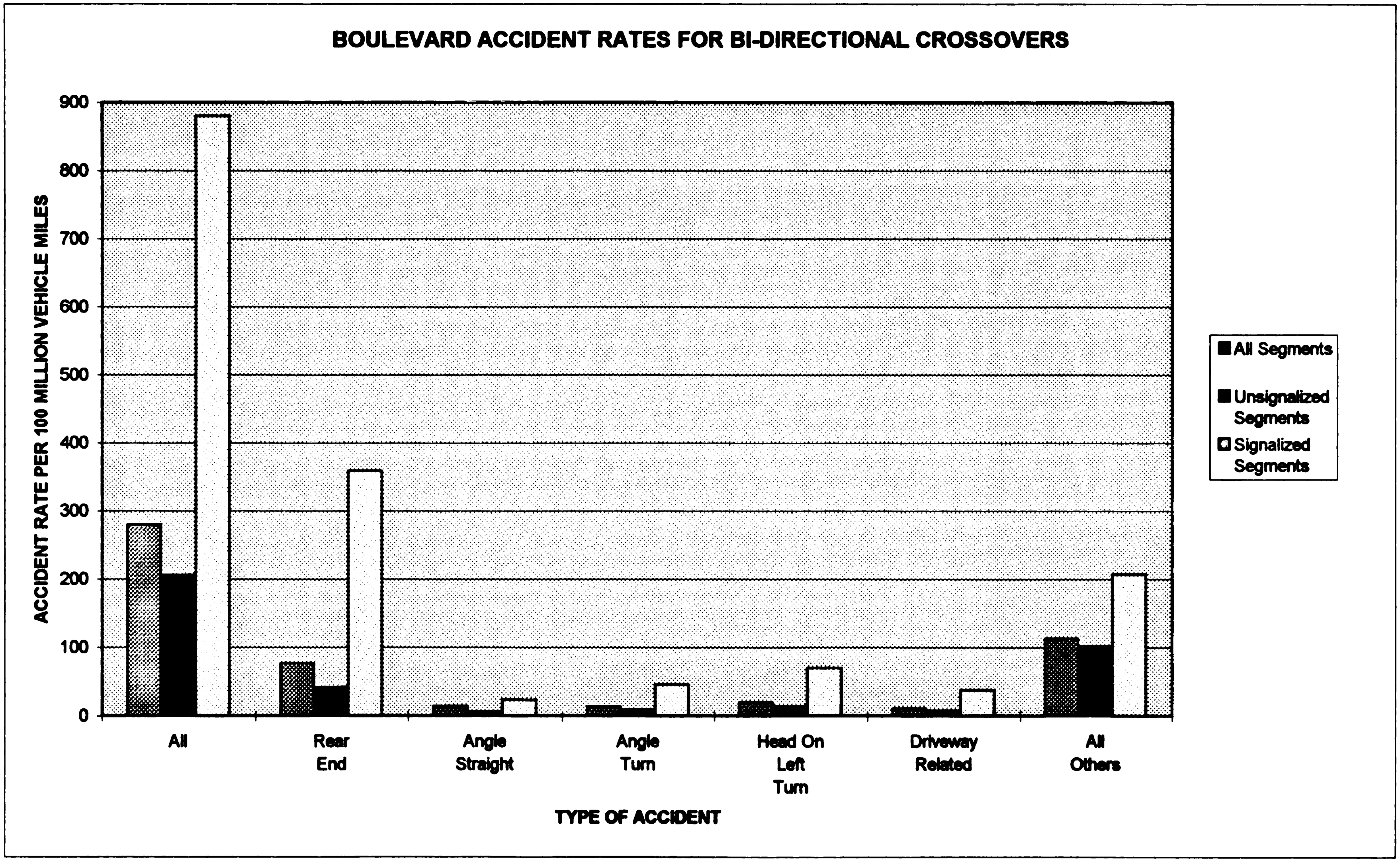


Figure C.27: Boulevard Accident Rates for Bidirectional Cross-Overs

APPENDIX D

SIGNIFICANCE TESTS

BOULEVARD/CCLTL *t* test

t-Test: Two-Sample Assuming Unequal Variances														
	ALL		REAR-END		ANGLE-STRAIGHT		ANGLE-TURN		HEAD-ON-LEFT		DRIVEWAY		OTHER TYPES	
	BLVD	CCLTL	BLVD	CCLTL	BLVD	CCLTL	BLVD	CCLTL	BLVD	CCLTL	BLVD	CCLTL	BLVD	CCLTL
Mean	362.26	764.39	147.66	290.05	46.70	62.40	20.64	49.69	16.26	63.23	21.95	143.52	109.06	155.50
Variance	153560.03	459263.82	40525.03	96141.79	6677.83	8916.29	952.53	3781.92	3694.94	10824.79	1452.24	35287.84	9101.24	19850.82
Observations	866.00	734.00	866.00	734.00	866.00	734.00	866.00	734.00	866.00	734.00	866.00	734.00	866.00	734.00
Hypothesized Mean Difference	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
df	1130.00		1219.00		1460.00		1039.00		1138.00		784.00		1253.00	
t Stat	-14.19		-10.68		-3.52		-11.62		-10.77		-17.23		-7.58	
P(T<=t) one-tail	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
t Critical one-tail	1.65		1.65		1.65		1.65		1.65		1.65		1.65	
P(T<=t) two-tail	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
t Critical two-tail	1.96		1.96		1.96		1.96		1.96		1.96		1.96	

Table D.1: Boulevard/CCLTL *t*-test

BOULEVARD/CCLTL *t* test FOR UNSGNALIZED ROADWAYS

t-Test: Two-Sample Assuming Unequal Variances														
	ALL		REAR-END		ANGLE-STRAIGHT		ANGLE-TURN		HEAD-ON-LEFT		DRIVEWAY		OTHER TYPES	
Mean	221.46	448.21	67.95	149.19	25.33	25.25	10.75	33.73	10.22	18.88	13.16	105.81	94.05	115.35
Variance	59873.81	194516.26	9826.73	36877.23	3647.62	2560.98	461.63	3210.50	4182.67	1603.87	743.60	30732.20	7058.66	12435.54
Observations	609.00	431.00	609.00	431.00	609.00	431.00	609.00	431.00	609.00	431.00	609.00	431.00	609.00	431.00
Hypothesized Mean Difference	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
df	617.00		593.00		1009.00		518.00		1021.00		445.00		758.00	
t Stat	-9.67		-8.06		0.02		-8.02		-2.66		-10.88		-3.35	
P(T<=t) one-tail	0.00		0.00		0.49		0.00		0.00		0.00		0.00	
t Critical one-tail	1.65		1.65		1.65		1.65		1.65		1.65		1.65	
P(T<=t) two-tail	0.00		0.00		0.98		0.00		0.01		0.00		0.00	
t Critical two-tail	1.96		1.96		1.96		1.96		1.96		1.97		1.96	

Table D.2: Boulevard/CCLTL Unsignalized Roadways *t*-test

BOULEVARD/CCLTL *t* test FOR SIGNALIZED ROADWAYS

t-Test: Two-Sample Assuming Unequal Variances														
	ALL		*REAR-END*		*ANGLE-STRAIGHT*		*ANGLE-TURN*		*HEAD-ON-LEFT*		*DRIVEWAY*		*OTHER TYPES*	
	BLVD	*CCLTL*	*BLVD*	*CCLTL*	*BLVD*	*CCLTL*	*BLVD*	*CCLTL*	*BLVD*	*CCLTL*	*BLVD*	*CCLTL*	*BLVD*	*CCLTL*
Mean	695.90	1214.13	336.55	490.42	97.33	115.24	44.05	72.38	30.57	126.32	42.78	197.15	144.62	212.62
Variance	217755.26	492136.11	62660.13	112244.10	10240.69	13223.82	1339.38	3728.28	2258.67	17188.59	2521.32	36976.10	12182.71	24900.79
Observations	257.00	303.00	257.00	303.00	257.00	303.00	257.00	303.00	257.00	303.00	257.00	303.00	257.00	303.00
Hypothesized Mean Difference	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
df	529.00		550.00		557.00		505.00		392.00		350.00		539.00	
t Stat	-10.42		-6.21		-1.96		-6.77		-11.83		-13.44		-5.97	
P(T<=t) one-tail	0.00		0.00		0.03		0.00		0.00		0.00		0.00	
t Critical one-tail	1.65		1.65		1.65		1.65		1.65		1.65		1.65	
P(T<=t) two-tail	0.00		0.00		0.05		0.00		0.00		0.00		0.00	
t Critical two-tail	1.96		1.96		1.96		1.96		1.97		1.97		1.96	

Table D.3: Boulevard/CCLTL *t*-test for Signalized Roadways

BOULEVARD *t* test for UNSIGNALIZED/SIGNALIZED ROADWAYS

t-Test: Two-Sample Assuming Unequal Variances														
	ALL		REAR-END		ANGLE-STRAIGHT		ANGLE-TURN		HEAD-ON-LEFT		DRIVEWAY		OTHER TYPES	
	UNSIG	SIG	UNSIG	SIG	UNSIG	SIG	UNSIG	SIG	UNSIG	SIG	UNSIG	SIG	UNSIG	SIG
Mean	221.46	695.90	67.95	336.55	25.33	97.33	10.75	44.05	10.22	30.57	13.16	42.78	94.05	144.62
Variance	59873.81	217755.26	9826.73	62660.13	3647.62	10240.69	461.63	1339.38	4182.67	2258.67	743.60	2521.32	7058.66	12182.71
Observations	609.00	257.00	609.00	257.00	609.00	257.00	609.00	257.00	609.00	257.00	609.00	257.00	609.00	257.00
Hypothesized Mean Difference	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
df	317.00		290.00		336.00		333.00		646.00		322.00		387.00	
t Stat	-15.43		-16.66		-10.63		-13.63		-5.14		-8.92		-6.58	
P(T<=t) one-tail	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
t Critical one-tail	1.65		1.65		1.65		1.65		1.65		1.65		1.65	
P(T<=t) two-tail	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
t Critical two-tail	1.97		1.97		1.97		1.97		1.96		1.97		1.97	

Table D.4: Boulevard *t*-test for Unsignalized/Signalized Roadways

CCLTL *t* test for UNSIGNALIZED/SIGNALIZED ROADWAYS

t-Test: Two-Sample Assuming Unequal Variances														
	ALL		REAR-END		ANGLE-STRAIGHT		ANGLE-TURN		HEAD-ON-LEFT		DRIVEWAY		OTHER TYPES	
	UNSIG	SIG	UNSIG	SIG	UNSIG	SIG	UNSIG	SIG	UNSIG	SIG	UNSIG	SIG	UNSIG	SIG
Mean	448.21	1214.13	149.19	490.42	25.25	115.24	33.73	72.38	18.88	126.32	105.81	197.15	115.35	212.62
Variance	194516.26	492136.11	36877.23	112244.10	2560.98	13223.82	3210.50	3728.28	1603.87	17188.59	30732.20	36976.10	12435.54	24900.79
Observations	431.00	303.00	431.00	303.00	431.00	303.00	431.00	303.00	431.00	303.00	431.00	303.00	431.00	303.00
Hypothesized Mean Difference	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
df	468.00		441.00		385.00		619.00		342.00		611.00		507.00	
t Stat	-16.81		-15.98		-12.78		-8.69		-13.82		-6.57		-9.23	
P(T<=t) one-tail	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
t Critical one-tail	1.65		1.65		1.65		1.65		1.65		1.65		1.65	
P(T<=t) two-tail	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
t Critical two-tail	1.97		1.97		1.97		1.96		1.97		1.96		1.96	

Table D.5: CCLTL *t*-test for Unsignalized/Signalized Roadways

ROADWAY=1; FILE

MED MEDIAN WIDTH

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
	4.00	3	.3	.3	.3
	6.00	1	.1	.1	.5
	10.00	1	.1	.1	.6
	15.00	19	2.2	2.2	2.8
	24.00	18	2.1	2.1	4.8
	28.00	10	1.2	1.2	6.0
	30.00	45	5.2	5.2	11.2
	35.00	33	3.8	3.8	15.0
	36.00	149	17.2	17.2	32.2
	38.00	41	4.7	4.7	37.0
	40.00	65	7.5	7.5	44.5
	45.00	42	4.8	4.8	49.3
	48.00	60	6.9	6.9	56.2
	55.00	33	3.8	3.8	60.0
	60.00	111	12.8	12.8	72.9
	65.00	17	2.0	2.0	74.8
	72.00	65	7.5	7.5	82.3
	80.00	6	.7	.7	83.0
	81.00	34	3.9	3.9	87.0
	85.00	88	10.2	10.2	97.1
	162.00	25	2.9	2.9	100.0
	Total	866	100.0	100.0	

Valid cases 866 Missing cases 0

Figure D.1: Tukey-b Test Example

ROADWAY=1

MED3 medians 0-30; 30 to 60; >60

Value Label	Value	Frequency	Percent	Valid Percent	Cum Percent
	1.00	97	11.2	11.2	11.2
	2.00	423	48.8	48.8	60.0
	3.00	346	40.0	40.0	100.0
	Total	866	100.0	100.0	

Valid cases 866 Missing cases 0

Figure D.1: Continued

ROADWAY=1 - - - - - O N E W A Y - - - - -

Variable RALL TOTAL ACCIDENT RATE
By Variable MED3 medians 0-30; 30 to 60; >60

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	1345628.787	672814.3935	4.4160	.0124
Within Groups	863	131483774.7	152356.6335		
Total	865	132829403.5			

Group	Count	Mean	Standard Deviation	Standard Error	95 Pct Conf Int for Mean		
Grp 1	97	375.3881	467.7201	47.4898	281.1217	TO	469.6546
Grp 2	423	323.0373	380.8345	18.5168	286.6407	TO	359.4340
Grp 3	346	406.5319	377.9345	20.3179	366.5694	TO	446.4944
Total	866	362.2604	391.8673	13.3162	336.1245	TO	388.3962

GROUP	MINIMUM	MAXIMUM
Grp 1	.0000	2717.8082
Grp 2	.0000	2598.9969
Grp 3	.0000	2380.7274
TOTAL	.0000	2717.8082

Figure D.1: Continued

ROADWAY=1

```
                    - - - - -  O N E W A Y  - - - - -

      Variable  RALL        TOTAL ACCIDENT RATE
   By Variable  MED3        medians 0-30; 30 to 60; >60

Multiple Range Tests:  LSD test with significance level .05

The difference between two means is significant if
  MEAN(J)-MEAN(I)  >= 276.0042 * RANGE * SQRT(1/N(I) + 1/N(J))
  with the following value(s) for RANGE: 2.78

   (*) Indicates significant differences which are shown in the lower triangle

                         G G G
                         r r r
                         p p p

                         2 1 3
     Mean       MED3

   323.0373    Grp 2
   375.3881    Grp 1
   406.5319    Grp 3     *
```

Figure D.1: Continued

```
ROADWAY=1

                    - - - - -  O N E W A Y  - - - - -

     Variable  RALL          TOTAL ACCIDENT RATE
  By Variable  MED3          medians 0-30; 30 to 60; >60

Multiple Range Tests:  Tukey-HSD test with significance level .050

The difference between two means is significant if
  MEAN(J)-MEAN(I)  >= 276.0042 * RANGE * SQRT(1/N(I) + 1/N(J))
  with the following value(s) for RANGE: 3.33

   (*) Indicates significant differences which are shown in the lower triangle

                           G G G
                           r r r
                           p p p

                           2 1 3
    Mean        MED3

  323.0373      Grp 2
  375.3881      Grp 1
  406.5319      Grp 3      *
```

Figure D.1: Continued

```
ROADWAY=1

                    - - - - -  O N E W A Y  - - - - -

      Variable  RALL          TOTAL ACCIDENT RATE
   By Variable  MED3          medians 0-30; 30 to 60; >60

Multiple Range Tests:  Tukey-B test with significance level .050

The difference between two means is significant if
  MEAN(J)-MEAN(I)  >= 276.0042 * RANGE * SQRT(1/N(I) + 1/N(J))
  with the following value(s) for RANGE:

 Step       2      3
 RANGE    3.07   3.33

   (*) Indicates significant differences which are shown in the lower triangle

                         G G G
                         r r r
                         p p p

                         2 1 3
    Mean        MED3

   323.0373     Grp 2
   375.3881     Grp 1
   406.5319     Grp 3    *
```

Figure D.1: Continued

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REFERENCES

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